Catalogue no. 82-003-X

Health Reports

Volume 21, Number 1

Statistics Canada Statistique Canada

Canada

How to obtain more information

Specific inquiries about this product and related statistics or services should be directed to: Health Information and Research Division, Statistics Canada, Ottawa, Ontario, K1A 0T6 (telephone: 613-951-1765).

For information about this product or the wide range of services and data available from Statistics Canada, visit our website at www.statcan.gc.ca, e-mail us at infostats@statcan.gc.ca, or telephone us, Monday to Friday from 8:30 a.m. to 4:30 p.m., at the following numbers:

Statistics Canada's National Contact Centre

Toll-free telephone (Canada and United States):

Inquiries line	1-800-263-1136
National telecommunications device for the hearing impaired	1-800-363-7629
Fax line	1-877-287-4369

Local or international calls:

Inquiries line	1-613-951-8116
Fax line	1-613-951-0581

Depository Services Program

Inquiries line	1-800-635-7943
Fax line	1-800-565-7757

To access and order this product

This product, Catalogue no. 82-003-X, is available free in electronic format. To obtain a single issue, visit our website at www.statcan.gc.ca and select "Publications."

This product, Catalogue no. 82-003-X, is also available as a standard printed publication at a price of CAN$24.00 per issue and CAN$68.00 for a one-year subscription.

The following additional shipping charges apply for delivery outside Canada:

	Single issue	**Annual subscription**
United States	CAN$6.00	CAN$24.00
Other countries	CAN$10.00	CAN$40.00

All prices exclude sales taxes.

The printed version of this publication can be ordered as follows:

- Telephone (Canada and United States) 1-800-267-6677
- Fax (Canada and United States) 1-877-287-4369
- E-mail infostats@statcan.gc.ca
- Mail Statistics Canada
  Finance
  R.H. Coats Bldg., 6th Floor
  150 Tunney's Pasture Driveway
  Ottawa, Ontario K1A 0T6
- In person from authorized agents and bookstores.

When notifying us of a change in your address, please provide both old and new addresses.

Standards of service to the public

Statistics Canada is committed to serving its clients in a prompt, reliable and courteous manner. To this end, Statistics Canada has developed standards of service that its employees observe. To obtain a copy of these service standards, please contact Statistics Canada toll-free at 1-800-263-1136. The service standards are also published on www.statcan.gc.ca under "About us" > "Providing services to Canadians."

Health Reports

Catalogue no. 82-003-XPE • Volume 21 Number 1

A Canadian peer-reviewed journal of population health and health services research

Published by authority of the Minister responsible for Statistics Canada

March 2010

Catalogue no. 82-003-XPE, Vol. 21, No. 1
ISSN 0840-6529

Catalogue no. 82-003-XIE, Vol. 21, No. 1
ISSN 1209-1367

Frequency: Quarterly

Ottawa

Note of Appreciation

Canada owes the success of its statistical system to a long-standing partnership between Statistics Canada, the citizens of Canada, its businesses, governments and other institutions. Accurate and timely statistical information could not be produced without their continued cooperation and goodwill.

Author information: We seek submissions from researchers based in government or academia. Submissions can come in the form of a traditional research article, a shorter descriptive piece that we call "Health Matters," or a contribution that addresses technical issues related to the analysis of complex health surveys or administrative databases—"Methodological Insights." For detailed author guidelines, please visit the journal's website at: *www.statcan.gc.ca/healthreports*.

Electronic version*: Health Reports* is available free in PDF or HTML format. The current issue may be obtained at *www.statcan.gc.ca/healthreports*. For previous issues, select "Other issues in the series" from the left sidebar of the *Health Reports* website.

Aussi disponible en français : *Rapports sur la santé*, n° 82-003-X au catalogue

Symbols

The following standard symbols are used in Statistics Canada publications:

- . not available for any reference period
- .. not available for specific reference period
- ... not applicable
- p preliminary
- r revised
- x suppressed to meet the confidentiality requirements of the Statistics Act
- E use with caution
- F too unreliable to be published

The paper used in this publication meets the minimum requirements of American National Standard for Information Sciences – Permanence of Paper for Printed Library Materials, ANSI Z39.48 – 1984.

About Health Reports

Health Reports publishes original research on diverse topics related to the health of populations and the delivery of health care. The journal archives, for the research and policy communities and for the general public, discoveries from analyses of national/provincial surveys and administrative databases, as well as results of international comparative health research. *Health Reports* is also a forum for sharing methodological information by those using health surveys or administrative databases. *Health Reports* is produced by the Health Analysis Division at Statistics Canada. Articles appear monthly in electronic format and quarterly in print, and are indexed in Index Medicus and MEDLINE.

For more information about *Health Reports*, contact the Editor-in-Chief, Health Analysis Division, Statistics Canada, 24th Floor, R.H. Coats Building, Ottawa, Ontario, Canada K1A 0T6. Telephone: (613) 951-1765; fax: (613) 951-3959; email: Christine.Wright@statcan.gc.ca

In this issue

Research articles

Health matters

Methodological insights

Fitness of Canadian children and youth: Results from the 2007-2009 Canadian Health Measures Survey

by Mark S. Tremblay, Margot Shields, Manon Laviolette, Cora L. Craig, Ian Janssen and Sarah Connor Gorber

Abstract

Background
The fitness of Canadian children and youth has not been measured in more than two decades, a period during which childhood obesity and sedentary behaviours have increased. This paper provides up-to-date estimates of the fitness of Canadians aged 6 to 19 years.

Data and methods
Data are from the 2007-2009 Canadian Health Measures Survey (CHMS), the most comprehensive direct health measures survey ever conducted on a nationally representative sample of Canadians. Descriptive statistics for indicators of body composition, aerobic fitness and musculoskeletal fitness are provided by sex and age group, and comparisons are made with the 1981 Canada Fitness Survey (CFS).

Results
Fitness levels of children and youth have declined significantly and meaningfully since 1981, regardless of age or sex. Significant sex differences exist for most fitness measures. Fitness levels change substantially between ages 6 and 19 years. Youth aged 15 to 19 years generally have better aerobic fitness and body composition indicators than 20- to 39-year-olds.

Interpretation
This decline in fitness may result in accelerated chronic disease development, higher health care costs, and loss of future productivity.

Keywords
adiposity, aerobic fitness, anthropometry, body composition, cardiorespiratory fitness, flexibility, muscular endurance, musculoskeletal fitness, obesity, physical fitness, strength

Authors
Mark S. Tremblay (613-737-7600 ext. 4114; mtremblay@cheo.on.ca) is with the Children's Hospital of Eastern Ontario Research Institute and Department of Pediatrics, University of Ottawa. Margot Shields (613-951-4177; Margot.Shields@statcan.gc.ca) and Sarah Connor Gorber are with the Health Analysis Division and Manon Laviolette is with the Physical Health Measures Division at Statistics Canada. Cora L. Craig is with the Canadian Fitness and Lifestyle Research Institute. Ian Janssen is with the School of Kinesiology and Health Studies, Queen's University.

Childhood obesity and inactivity have been at the forefront of child health concerns in Canada in recent years,[1-5] with compelling evidence that childhood obesity is rising[6-8] and inactivity levels are high.[2,3,9] These trends are particularly important given the strength of the evidence demonstrating the health consequences of childhood obesity[4,5,10] and the benefits of physical activity to childhood health and wellness.[2,3,11-15]

Evidence also indicates that childhood aerobic fitness levels are declining worldwide,[16] that aerobic fitness is related to health in children in a dose-response fashion,[17] and that these relationships are independent of physical activity.[18] Overwhelming evidence demonstrates that higher or improved fitness, including measures of body composition (for example, body mass index, waist circumference, skinfolds), cardiorespiratory function (for example, aerobic fitness) and musculoskeletal fitness (for example, strength, muscular endurance, flexibility), is associated with improved health in children and youth.[11-13,17,18]

The importance of measuring and monitoring the fitness of children and youth is obvious but logistically challenging, and rarely done on large, representative national samples. Notable studies in Canada include the 1972 Nutrition Canada Survey,[19] the 1978 Canada Health Survey,[20] the 1981 Canada Fitness Survey (CFS)[21] and the 1988 Campbell's Survey on the Well-being of Canadians,[22] with the latter two providing the most comprehensive and recent data.

Fitness has not been measured at the national level in more than two decades in Canada. In 2007, in partnership with Health Canada and the Public Health Agency of Canada, Statistics Canada launched the Canadian Health Measures Survey (CHMS) to address this (and other) data gap(s).[23-27] The CHMS is the most comprehensive direct health measures survey ever conducted in Canada. In addition to a detailed health interview, the CHMS includes direct measurement of indicators of, and risk factors for, chronic disease, infectious disease, environmental exposures, nutritional status, physical activity and physical fitness.[23-27]

Using data from the CHMS, this paper provides an up-to-date overview of the fitness levels of Canadian children and youth aged 6 to 19 years, including estimates of body composition (body mass index, waist circumference, waist-to-hip ratio and skinfolds), aerobic fitness and musculoskeletal fitness (including muscular strength, endurance and flexibility). Where possible, CHMS results are compared with findings from the 1981 CFS[21] to examine temporal changes in fitness.

Methods

Data sources

The Canadian Health Measures Survey covers the Canadian population aged 6 to 79 years living in private households at the time of the survey. Residents of Indian Reserves or Crown lands, institutions and certain remote regions, and full-time members of the Canadian Forces are excluded. Approximately 97% of Canadians are represented.

Ethics approval to conduct the survey was obtained from Health Canada's Research Ethics Board.[26] Informed written consent was obtained from respondents aged 14 years or older. For younger children, a parent or legal guardian provided written consent, in addition to written assent from the child. Participation was voluntary; respondents could opt out of any part of the survey at any time.

Data were collected at 15 sites across Canada from March 2007 through February 2009. Of the households selected, the response rate was 69.6%, meaning that in 69.6% of the selected households, a resident provided the sex and date of birth of all household members. Within each responding household, one or two members were chosen to participate in the CHMS; 88.5% of selected 6- to 19-year-olds completed the household questionnaire, and 86.9% of those who completed the questionnaire participated in the subsequent examination centre component. The final response rate for 6- to 19-year-olds, after adjusting for the sampling strategy,[27] was 53.5%. This article is based on 2,087 examination centre participants aged 6 to 19 years.

Historical estimates of fitness measures are based on data from the 1981 Canada Fitness Survey (CFS), a nationally representative sample of the Canadian population,[21,28,29] initiated and funded by Fitness Canada. The sample was designed by Statistics Canada, using the Labour Force Survey sampling frame. The CFS sample consisted of 13,500 households, 88% of which agreed to participate, meaning that basic demographic information was collected for all household members, and a household member agreed to a follow-up visit when all members would be at home. In these responding households, 30,652 people aged 7 years or older were eligible to participate in the CFS. The CFS had two components: a questionnaire on health and lifestyle (administered to household members aged 10 years or older) and a physical measures component (for respondents aged 7 to 69 years). A respondent to the CFS was defined as a household member who completed the questionnaire and/or participated in the physical measures component. In total, 23,400 household members (76%) responded. Therefore, the overall response rate to the CFS was 67% (88% x 76%). Among CFS respondents who were eligible for the physical measures component, 73% participated, yielding a response rate of 49% to this component (88% x 76% x 73%). The CFS estimates in this article are based on 5,116 respondents aged 7 to 19 years. Fitness testing and anthropometric measures were taken in sampled households between February and July 1981, using standardized equipment and procedures. Testing was performed by university graduates who had degrees in physical education and recreation and additional qualifications in fitness appraisal.

Measures

In addition to a comprehensive health interview conducted in the home, CHMS respondents underwent body composition measurements and participated in directly measured fitness tests in a mobile examination centre.[25]

Most of the measurement protocols for assessing body composition, aerobic fitness and musculoskeletal fitness were taken from the Canadian Physical Activity, Fitness and Lifestyle Approach (CPAFLA).[30] A detailed description of the specific collection procedures can be found in the *CHMS Data Users' Guide*.[31] The CPAFLA assigns "health benefit ratings" for individual and aggregate fitness measures.[30] These ratings are available only for ages 15 to 69 years and reflect changes expected with age.

The fitness tests and anthropometric measures in the CHMS were conducted by specialists with a degree in kinesiology and certification from the Canadian Society for Exercise Physiology (www.csep.ca) as either Certified Exercise Physiologists or Certified Personal Trainers. Before undergoing any clinic tests, respondents were interviewed to ensure that they were physically able to perform the tests for which they were eligible. They were asked about their physical and health conditions and their use of prescription medications. A Physical Activity Readiness Questionnaire (http://www.csep.ca/CMFiles/publications/parq/par-q.pdf) was completed and signed by all respondents (and by the guardian if the respondent was younger than 14 years). To ensure their safety, respondents were screened out of certain tests, depending on the answers they provided to the screening questions. They were requested to adhere to pre-testing guidelines about food, alcohol, caffeine, nicotine, exercise and blood donations. Detailed information about screening questions, pre-testing guidelines and test eligibility criteria can be found in the

CHMS Clinic Questionnaire[32] and *Data Users' Guide*.[31]

The anthropometric measures collected included height, weight, waist circumference, hip circumference and skinfold measurements. Height was measured using a ProScale M150 digital stadiometer (Accurate Technology Inc., Fletcher, USA), and weight was taken with a Mettler Toledo VLC with Panther Plus terminal scale (Mettler Toledo Canada, Mississauga, Canada). Waist circumference was measured with a Gulick measuring tape (Fitness Mart, Gay Mills, USA) following the World Health Organization (WHO) protocol[33] (mid-point between last floating rib and top of the iliac crest in mid-axillary line), and hip circumference was measured following the Canadian Standardized Test of Fitness (CSTF) protocol[34] at the level of the symphysis pubis and the greatest gluteal protuberance. The skinfolds were measured using Harpenden skinfold calipers (Baty International, UK) at five sites: triceps, biceps, subscapular, iliac crest and calf.[30] Body mass index (BMI), waist-to-hip ratio, and the sum of the five skinfolds were calculated according to standard procedures.[30,34]

Body composition ratings were derived from the anthropometric measures. Based on BMI, 18- to 19-year-olds were classified as underweight (less than 18.5 kg/m^2), normal weight (18.5 to 24.9 kg/m^2), overweight (25 to 29.9 kg/m^2), or obese (30 kg/m^2 or more).[35] Children aged 6 to 17 years were classified as being normal weight, overweight or obese based on definitions proposed by the International Obesity Task Force.[36] Based on their waist circumference, respondents aged 15 years or older were classified as having a low (less than 80 cm in females; less than 94 cm in males), increased (80 to 87 cm in females; 94 to 101 cm in males) or high (more than 87 cm in females; more than 101 cm in males) health risk.[30,37-39] Finally, an overall body composition health rating was assessed for respondents aged 15 years or older, based on an aggregation of BMI, waist circumference and the sum of five skinfolds, as defined in the CPAFLA.[30]

Aerobic fitness was measured using the modified Canadian Aerobic Fitness Test (mCAFT), during which respondents had to complete one or more three-minute "stepping" stages (up and down steps with increasing intensity) at predetermined speeds, based on their age and sex.[30] Children aged 6 to 14 years started at what is Stage 5 for women, to a maximum of 3 stages. Respondents' heart rate was recorded after each stage, and the test was completed when it reached 85% of their age-predicted maximal heart rate (220 – age). Heart rate was measured with a Polar (Polar Electro Canada Inc, Lachine, Canada) heart rate monitor, or in the case of inadequate signal from the monitor, by auscultation/palpation. Predicted maximal aerobic power (VO_2max) was determined for all participants.[30,40,41] Respondents who completed at least one stage, but stopped midway through a subsequent stage ("partials"), were assigned a score based on their last fully completed stage. "Partials" were usually due to respondents' inability to maintain the cadence of the stepping test, which was particularly evident among younger children. Those unable to fully complete even one stage were coded as "not stated" and were not assigned an aerobic fitness score.

Muscular strength was assessed by measuring grip strength with a Smedley III hand-grip dynamometer (Takei Scientific Instruments, Japan) twice on each hand (alternating) and combining the maximum score for each hand (in kg). Muscular endurance was measured with the partial curl-up test, which required respondents to perform as many partial curl-ups as possible in one minute, at a set pace, to a maximum of 25. Flexibility was assessed with the sit-and-reach test, for which respondents sat on a mat on the floor with their legs extended against a flexometer (a device to measure the distance of a stretch) (Fit Systems Inc, Calgary, Canada); the best of two attempts to stretch as far forward as possible without bending the knees was recorded to the nearest 0.1 cm.

Youth aged 15 to 19 years were assigned "health benefit ratings" of excellent, very good, good, fair, or needs improvement based on their score for each fitness test (aerobic fitness, flexibility, muscular endurance, and muscular strength), their sex and their age, according to definitions specified in the CPAFLA.[30] An overall musculoskeletal fitness health benefit rating was assessed based on the results of the grip strength, partial curl-up and sit-and-reach tests. A back fitness health benefit rating was calculated based on waist circumference and the partial curl-ups and sit-and-reach tests.[30]

The 1981 CFS measured grip strength, sit-and-reach and body composition following collection protocols[21] very similar to those of the CHMS.

Analytical techniques

Data were analyzed separately by sex for three age groups: 6 to 10, 11 to 14, and 15 to 19 years. Estimates of means, standard deviations and medians were produced for all fitness measures (body composition measurements and fitness test scores). Estimates of the means and medians were similar for most measures, although in some cases, means were marginally higher, reflecting somewhat positively skewed distributions. An exception was the bimodal distribution of the number of partial curl-ups completed in one minute (to a maximum of 25), with large percentages of respondents completing either none or 25. As a result, percentage distributions are presented for this measure. Estimates of aerobic fitness from the mCAFT and the partial curl-ups do not include 6- and 7-year-olds, who often could not perform these tests for reasons unrelated to fitness (for example, lacking the co-ordination to follow the cadence). The equation used to predict maximal aerobic power (VO_2 max) is applicable to people aged 15 to 69 years.[30,40,41] In this article, the equation was also applied to 8- to 14-year-olds. Graphs of medians were produced by single year of age, but separate graph lines are presented for those aged 8 to 14 years and 15 to 19 years to highlight the fact that the equation has not been validated for the younger children (Figure 1).

For the health benefits ratings, percentage distributions are presented. The health benefits ratings used in the analyses apply only to those aged 15 years or older;[30] to provide context, ratings are compared with those for 20- to 39-year-olds (n = 1,185).[42]

Comparisons with the 1981 CFS were made for estimates of grip strength, sit-and-reach, and all body composition measurements. For muscular endurance, comparisons could not be made because the partial curl-up test, which was used to assess this component of fitness in the CHMS, was administered as speed sit-ups in the CFS. And although the same testing modality was used to assess aerobic fitness in the two surveys, small differences in the protocols negated a simple temporal comparison. Additional analyses, which are beyond the scope of this study, will be conducted in future research to fully understand the impact of these differences.

As in the CHMS, CFS respondents were interviewed before undergoing any fitness tests to ensure that they were physically able to perform them. The CFS used screen-out procedures similar to those used for the mCAFT for the CHMS.[31] Therefore, for comparisons of estimates of grip strength and sit-and-reach between the two surveys, respondents who were screened-out of the mCAFT were excluded from CHMS estimates. Because of the potential for changes over time in the age distribution within the three age groups considered, the 1981 estimates were recalculated to standardize to the CHMS population. However, in all cases, the crude and age-standardized estimates for means were similar, so only crude estimates are presented in this study.

The fitness profiles of a typical 12-year-old boy and girl in 1981 and in 2007-2009 are compared. Age 12 was chosen because it is the midpoint of the 6 to 19 year age range examined in this paper. To ensure adequate sample sizes, estimates are based on median values for children aged 11 to 13 years. The silhouettes used to illustrate the comparisons in Figure 3 are not sized to scale.

To account for the survey design effects of the CHMS, standard errors, coefficients of variation and 95% confidence intervals were estimated using the bootstrap technique.[43,44] Estimates of sampling error for the CFS are based on formulae for simple random sampling with the incorporation of a design effect of 1.5 to account for the complex survey design. Differences between estimates were tested for statistical significance, which was established at the level of $p<0.05$.

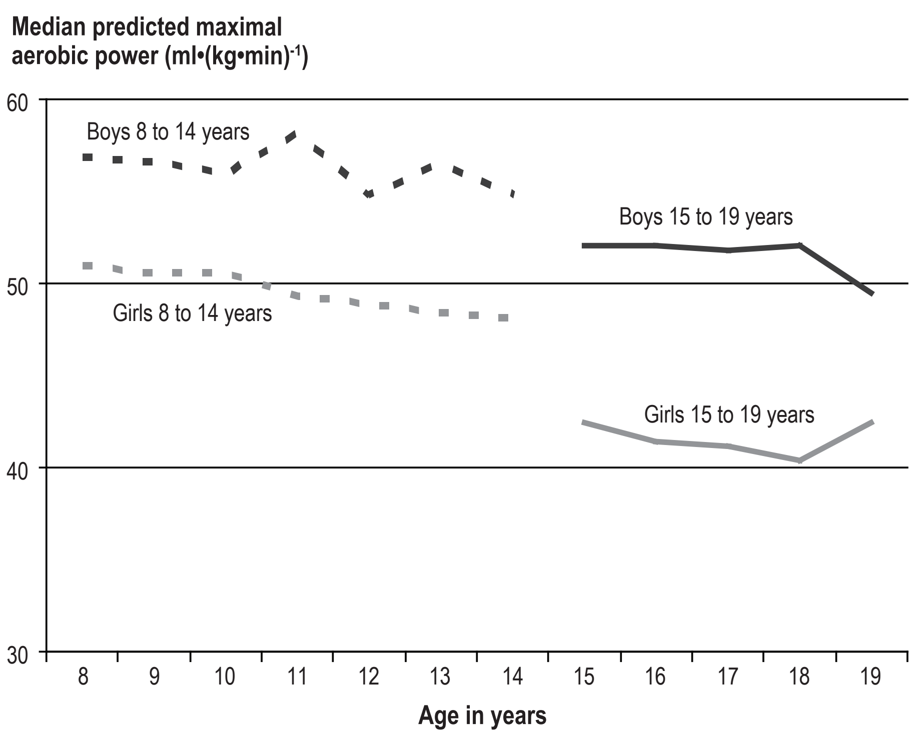
Response, non-response and screen-out rates for the CHMS fitness tests are given in Appendix Table A. Appendix Table B compares screen-out rates for the mCAFT for the CHMS with those for the CFS fitness test. Sample sizes for CHMS fitness measures are given in Appendix Table C. Among respondents who participated in the examination centre component of the survey, partial non-response (opting out of certain tests or portions of tests) to the fitness tests and anthropometric measures was rare.

Results

Response outcomes

Most children and youth who participated in the examination centre component of the CHMS completed all four fitness tests. Virtually everyone completed the flexibility (sit-and-reach) and muscular strength (grip strength) tests, and were assigned scores (Appendix Table A). Some were screened out of the aerobic fitness test (mCAFT) and the muscular endurance test (partial curl-ups), most because of health problems they reported during the screening component.

Figure 1
Median predicted maximal aerobic power (ml·(kg·min)$^{-1}$), by sex and age, household population aged 8 to 19 years, Canada, March 2007 to February 2009



Note: Equation for predicted maximal aerobic power has not been validated for children aged 8 to 14 years.
Source: 2007-2009 Canadian Health Measures Survey.

Relatively high percentages of 15- to 19-year-olds were screened out of the mCAFT (18% of girls and 17% of boys) and the partial curl-up test (14% of girls and 13% of boys). Based on their body composition measurements, those who were screened out tended to be less fit. For example, among those screened out of the mCAFT, mean BMI was 24.1 kg/m^2 and mean waist circumference was 80.4 cm, compared with a mean BMI of 23.2 kg/m^2 and a mean waist circumference of 78.0 cm among those who completed the test. Some younger children had difficulty with the mCAFT because of an inability to maintain the proper stepping cadence. This was especially the case for 8- to 10-year-olds, among whom 19% of boys and 13% of girls were not assigned VO_2max scores for this reason.

Body composition measurements were taken for virtually all children and youth who participated in the examination centre component (Appendix Table C).

Fitness measures

Predicted maximal aerobic power (VO_2max) declined with age for both boys and girls (Figure 1). However, these results should be interpreted with caution, because the equation for VO_2max has not been validated for children aged 8 to 14 years. At all ages, boys had higher VO_2max values than did girls.

Based on the sit-and-reach test, girls were more flexible than boys (Table 1). Flexibility scores were fairly stable across the three age groups for both sexes.

At ages 8 to 10 years, 28% of boys and 23% of girls were unable to complete even one partial curl-up. However, boys aged 15 to 19 years excelled at this test, with 64% completing 25 partial curl-ups. Girls in all three age groups tended to fall in the middle group, completing between one and 24 curl-ups.

In all three age groups, boys' mean scores for grip strength were higher than those of girls, and as might be expected, grip strength increased at older ages for both sexes.

BMI rose with age, although average BMIs were similar for boys and girls in all

Table 1
Descriptive statistics for selected fitness measures, by sex and age group, household population aged 6 to 19 years, Canada, March 2007 to February 2009

	6 to 10 (8 to 10) years‡			11 to 14 years			15 to 19 years		
		95% confidence interval			95% confidence interval			95% confidence interval	
Fitness measure and sex	Estimate	from	to	Estimate	from	to	Estimate	from	to
Aerobic fitness: predicted maximal aerobic power (ml • (kg • min)$^{-1}$)§									
Mean									
Boys	56.3†	55.7	56.8	54.9†	54.5	55.4	50.8	49.5	52.0
Girls	50.7†*	50.2	51.3	48.9†*	48.3	49.5	42.2*	41.6	42.8
Standard deviation									
Boys	3.5	...	...	3.4	...	...	5.8	...	...
Girls	3.8	...	...	4.0	...	...	4.3	...	...
50th percentile									
Boys	56.5†	55.3	57.7	55.7†	54.9	56.5	51.4	50.7	52.1
Girls	50.6†*	50.4	50.8	48.8†*	48.5	49.1	42.0*	41.1	42.9
Flexibility: sit-and-reach (cm)									
Mean									
Boys	24	23	26	21	20	23	23	22	24
Girls	29*	29	30	28*	27	29	30*	28	32
Standard deviation									
Boys	7	...	...	8	...	...	9	...	...
Girls	8	...	...	9	...	...	11	...	...
50th percentile									
Boys	25	24	27	22	19	24	24	23	25
Girls	30*	28	31	29*	27	30	29*	25	33
Muscular endurance: number of partial curl-ups in one minute (maximum 25)									
% completing zero									
Boys	28†	23	33	<10	...	...	4E	2	7
Girls	23†E	15	31	<10	...	...	10*	7	13
% completing 1 to 24									
Boys	61†	54	69	51†	41	60	32	26	37
Girls	64	55	72	56	52	61	52*	41	62
% completing 25									
Boys	11†E	5	17	44†	32	55	64	58	70
Girls	13†E	8	18	38	33	43	38*	26	50
Muscular strength: grip strength (kg)									
Mean									
Boys	25†	24	27	51†	48	54	85	81	89
Girls	23†*	21	24	42†*	41	43	54*	52	56
Standard deviation									
Boys	8	...	...	17	...	...	18	...	...
Girls	9	...	...	10	...	...	10	...	...
50th percentile									
Boys	25†	23	27	46†	43	49	85	79	91
Girls	22†*	20	24	41†*	40	42	54*	52	56
Body mass index (kg/m^2)									
Mean									
Boys	17.7†	17.3	18.1	20.6†	19.8	21.3	23.8	22.6	25.1
Girls	17.1†*	16.8	17.4	20.4†	19.9	21.0	23.1	22.5	23.8
Standard deviation									
Boys	2.9	...	...	4.4	...	...	5.3	...	...
Girls	3.2	...	...	3.8	...	...	4.6	...	...
50th percentile									
Boys	16.9†	16.5	17.3	19.3†	18.7	20.0	22.4	21.6	23.1
Girls	16.3†*	16.1	16.6	19.7†	19.0	20.5	22.0	21.3	22.7
Waist circumference (cm)									
Mean									
Boys	61†	59	62	71†	69	74	81	78	84
Girls	58†*	57	59	70†	68	72	77*	75	78
Standard deviation									
Boys	9	...	...	12	...	...	13	...	...
Girls	9	...	...	10	...	...	12	...	...
50th percentile									
Boys	59†	57	60	68†	66	70	77	75	80
Girls	56†*	55	56	69†	67	71	73*	71	75
Sum of five skinfolds (mm)††									
Mean									
Boys	48	44	52	54†	51	58	48	46	51
Girls	50†	47	53	67†*	61	73	79*	75	82
Standard deviation									
Boys	27	...	...	30	...	...	22	...	...
Girls	24	...	...	29	...	...	27	...	...
50th percentile									
Boys	36	32	40	44	41	46	41	37	45
Girls	42†*	39	44	61†*	52	69	74*	67	81
Waist-to-hip ratio									
Mean									
Boys	0.84	0.84	0.84	0.82	0.81	0.83	0.83	0.81	0.84
Girls	0.82†*	0.82	0.83	0.80†*	0.78	0.81	0.77*	0.76	0.79
Standard deviation									
Boys	0.05	...	...	0.06	...	...	0.06	...	...
Girls	0.05	...	...	0.06	...	...	0.06	...	...
50th percentile									
Boys	0.84†	0.84	0.84	0.81	0.80	0.82	0.82	0.81	0.83
Girls	0.82†*	0.81	0.83	0.79†*	0.78	0.80	0.76*	0.75	0.77

* significantly different from estimate for boys ($p < 0.05$)
† significantly different from estimate for 15- to 19-year-olds ($p < 0.05$)
‡ 6- and 7-year-olds excluded from estimates for aerobic fitness and muscular endurance (partial curl-ups)
§ equation for predicted maximal aerobic power (ml•(kg•min)$^{-1}$) has not been validated for children younger than 15 years
†† excludes respondents with BMI 30.0 kg/m^2 or higher
E use with caution (coefficient of variation 16.6% to 33.3%)
... not applicable
Note: If coefficient of variation of estimate is greater than 33%, estimate is indicated as being less than upper limit of 95% confidence interval.
Source: 2007-2009 Canadian Health Measures Survey.

three age groups. Waist circumference, too, increased with age. Average waist circumference was similar for boys and girls aged 11 to 14 years, but in the older and younger age groups, boys' average waist circumference was larger.

Skinfold measurements were taken for children and adolescents whose BMI was less than 30.0 kg/m^2 (94% of boys and girls). At ages 11 to 14 years, boys, average skinfold measurements were higher than at ages 6 to 10 or 15 to 19 years. Among girls, average skinfold measurements rose with age, and in the two older age groups, girls had higher average skinfold measurements than did boys.

Girls aged 6 to 10 years had higher waist-to-hip ratios than did 15- to 19-year-olds. In all three age groups, girls' waist-to-hip ratios were lower than those of boys.

Health benefit ratings

Based on their fitness measures, 15- to 19-year-olds were assigned health benefit ratings (Table 2). To provide context, these ratings are compared with those for adults aged 20 to 39 years. The "excellent" and "very good" categories and the "fair" and "needs improvement" categories were combined to ensure sufficient sample size for all measures. Health benefit ratings for aerobic and musculoskeletal fitness are based on age-specific cut-offs that take account of expected changes in these measures that occur with age.[30]

At ages 15 to 19 years, 32% of boys and 20% of girls had VO$_2$max scores that placed them in the fair/ needs improvement category. Percentages were much higher among 20- to 39-year-olds: 46% of men and 37% of women.

More than two-thirds (68%) of boys and 59% of girls aged 15 to 19 years had sit-and-reach (*flexibility*) scores that placed them in the fair/needs improvement category, similar to the percentages for 20- to 39-year-olds. Teens and young adults also had similar ratings for *muscular endurance*—38% of teenage girls and 20% of teenage boys were in the fair/needs improvement category. Just

Table 2
Percentage distribution of health benefit ratings of selected fitness measures, by sex, household population aged 15 to 19 years and 20 to 39, Canada, March 2007 to February 2009

	15 to 19 years			20 to 39 years		
		95% confidence interval			95% confidence interval	
Health benefit rating and sex	%	from	to	%	from	to
Aerobic fitness health benefit zone						
Fair/Needs improvement						
Boys	32†	24	39	46	41	51
Girls	20†*	14	25	37*	31	44
Good						
Boys	31	24	38	26	20	33
Girls	54†*	47	62	40*	37	44
Excellent/Very good						
Boys	38†	31	45	27	19	36
Girls	26*	19	34	23	16	29
Flexibility (sit-and-reach) health benefit zone						
Fair/Needs improvement						
Boys	68	62	74	61	55	66
Girls	59*	49	69	55	52	59
Good						
Boys	19	13	24	16	12	21
Girls	12[E]	8	16	16	12	19
Excellent/Very good						
Boys	13†[E]	8	19	23	19	27
Girls	30*	21	38	29*	26	32
Muscular endurance (partial curl-up) health benefit zone						
Fair/Needs improvement						
Boys	20[E]	13	27	19	14	23
Girls	38*	28	47	46*	41	52
Good						
Boys	<10	...	...	7[E]	4	9
Girls	9	7	12	10	7	13
Excellent/Very good						
Boys	74	68	80	75	70	80
Girls	53*	44	62	44*	39	49
Muscular strength (grip strength) health benefit zone						
Fair/Needs improvement						
Boys	59†	51	67	42	35	49
Girls	47†*	38	55	56*	50	61
Good						
Boys	19[E]	13	25	24[E]	15	32
Girls	27†	22	32	18	14	22
Excellent/Very good						
Boys	22†	17	27	34	27	42
Girls	27	20	33	27	19	34
Overall musculoskeletal health benefit zone‡						
Fair/Needs improvement						
Boys	46†	36	55	30	25	36
Girls	47	37	56	51*	46	56
Good						
Boys	30	21	39	32	26	38
Girls	29	20	38	28	23	33
Excellent/Very good						
Boys	25†	19	31	38	31	44
Girls	24[E]	16	33	21*	17	24
Body mass index category§						
Obese						
Boys	14[E]	6	22	19	15	23
Girls	10†	7	13	21	16	25
Overweight						
Boys	17†	12	22	37	30	45
Girls	16†	12	20	23*	17	30
Normal weight						
Boys	69†	60	77	43	37	48
Girls	74†	69	80	50	41	60
Waist circumference health risk						
High risk						
Boys	<13†	...	...	21	18	24
Girls	17†*	12	21	31*	25	37
Increased risk						
Boys	<12†			14	11	18
Girls	11[E]	5	17	17[E]	11	23
Low risk						
Boys	85†	78	93	65	61	69
Girls	72† *	64	80	52*	43	61
Body composition health benefit zone††						
Fair/Needs improvement						
Boys	<13†	...	...	20	17	23
Girls	15†[E]	9	20	29*	23	34
Good						
Boys	<11	...	...	<5	...	...
Girls	<4	...	...	<6	...	...
Excellent/Very good						
Boys	86†	79	94	77	73	82
Girls	84†	79	88	68*	61	74
Back fitness health benefit zone‡‡						
Fair/Needs improvement						
Boys	13†	10	16	22	18	25
Girls	22†[E]	13	31	30*	24	36
Good						
Boys	29	23	35	21	15	27
Girls	14*[E]	8	20	17	12	22
Excellent/Very good						
Boys	58	52	65	58	53	62
Girls	64†	56	72	53	47	59

* significantly different from estimate for boys ($p < 0.05$)
† significantly different from estimate for 20- to 39-year-olds ($p < 0.05$)
‡ based on flexibility, muscular endurance and muscular strength
§ estimates for underweight not reported because of small sample sizes
†† based on BMI, waist circumference and sum of five skinfolds
‡‡ based on flexibility, muscular endurance and waist circumference
E use with caution (coefficient of variation 16.6% to 33.3%)
... not applicable
Note: If coefficient of variation of estimate is greater than 33%, estimate is indicated as being less than upper limit of 95% confidence interval.
Source: 2007-2009 Canadian Health Measures Survey.

under half (47%) of teenage girls were in the fair/needs improvement category for *muscular strength,* compared with 59% of teenage boys. Men aged 20 to 39 years fared better than teenage boys, with 42% being assessed this low rating. However, women aged 20 to 39 did not score as well as teenage girls, with 56% in the fair/needs improvement category.

Based on a combination of their flexibility, muscular endurance and muscular strength scores, almost half of 15- to 19-year-olds were assessed as fair/ needs improvement for *musculoskeletal health*; slightly less than a third were assessed as good; and the remaining quarter, as very good/ excellent. Teenage boys' ratings were not as favourable as those of men aged 20 to 39 years; teenage girls and women aged 20 to 39 years had similar ratings.

For all body composition measurements, teens' health benefit ratings were better than those of 20- to 39-year-olds. Teens were more likely to have BMIs that placed them in the normal weight group, less likely to have waist circumferences that placed them in the high-risk group, and for the composite measure based on BMI, waist circumference and the sum of five skinfolds, smaller percentages were in the fair/needs improvement category.

The back fitness of 13% of boys and 22% of girls aged 15 to 19 years was assessed as fair/needs improvement. The corresponding figures among 20- to 39-year-olds were higher, at 22% for men and 30% for women.

Comparisons with 1981

Where comparable tests were administered for flexibility and muscular strength and similar anthropometric measurements were taken, CHMS results were compared with data collected in the 1981 Canadian Fitness Survey (CFS). To make estimates more comparable, respondents screened out of the aerobic fitness test were excluded from CHMS estimates of flexibility and muscular strength (see *Methods*). Screen-out rates (based on the aerobic fitness test) for the two surveys are given in Appendix Table B. Screen-out rates were similar between the two surveys for children aged 7 to 10 and 11 to 14 years, but much higher percentages of 15- to 19-year-olds were screened out in 2007-2009 than in 1981.

Fitness scores for children and adolescents were less favourable in 2007-2009 than in 1981 (Table 3). For boys and girls in all age groups, flexibility and muscular strength scores were lower in 2007-2009, and mean BMI, waist circumference and the sum of five skinfolds were higher.

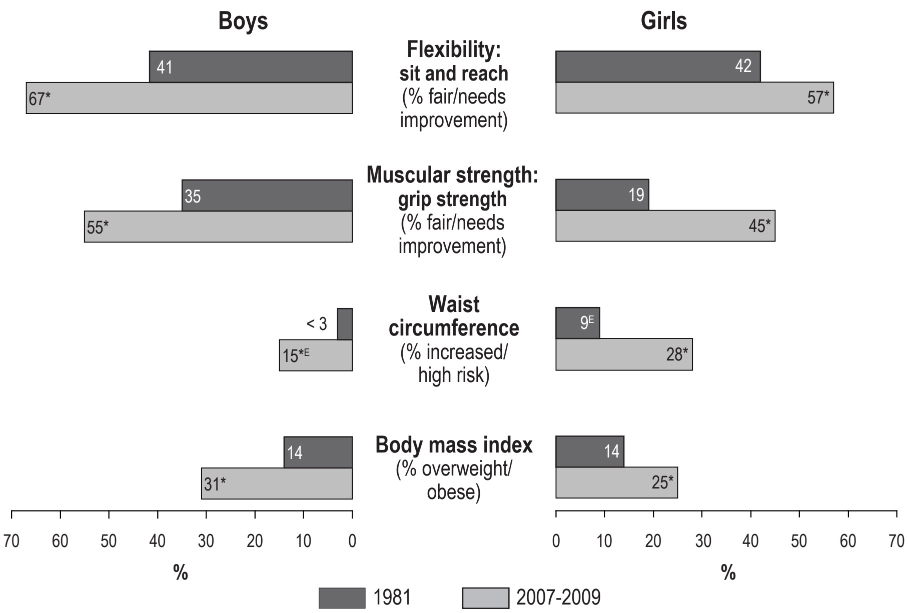
Compared with 1981, in 2007-2009, higher percentages of boys and girls aged 15 to 19 years were in the fair/needs improvement category for flexibility and muscular strength (Figure 2). The percentage in the increased/high-risk waist circumference category more than tripled for both sexes. The percentage classified as overweight or obese rose from 14% to 31% among boys, and from 14% to 25% among girls. For overall body composition, the percentage assigned to the bottom three categories (good/

Table 3
Mean and median values for selected fitness measures, by sex and age group, household population aged 7 to 19 years, Canada, 1981 and 2007-2009

Fitness measure, sex and survey year	7 to 10 years		11 to 14 years		15 to 19 years	
	Mean	Median	Mean	Median	Mean	Median
Flexibility: sit-and-reach (cm)						
Boys						
1981	27	28	26	27	30	30
2007-2009	24*	25*	21*	22*	24*	24*
Girls						
1981	32	32	32	33	34	35
2007-2009	29*	29*	28*	29*	30*	29*
Muscular strength: grip strength (kg)						
Boys						
1981	32	32	57	53	96	96
2007-2009	27*	28*	51*	46*	86*	87*
Girls						
1981	29	28	48	47	60	60
2007-2009	24*	24*	42*	41*	54*	54*
Body mass index (kg/m²)						
Boys						
1981	16.8	16.3	18.9	18.4	21.9	21.4
2007-2009	18.1*	17.4*	20.6*	19.3*	23.8*	22.4*
Girls						
1981	16.9	16.4	19.3	19.1	21.6	21.1
2007-2009	17.4*	16.5	20.4*	19.7	23.1*	22.0*
Waist circumference (cm)						
Boys						
1981	59	58	67	66	76	75
2007-2009	62*	60*	71*	68	81*	77
Girls						
1981	58	57	64	64	69	68
2007-2009	59*	57	70*	69*	77*	73*
Sum of five skinfolds (mm)†						
Boys						
1981	37	32	43	37	43	37
2007-2009	51*	39*	54*	44*	48*	41
Girls						
1981	47	42	55	50	64	60
2007-2009	52*	45	67*	61*	79*	74*

* significantly different from estimate for 1981 ($p < 0.05$)
† excludes respondents with BMI 30.0 kg/m² or more
Note: To make estimates more comparable, Canadian Health Measures Survey estimates for flexibility and muscular strength exclude respondents screened out of aerobic fitness test (see *Methods*).
Source: 1981 Canada Fitness Survey; 2007-2009 Canadian Health Measures Survey.

Figure 2
Percentage with suboptimal health benefit ratings for selected anthropometric measures, by sex, household population aged 15 to 19 years, Canada, 1981 and 2007-2009



* significantly higher than estimate for 1981 (p<0.05)
E use with caution (coefficient of variation 16.6% to 33.3%)
Note: To make estimates more comparable, Canadian Health Measures Survey estimates for flexibility and muscular strength exclude respondents screened out of aerobic fitness test (see *Methods*). If coefficient of variation of estimate is greater than 33.3%, estimate is indicated as being less than upper limit of 95% confidence interval
Sources: 1981 Canada Fitness Survey; 2007-2009 Canadian Health Measures Survey.

fair/needs improvement; combined to ensure adequate sample sizes) more than quadrupled from less than 2% to 14% for boys, and from 4% to 16% for girls (not shown in Figure 2).

A typical 12-year-old

Figure 3 depicts a typical 12-year-old boy and girl in 1981 and in 2007-2009. In 2007-2009, a 12-year-old boy was, on average, about 5 cm (2 inches) taller than his 1981 counterpart and weighed 6.4 kg (14 pounds) more. His waist circumference was 1.3 cm larger, his hip circumference 6.0 cm larger, and his BMI had increased by 1.1 kg/m^2. His grip strength had declined by 5 kg, and his score in the sit-and-reach test decreased by 5.1 cm.

In 2007-2009, a typical 12-year-old girl was 2.8 cm (1.1 inches) taller than her 1981 counterpart, and she weighed 4.9 kg (11 pounds) more. Her waist circumference was 5.6 cm larger, her hip circumference 4.8 cm larger, and her BMI had risen by 1.1 kg/m^2. Her grip strength had declined by 3 kg, and her score on the sit-and-reach test had decreased by 3.8 cm.

Discussion

Nationally representative data on the fitness of Canadian children and youth have not been available in two decades, a period that saw a remarkable rise in childhood obesity.[6-8] Using data from cycle 1 of the Canadian Health Measures Survey, this paper provides an important update, demonstrating that fitness levels have declined significantly and meaningfully since 1981; that significant sex differences exist for most measures of fitness; that fitness levels change substantially from age 6 through 19 years; and that 15- to 19-year-olds generally have better health benefit ratings for aerobic fitness and body composition than do adults aged 20 to 39, but results for musculoskeletal fitness are mixed. Overall, the patterns by age and sex in the CHMS are consistent with those in the 1981 CFS. Sex and age-related differences reflect complex and interconnected effects of genetics, anatomy, physiology, behaviour and social and physical environments.

Fitness testing of children and youth has been done in Canada and the United States with varying degrees of rigour for more than 50 years,[45] but the lack of standardization in test protocols makes it difficult to assess temporal trends. School-based fitness testing was common in Canada in the 1960-to-1980 period, but testing protocols were oriented toward performance-related fitness (for example, standing long jump, 50-metre sprint, flexed arm hang)[46-48] rather than health-related fitness,[30] which is the focus of measures in the CHMS.

Body composition

The estimates of height and weight of a typical 12-year-old boy and girl from the CHMS are significantly greater than those for age-matched counterparts from the CFS. This upward trend in height and weight has been evident in developed countries since the early 19th century and likely reflects a combination of improved health and nutrition, accelerated maturation, and more favourable living conditions.[49]

Indicators of body composition (BMI, waist circumference, skinfold measures) increased substantially between 1981 and 2007-2009. These direct measures of adiposity further verify previously reported trends[6-8] and provide strong evidence that the increases in childhood obesity and overweight based on BMI are related to greater adiposity, not greater muscularity.

Girls had higher mean skinfolds than did boys, but generally had lower

Figure 3
Portrait of typical 12-year-old boy and girl, 1981 and 2007-2009

BOY

1981	BODY COMPOSITION	2007-2009
150.9 cm (4'11")	Height	155.8 cm (5'1")*
41.6 kg (92 pounds)	Weight	48.0 kg (106 pounds)*
18.1 kg/m²	Body mass index	19.2 kg/m²*
64.9 cm (25.6")	Waist circumference	66.2 cm (26.1")
78.0 cm (30.7")	Hip circumference	84.0 cm (33.1")*
0.83	Waist-to-hip ratio	0.82*
	FITNESS TESTS	
49 kg	Grip strength	44 kg*
26.5 cm	Sit-and-reach	21.4 cm*

GIRL

1981	BODY COMPOSITION	2007-2009
153.1 cm (5'0")	Height	155.9 cm (5'1")*
42.7 kg (94 pounds)	Weight	47.6 kg (105 pounds)*
18.4 kg/m²	Body mass index	19.5 kg/m²*
62.4 cm (24.6")	Waist circumference	68.0 cm (26.8")*
81.2 cm (32.0")	Hip circumference	86.0 cm (33.9")*
0.76	Waist-to-hip ratio	0.79*
	FITNESS TESTS	
43 kg	Grip strength	40 kg*
32.0 cm	Sit-and-reach	28.2 cm*

* significantly different from estimate for 1981 ($p<0.05$)
Note: Estimates are based on median values for boys and girls aged 11 to 13 years. To make estimates more comparable, Canadian Health Measures Survey estimates for flexibility and muscular strength exclude respondents screened out of aerobic fitness test (see *Methods*).
Sources: 1981 Canada Fitness Survey; 2007-2009 Canadian Health Measures Survey.

waist circumferences and waist-to-hip ratios. Mean BMIs were similar. Earlier Canadian studies showed that while BMI was equivalent, levels of subcutaneous fat as measured by the sum of skinfolds were higher among girls and that BMI in boys and girls and sum of skinfolds in girls increased with age.[21,22]

Compared with results from the Amsterdam Growth and Health Longitudinal Study,[50,51] which began in 1974 and followed participants for 32 years, the BMI of Canadian children aged 11 to 14 years is approximately 3 units (kg/m²) higher for boys and 4 units higher for girls. If the BMI of Canadian children follows trajectories over the next few decades similar to those of the Amsterdam children, the average 11- to 14-year-old Canadian of today will be overweight by age 36 years.

Aerobic fitness

Because of refinements in the aerobic fitness measures used in the CPAFLA (mCAFT) over time, direct comparisons of aerobic fitness between the CFS and the CHMS are difficult, and require additional analyses beyond the scope of this paper. Based on field fitness testing, global temporal trend data demonstrate a worldwide decrease in pediatric aerobic fitness[16,52] that cannot be explained solely by the increase in child adiposity.[53] These findings suggest that a decrease in physical activity and subsequent detraining effect are likely at least partially responsible for the decline in aerobic fitness.[53] Absolute comparisons of aerobic fitness results to international data are hampered by the lack of data using the same protocol (mCAFT) and the lack of a validated method to convert mCAFT scores to VO_2max in children younger than 15 years.

In the CHMS, aerobic fitness was higher in boys than girls and decreased with age among both sexes, consistent with previous Canadian findings.[21] Recent data from the United States National Health and Nutrition Examination Survey also showed significantly higher estimated VO_2max in boys than girls aged 12 to 19 years and an increase in maximal aerobic power with age in boys, but a decrease with age in girls.[54] Age-related declines may be due to less physical activity, increased adiposity, or changes in hemodynamic and/or metabolic functions associated with growth and development.[49] Although the age-related decline in aerobic fitness (expressed relative to body weight) through childhood is well documented,[49] routine participation in moderate to vigorous physical activity could slow or reverse this trend.[55]

The age- and sex-matched median predicted maximal aerobic power values from the United States[54] are lower than the Canadian values reported in Figure 1. The differences may reflect higher aerobic fitness among Canadian children and youth, fundamental differences in testing protocols, problems with the equation used to predict maximal aerobic power in Canadian children and youth (not validated for children younger than 15 years), or some combination of explanations. The mCAFT uses age-predicted maximum heart rate (220 – age) to determine the heart rate at which the test is completed. Because maximal heart

What is already known on this subject?

- Childhood obesity has risen significantly over the past 20 to 30 years.
- Excess adiposity in childhood is associated with elevated cardio-metabolic disease risk.
- Even in childhood, strong evidence indicates a direct relationship between fitness and health.
- Boys generally demonstrate better aerobic fitness and strength than girls, while girls demonstrate better flexibility.
- Aerobic fitness, relative to body weight, declines with age through childhood and adolescence and is lower in girls than boys.

What does this study add?

- At age 12 years, Canadian boys and girls are now taller and heavier than in 1981.
- Based on a variety of direct measures of anthropometry from the Canadian Health Measures Survey, the body composition of Canadian children and youth is less healthy than in 1981.
- The strength and flexibility of boys and girls has declined significantly since 1981.
- Increases in childhood obesity and overweight are related to increased adiposity, not greater muscularity.

rate does not change much in childhood, this methodology may affect predicted maximal aerobic power results. Further research is required to substantiate these potential explanations.

VO_2max estimates for Canadian children aged 11 to 14 years appear slightly lower than earlier estimates from a sample of 13-year-olds in the Amsterdam Growth and Health Longitudinal Study in 1974.[50,51] At age 36 years, VO_2max estimates for these participants were about 50 ml•(kg•min)$^{-1}$ for men and 40 ml•(kg•min)$^{-1}$ for women, which are higher than estimates for men and equivalent to those for women aged 20 to 39 years in the CHMS.[42] Based on this age-related decline of VO_2max and the secular trend toward poorer fitness levels indicated by a comparison between the CHMS and CFS, it is likely that when these 11- to 14-year-old Canadians are adults, their fitness profile will be poorer than that of current adults.

Musculoskeletal fitness

Significantly lower flexibility and muscular strength scores were observed for boys and girls of all ages in the CHMS, compared with the 1981 CFS. Prospective, longitudinal studies examining health-related outcomes related to flexibility and strength through childhood are lacking, as are international comparisons that employed similar measurement protocols. However, studies of communities that have not adopted modern technology and lifestyles are useful bases of comparison. Results for Canadian Old Order Amish and Old Order Mennonite children indicate that their grip strength is approximately 50% higher than the results obtained from the CHMS.[56,57]

Muscular strength was higher in boys than in girls and increased with age among both sexes. Girls had better flexibility scores than did boys at all ages, and there was no age-related difference in mean flexibility scores. Neither of these findings is new, and they reaffirm patterns observed in earlier surveys.[21,22]

The muscular endurance test is influenced by floor and ceiling effects (Table 1). Nonetheless, results seem to improve with age, with boys aged 15 to 19 years performing better than girls. Further research on the validity and reliability of this test for children younger than 15 years is required.

Limitations

The findings in this study have important limitations that should be considered when interpreting the results. Most notably, the screening criteria for the various fitness tests, which were employed to ensure respondent safety, could have biased the sample. For example, the mean BMI of the 17% of 15- to 19-year-olds screened out of the aerobic fitness test was 24.1 kg/m^2, compared with 23.2 kg/m^2 among those who completed the test, indicating that those who were screened out were heavier.

As much as possible, the fitness tests and anthropometric measures in the CHMS were selected for their similarity to those in the CFS. However, differences in the sample design, the educational and training requirements of survey administrators, the testing venue, and response rates and weighting procedures may have weakened the comparability of estimates.

Maximal aerobic power in children is most often referred to as "peak VO_2" rather than VO_2max, as is often used in adults. This difference highlights the challenge of getting directly measured "true" maximal tests from children.[58] The adult convention of expressing VO_2max relative to body weight (for example, O_2 per kg per min) has been challenged in the pediatric literature because of strong evidence demonstrating a non-linear relationship between peak VO_2 and body mass during growth and maturation.[49,58] However, no allometric scaling was performed on the data in these analyses. Furthermore, as previously noted, the equation for calculating VO_2max has not been validated for chidren younger than 15 years.

It was noted during field observations that some younger children had difficulty performing the partial curl-up test for reasons other than level of muscular endurance. Thus, 6- and 7-year-olds were excluded from CHMS estimates. Difficulty performing the test may also explain, in part, the high percentage of 8- to 10-year-olds who completed no curl-ups.

The overall non-response rate to the CHMS was 46.5%. Although adjustments were made to the sampling weights to compensate, CHMS estimates may be biased if there were systematic differences between respondents and non-respondents. One concern is the possibility that less-fit individuals may have been less likely to participate, particularly in the examination centre component of the survey. To assess this source of bias, estimates of overweight/obesity from the 2007-2009 CHMS were compared with those from the 2008 Canadian Community Health Survey (CCHS) that were based on measured height and weight. Among 12- to 19-year-olds, the estimated prevalence of overweight/obesity according to 2008 CCHS data was 30.8%, somewhat higher than the CHMS estimate of 28.2%, which suggests that CHMS data may overestimate fitness levels to some extent. The same concern about bias may also apply to the CFS estimates. Based on CFS data, 13.1% of children aged 7 to 19 years were overweight/obese in 1981, compared with the estimate of 13.9% based on data from the 1978/1979 Canada Health Survey.[20]

Finally, it is possible that secular changes in the timing and tempo of maturation influenced the results. The comparisons in Figure 3 should be interpreted with this possibility in mind.

Conclusions

This paper provides the first comprehensive assessment of the fitness of Canadian children and youth in a generation. The results demonstrate a significant deterioration since 1981, regardless of sex or age. In particular, muscular strength and flexibility have decreased, and all measures of adiposity have increased. Children are taller, heavier, fatter and weaker than in 1981. Previous research predicts that a population decline in fitness, as observed here, may result in accelerated non-communicable disease development, increased health care costs, and loss of future productivity.[5,10-15,17,49,59] Ongoing surveillance of fitness through the Canadian Health Measure Survey will be important for monitoring trends, examining relationships between fitness and health, and assessing future interventions designed to improve the fitness of the nation. ■

References

1. Tremblay MS. Major initiatives related to childhood obesity and physical inactivity in Canada: the year in review. *Canadian Journal of Public Health* 2007; 98: 457-9.
2. Active Healthy Kids Canada. *2008 Report Card on Physical Activity for Children and Youth*. Active Healthy Kids Canada, 2008. [cited 2009 July 4] Available at: http://www.activehealthykids.ca/ReportCard/ArchivedReportCards.aspx.
3. Active Healthy Kids Canada. *2009 Report Card on Physical Activity for Children and Youth*. Active Healthy Kids Canada, 2009. [cited 2009 July 4] Available at: http://www.activehealthykids.ca/ReportCard/2009ReportCardOverview.aspx.
4. Leitch KK. *Reaching for the Top: A Report by the Advisor on Healthy Children and Youth.* Health Canada (Catalogue H21-296/2007E) Ottawa: Minister of Public Works and Government Services Canada, 2007.
5. House of Commons Canada. *Healthy Weights for Healthy Kids: Report of the Standing Committee on Health*. Ottawa: Communication Canada – Publishing, 2007.
6. Tremblay MS, Willms JD. Secular trends in body mass index of Canadian children. *Canadian Medical Association Journal* 2000; 163: 1429-33; erratum 2001; 164(7): 970.
7. Tremblay MS, Katzmarzyk PT, Willms JD. Temporal trends in overweight and obesity in Canada, 1981-1996. *International Journal of Obesity and Related Metabolic Disorders* 2002; 26: 538-43.
8. Shields M. Overweight and obesity among children and youth. *Health Reports* (Statistics Canada, 82-003) 2006; 17(3): 27-42.
9. Canadian Fitness and Lifestyle Research Institute. *Kids CAN PLAY!* [cited 2009 July 31] Available at: http://www.cflri.ca/eng/statistics/surveys/documents/CANPLAY_2008_b1.pdf.
10. Ball GDC, McCargar LJ. Childhood obesity in Canada: a review of prevalence estimates and risk factors for cardiovascular diseases and type 2 diabetes. *Canadian Journal of Applied Physiology* 2003; 28: 117-40.
11. Janssen I. Physical activity guidelines for children and youth. *Applied Physiology, Nutrition and Metabolism* 2007; 32(Suppl.2E): S109-S121.
12. Strong WB, Malina RM, Blimkie CJ, et al. Evidence based physical activity for school-age youth. *Journal of Pediatrics* 2005; 146: 732-7.
13. Physical Activity Guidelines Advisory Committee. *Physical Activity Guidelines Advisory Committee Report, 2008*. Washington, DC: U.S. Department of Health and Human Services, 2008.
14. Katzmarzyk PT, Baur LA, Blair SN, et al. International conference on physical activity and obesity in children: summary statement and recommendations. *International Journal of Pediatric Obesity* 2008; 3: 3-21.
15. Andersen LB, Harro M, Sardinha LB, et al. Physical activity and clustered cardiovascular risk in children: a cross-sectional study (The European Youth Heart Study). *Lancet* 2006; 368: 299-304.
16. Tomkinson GR, Leger LA, Olds TS, Cazorla G. Secular trends in the performance of children and adolescents (1980-2000). *Sports Medicine* 2003; 33: 285-300.
17. Anderssen SA, Cooper AR, Riddoch C, et al. Low cardiorespiratory fitness is a strong predictor for clustering of cardiovascular disease risk factors in children independent of country, age and sex. *European Journal of Cardiovascular Disease Prevention and Rehabilitation* 2007; 14: 526-31.
18. Ekelund U, Anderssen SA, Froberg K, et al. Independent associations of physical activity and cardiorespiratory fitness with metabolic risk factors in children: the European Youth Heart Study. *Diabetologia* 2007; 50: 1832-40.
19. Nutrition Canada. *Nutrition – A National Priority* (Catalogue H58-36) Ottawa: Department of National Health and Welfare, 1973.
20. Canada Health Survey. *The Health of Canadians: Report of the Canada Health Survey* (Catalogue 82-538) Ottawa: Health and Welfare Canada/Statistics Canada, 1981.
21. Canada Fitness Survey. *Fitness and Lifestyle in Canada*. Ottawa: Minister of Fitness and Amateur Sport, 1983.

22. Stephens T, Craig CL. *The Well-Being of Canadians: Highlights of the 1988 Campbell's Survey*. Ottawa: Canadian Fitness and Lifestyle Research Institute, 1990.

23. Tremblay MS, Connor Gorber, S. Canadian Health Measures Survey: brief overview. *Canadian Journal of Public Health* 2007; 98: 453-6.

24. Tremblay MS, Wolfson M, Connor Gorber S. Canadian Health Measures Survey: background, rationale and overview. *Health Reports* (Statistics Canada, Catalogue 82-003) 2007; 18(Suppl.): 7-20.

25. Bryan S, St-Denis M, Wojtas D. Canadian Health Measures Survey: Clinic operations and logistics. *Health Reports* (Statistics Canada, Catalogue 82-003) 2007; 18(Suppl.): 53-70.

26. Day B, Langlois R, Tremblay M, et al. Canadian Health Measures Survey: Ethical, legal and social issues. *Health Reports* (Statistics Canada, Catalogue 82-003) 2007; 18(Suppl.): 37-52.

27. Giroux S. Canadian Health Measures Survey: Sampling strategy overview. *Health Reports* (Statistics Canada, Catalogue 82-003) 2007; 18(Suppl): 31-6.

28. Canada Fitness Survey. *A User's Guide to CFS findings*. Ottawa: Canada Fitness Survey, 1983.

29. Canadian Fitness and Lifestyle Research Institute. *Canada Fitness Survey Household Survey: Micro-data tape documentation*. Ottawa: Canadian Fitness and Lifestyle Research Institute, 1992.

30. Canadian Society for Exercise Physiology. *The Canadian Physical Activity, Fitness and Lifestyle Approach (CPAFLA) Third Edition*. Ottawa: Canadian Society for Exercise Physiology, 2003.

31. Statistics Canada. *Canadian Health Measures Survey (CHMS) Data Users' Guide: Cycle 01, September 2007*. Available at: www.statcan.gc.ca.

32. Statistics Canada. *Canadian Health Measures Survey (CHMS) Clinic Questionnaire: Cycle 01, September 2007*. Available at: www.statcan.gc.ca/imdb-bmdi/instrument/5071_Q2_V1-eng.pdf.

33. World Health Organization. *Physical Status: The Use and Interpretation of Anthropometry, Report of the WHO Expert Committee* (WHO Technical Report Series, No. 854) Geneva: World Health Organization, 1995.

34. Fitness Canada. *Canadian Standardized Test of Fitness (CSTF) Operations Manual. Third Edition.* Ottawa: Fitness and Amateur Sport, Government of Canada, 1986.

35. Health Canada. *Canadian Guidelines for Body Weight Classification in Adults* (Catalogue H49-179) Ottawa: Health Canada, 2003.

36. Cole TJ, Bellizzi MC, Flegal KM, et al. Establishing a standard definition for child overweight and obesity worldwide: international survey. *British Medical Journal* 2000; 320(7244): 1240-3.

37. Lau DC, Douketis JD, Morrison KM, et al. 2006 Canadian clinical practice guidelines on the management and prevention of obesity in adults and children [summary]. *Canadian Medical Association Journal* 2007; 176(8 Suppl.): Online 1-12.

38. World Health Organization. *Obesity: Preventing and Managing the Global Epidemic* (WHO Technical Report Series, No. 894) Geneva: World Health Organization, 2000.

39. Lean ME, Han TS, Morrison CE. Waist circumference as a measure for indicating need for weight management. *British Medical Journal* 1995; 311(6998): 158-61.

40. Weller IM, Thomas SG, Corey PN, et al. Prediction of maximal oxygen uptake from a modified Canadian aerobic fitness test. *Canadian Journal of Applied Physiology* 1993; 18(2): 175-88.

41. Weller IM, Thomas SG, Gledhill N, et al. A study to validate the modified Canadian Aerobic Fitness Test. *Canadian Journal of Applied Physiology* 1995; 20(2): 211-21.

42. Shields M, Tremblay MS, Laviolette M, et al. Fitness of Canadian adults: Results from the 2007-2009 Canadian Health Measures Survey. *Health Reports* (Statistics Canada, Catalogue 82-003) 2009; 21(1): online: 1-15.

43. Rao JNK, Wu CFJ, Yue K. Some recent work on resampling methods for complex surveys. *Survey Methodology* (Statistics Canada, Catalogue 12-001) 1992; 18(2): 209-17.

44. Rust KF, Rao JNK. Variance estimation for complex surveys using replication techniques. *Statistical Methods in Medical Research* 1996; 5: 281-310.

45. Morrow JR, Zhu W, Franks D, et al. 1958-2008: 50 years of youth fitness tests in the United States. *Research Quarterly for Exercise and Sport* 2009; 80: 1-11.

46. *Canada Fitness Award Manual*. Ottawa: Fitness and Amateur Sport, Government of Canada, 1984.

47. *CAHPER Fitness-Performance Test II Manual*. Ottawa: Canadian Association for Health Physical Education and Recreation, 1980.

48. *The CAHPER Fitness-Performance Test Manual – for Boys and Girls 7-17 years of age*. Ottawa: Canadian Association for Health Physical Education and Recreation, 1966.

49. Malina RM, Bouchard C, Bar-Or O. *Growth, Maturation, and Physical Activity (Second Edition)*. Champaign, Illinois: Human Kinetics Publishers, 2004.

50. Kemper HCG, Snel, J, van Mechelen W. General introduction. In: Kemper HCG (ed.) Amsterdam Growth and Health Longitudinal Study (AGAHLS): A 23-year follow-up from teenager to adult about lifestyle and health. *Medicine and Sport Science* 2004; 47: 5-20.

51. Koppes LLJ, Twisk JWR, Kemper HCG. Longitudinal trends, stability and error of biological and lifestyle characteristics. In: HCG Kemper (ed.) Amsterdam Growth and Health Longitudinal Study (AGAHLS): A 23-year follow-up from teenager to adult about lifestyle and health. *Medicine and Sport Science* 2004; 47: 45-63.

52. Tomkinson GR, Olds TS. Secular changes in pediatric aerobic fitness test performance: the global picture. In: Tomkinson GR, Olds TS (eds.) *Pediatric Fitness: Secular Trends and Geographic Variability*. Basel, Switzerland: Karger: 46-66.

53. Olds TS, Ridley K, Tomkinson GR. Declines in aerobic fitness: are they only due to increasing fatness? In: Tomkinson GR, Olds TS (eds.). *Pediatric Fitness: Secular Trends and Geographic Variability*. Basel, Switzerland: Karger: 226-40.

54. Pate RR, Wang C-Y, Dowda M, et al. Cardiorespiratory fitness levels among US youth 12 to 19 years of age. *Archives of Pediatric and Adolescent Medicine* 2006; 160: 1005-12.

55. Pfeiffer KA, Dowda M, Dishman RK, et al. Cardiorespiratory fitness in girls change from middle to high school. *Medicine and Science in Sports and Exercise* 2007; 39: 2234-41.

56. Tremblay MS, Esliger DW, Copeland JL, et al. Moving forward by looking back: Lessons learned from lost lifestyles. *Applied Physiology, Nutrition and Metabolism* 2008; 33: 836-42.

57. Tremblay MS, Barnes JD, Copeland JL, Esliger DW. Conquering childhood inactivity: Is the answer in the past? *Medicine and Science in Sports and Exercise* 2005; 37: 1187-94.

58. Armstrong N, Welsman JR. Aerobic fitness: what are we measuring? In: Tomkinson GR, Olds TS (eds.). *Pediatric Fitness: Secular Trends and Geographic Variability*. Basel, Switzerland: Karger: 5-25.

59. U.S. Department of Health and Human Services. *Physical Activity and Health: A Report of the Surgeon General.* Atlanta, Georgia: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Chronic Disease Prevention and Health Promotion, 1996.

Table A
Percentage distribution of participation outcomes for fitness tests, by sex and age group, household population aged 6 to 19 years, Canada, March 2007 to February 2009

Fitness test, outcome and sex	6 to 8 (8 to10) years§	11 to 14 years	15 to 19 years
	%		
Aerobic fitness test (mCAFT)			
Screened in			
Test completed			
Boys	76.1	88.8	80.0
Girls	79.1	91.8†	80.2
Test not done: trouble maintaining cadence			
Boys	18.5†	5.8	2.0
Girls	13.1†	3.6	0.7
Test not done: other reason‡			
Boys	0.8	0.0	1.0
Girls	0.6	0.7	1.5
Screened out			
Boys	4.6†	5.4†	17.0
Girls	7.2†	4.0†	17.6
Flexibility test (sit-and-reach)			
Screened in			
Test completed			
Boys	97.2†	99.0	100.0
Girls	98.8	99.1	97.7*
Test not done			
Boys	2.5†	1.0	0.0
Girls	0.8	0.7	1.4
Screened out			
Boys	0.2	0.0	0.0
Girls	0.4	0.2	0.9
Muscular endurance (partial curl-ups)			
Screened in			
Test completed			
Boys	96.6†	95.9†	86.9
Girls	94.3†	96.1†	83.9
Test not done			
Boys	0.4	0.2	0.2
Girls	0.5	1.2	2.2
Screened out			
Boys	2.9†	3.8†	12.9
Girls	5.2†	2.7†	13.9
Muscular strength (grip strength)			
Screened in			
Test completed			
Boys	98.9	98.7	99.6
Girls	99.5	99.3	98.8
Test not done			
Boys	0.5	1.3	0.0
Girls	0.5	0.7	1.2
Screened out			
Boys	0.6	0.0	0.4
Girls	0.0	0.0	0.0

* significantly different from estimate for boys ($p<0.05$)
† significantly different from estimate for 15- to 19-year-olds ($p<0.05$)
‡ includes refusal, home inteview and other reasons
§ 6- and 7-year-olds excluded from estimates for aerobic fitness and muscular endurance (partial curl-ups)
Source: 2007-2009 Canadian Health Measures Survey.

Table B
Percentage screened out of aerobic fitness tests, by sex and age group, household population aged 7 to 19 years, Canada, 1981 and 2007-2009

Sex and survey year	7 to 10 years	11 to 14 years	15 to 19 years
		%	
Boys			
1981	4.3	2.1	6.0
2007-2009	4.2	5.4	17.0*
Girls			
1981	3.0	3.2	9.9
2007-2009	7.0	4.0	17.6*

* significantly different from estimate for 1981 ($p<0.05$)
Sources: 1981 Canada Fitness Survey; 2007-2009 Canadian Health Measures Survey.

Table C
Sample sizes for fitness assessments, by age group and sex, household population aged 6 to 19 years, Canada, March 2007 to February 2009

	6 to 10 (8 to 10) years†		11 to 14 years		15 to 19 years	
Fitness assessment	Boys	Girls	Boys	Girls	Boys	Girls
Total sample	**450**	**420**	**318**	**302**	**288**	**309**
Total sample excluding 6- and 7-year-olds†	**283**	**259**	**318**	**302**	**288**	**309**
Total sample with score assigned for:						
Aerobic fitness (mCAFT)	215	209	283	272	242	241
Flexibility (sit-and-reach)	438	414	315	300	288	302
Muscular endurance (partial curl-ups)	271	246	305	289	260	261
Muscular strength (grip strength)	446	418	316	301	286	307
Total sample with measurements taken for:						
Body mass index	448	420	318	302	287	306
Waist circumference	449	420	317	301	288	306
Sum of five skinfolds‡	445	409	305	290	261	280

† 6- and 7-year-olds excluded from estimates for aerobic fitness and muscular endurance (partial curl-ups)
‡ excludes respondents with BMI 30.0 kg/m^2 or higher
Source: 2007-2009 Canadian Health Measures Survey.

Fitness of Canadian adults: Results from the 2007-2009 Canadian Health Measures Survey

by Margot Shields, Mark S. Tremblay, Manon Laviolette, Cora L. Craig, Ian Janssen and Sarah Connor Gorber

Abstract

Background
Estimates of obesity, based on body mass index (BMI) reveal that Canadian adults have become heavier over the past quarter century. However, a comprehensive assessment of fitness requires additional measures. This article provides up-to-date estimates of fitness levels of Canadians aged 20 to 69 years. Results are compared with estimates from 1981.

Data and methods
Data are from the 2007-2009 Canadian Health Measures Survey (CHMS). Historical estimates are from the 1981 Canada Fitness Survey. Means, medians and cross-tabulations were used to compare fitness levels by sex and age group and between survey years.

Results
Mean scores for aerobic fitness, flexibility, muscular endurance and muscular strength declined at older ages, and BMI, waist circumference, skinfold measurements and waist-to-hip ratio increased. Males had higher scores than females for aerobic fitness, muscular endurance and muscular strength; females had higher scores for flexibility. Muscular strength and flexibility decreased between 1981 and 2007-2009; BMI, waist circumference and skinfold measurements increased.

Interpretation
Based on results of the fitness tests and anthropometric measurements, many Canadian adults face health risks due to suboptimal fitness levels.

Keywords

anthropometry, body composition, cardiorespiratory fitness, flexibility, muscular endurance, musculoskeletal fitness, obesity, physical fitness, strength

Authors

Margot Shields (613-951-4177; Margot.Shields@statcan.gc.ca) and Sarah Connor Gorber are with the Health Analysis Division and Manon Laviolette is with the Physical Health Measures Division at Statistics Canada, Ottawa, Ontario K1A 0T6. Mark S. Tremblay is with the Children's Hospital of Eastern Ontario Research Institute and Department of Pediatrics, University of Ottawa, Ottawa Ontario. Cora L. Craig is with the Canadian Fitness and Lifestyle Research Institute, Ottawa, Ontario. Ian Janssen is with the School of Kinesiology and Health Studies, Queen's University, Kingston, Ontario.

The health benefits of being physically fit are widely acknowledged. Physical fitness comprises several components including morphological fitness (for example, body mass index, waist circumference, percent body fat, body fat distribution), muscular fitness (for example, strength, muscular endurance, flexibility), motor fitness (for example, speed, agility), cardiorespiratory fitness (for example, aerobic fitness, resting blood pressure, resting heart rate), and metabolic fitness (for example, blood lipid profile, glucose tolerance, insulin sensitivity).[1] The new Canadian Health Measures Survey was designed to collect data about most of these elements of fitness from a representative sample of Canadians aged 6 to 79 years.

In Canada, for the past two decades, we have relied almost exclusively on body mass index (BMI) to assess the fitness of the nation because it can easily be calculated from height and weight. Estimates based on BMI reveal that Canadian adults have become far heavier for their height over the past 25 to 30 years,[2] mirroring a phenomenon observed in both developed and developing countries.[3] BMI is correlated with heath risk, with most studies reporting a J-shaped relationship reflective of an increased risk among underweight, overweight and obese individuals.[4-8] Some recent studies, however, have found that being overweight (but not obese) may be protective against certain causes of mortality.[9,10]

BMI, however, is only one indicator of one component of physical fitness and is, therefore, limited as an assessment of overall fitness. For example, it provides no information on the distribution of body fat. This is an important shortcoming, because excess abdominal fat, as determined by waist circumference, is associated with an increased risk of disease for both sexes and premature mortality for males, independent of BMI.[7,11-16] Furthermore, skinfold thickness is positively associated with increased risk of premature mortality,[16] and is a better predictor of total body fat than BMI.[7]

Other aspects of fitness are also important for health, regardless of BMI or other morphological measures. Cardiorespiratory (aerobic) fitness is protective against cardiovascular disease, diabetes, functional limitations and mortality, independent of BMI and physical activity levels.[17-24] Considerable evidence indicates that musculoskeletal fitness confers substantial health benefits, particularly among women and older people, including decreased risk of mortality, increased mobility, less functional impairment, greater independence, reduced likelihood of falls, lower levels of pain, and an overall increase in quality of life.[25-29] Back health is a leading predictor of low back pain and injury that, in turn, cause decreased productivity and lost time in the workplace, as well as increased use of health care services.[30] A variety of measures, therefore, is required to gain a more complete understanding of the fitness levels of Canadians and associations between fitness and current and future disease risk.

In 2007, in partnership with Health Canada and the Public Health Agency of Canada, Statistics Canada launched the Canadian Health Measures Survey (CHMS).[31,32] In addition to a household interview, the CHMS involved a visit to a mobile examination centre where respondents underwent anthropometric measurements and participated in fitness tests. This survey is the first time in more than two decades that a comprehensive assessment of the fitness of Canadians has been performed. Using data from these assessments, this article provides an up-to-date overview of the fitness levels of Canadians aged 20 to 69 years, including estimates of:

- cardiorespiratory (aerobic) fitness,
- musculoskeletal fitness (including strength, endurance and flexibility),
- body composition (including BMI, waist circumference, waist-to-hip ratio and skinfolds).

Percentage distributions of the health benefits ratings based on fitness scores[33] are also presented. Estimates are provided by sex and age group. Where possible, CHMS results are compared with findings from the 1981 Canada Fitness Survey.

Methods

Data sources

The data are from the Canadian Health Measures Survey, the most comprehensive direct health measures survey ever conducted in Canada on a nationally representative sample.[32,34-36] The CHMS covers the population aged 6 to 79 years living in private households at the time of the interview. Residents of Indian Reserves or Crown lands, institutions and certain remote regions, and full-time members of the Canadian Forces are excluded. The survey was designed to provide statistically reliable national estimates by sex for five age groups: 6 to 11, 12 to 19, 20 to 39, 40 to 59, and 60 to 79 years. Approximately 97% of Canadians are represented.

Ethics approval for conducting the survey was obtained from Health Canada's Research Ethics Board.[35] Written informed consent was obtained from participating respondents. Participation was voluntary; respondents could opt out of any part of the survey at any time.

Data were collected at 15 sites across Canada from March, 2007 through February, 2009. Of the households selected, the response rate was 69.6%—meaning that in 69.6% of the selected households, the sex and date of birth of all household members were provided by a household resident. One or two members of each responding household were chosen to participate in the survey: 87.6% of selected 20- to 69-year-olds completed the household questionnaire, and 83.6% of those who completed the questionnaire participated in the subsequent examination component of the survey. The final response rate for 20- to 69-year-olds, after adjusting for the sampling strategy,[37] was 51.0% (69.6% x 87.6% x 83.6%). This article is based on 3,102 examination participants aged 20 to 69 years. Respondents aged 70 to 79 years were not included in this analysis because only a limited subset of fitness measures was collected for this age group.

Historical estimates of fitness are based on data from the 1981 Canada Fitness Survey (CFS), a nationally representative sample of the Canadian population.[38-40] The survey was initiated and funded by Fitness Canada; the sample was designed by Statistics Canada using the Labour Force Survey sampling frame. The sample consisted of 13,500 households, 88% of which agreed to participate—meaning that basic demographic information was collected for all household members, and a household member agreed to a follow-up visit when all members would be at home. In the responding households, 30,652 people aged 7 years or older were eligible to participate.

The CFS had two components: a questionnaire on health and lifestyle (administered to household members aged 10 years or older) and a physical measures component (for respondents aged 7 to 69 years). A respondent was defined as a household member who completed the questionnaire and/or participated in the physical measures component. In total, 23,400 household members (76%) responded, for an overall response rate of 67% (88% x 76%). Among respondents eligible for the physical measures component, 73% participated, yielding response rate of 49% to this component (88% x 76% x 73%). The CFS estimates in this article are based on 10,911 respondents aged 20 to 69 years. Fitness testing and anthropometric measures were taken in sampled households from February through July 1981, with standardized equipment using standardized procedures. All testing was performed by university graduates with degrees in physical education and recreation and additional qualifications in fitness appraisal.

Measures

As well as a comprehensive health interview conducted in the home, CHMS respondents underwent body composition measurements and participated in fitness tests in a mobile examination centre.[34]

Most of the measurement protocols for assessing body composition, aerobic fitness and musculoskeletal fitness were taken from the Canadian Physical Activity, Fitness and Lifestyle Approach (CPAFLA).[33] A detailed description of the specific collection procedures can be found in the *Canadian Health Measures Survey (CHMS) Data User Guide.*[37]

The CHMS fitness tests and measures were conducted by specialists who had a degree in kinesiology with certification from the Canadian Society for Exercise Physiology (www.csep.ca) as either Certified Exercise Physiologists or Certified Personal Trainers.

Before undergoing any fitness tests, respondents were interviewed to ensure that they were physically capable of performing the tests for which they were eligible. They were asked about their physical and health conditions and their use of prescription medications, and a Physical Activity Readiness Questionnaire (PAR-Q) was completed and signed (http://www.csep.ca/CMFiles/publications/parq/par-q.pdf). To ensure their safety, respondents were screened out of some tests, depending on their answers to the screening questions. Respondents were also asked to adhere to the pre-testing guidelines about food, alcohol, caffeine, nicotine, exercise, and blood donations.

The anthropometric measures collected included height, weight, waist circumference, hip circumference and skinfold measurements. Height was measured using a ProScale M150 digital stadiometer, (Accurate Technology Inc., Fletcher, USA), and weight was taken with a Mettler Toledo VLC with Panther Plus terminal scale (Mettler Toledo Canada, Mississauga, Canada). Waist circumference was measured with a Gulick measuring tape (Fitness Mart, Gay Mills, USA), following the World Health Organization (WHO) protocol[41] (mid-point between last floating rib and top of iliac crest in the mid-axillary line). Hip circumference was measured following the Canadian Standardized Test of Fitness (CSTF) protocol,[42] at the level of the symphysis pubis and the greatest gluteal protuberance. Skinfolds were measured using Harpenden skinfold calipers (Baty International, UK) at five sites: triceps, biceps, subscapular, iliac crest and calf[33] for respondents with a BMI less than 30kg/m^2. BMI, waist-to-hip ratio, and the sum of five skinfolds were calculated according to standard procedures.[33,42]

Health benefit ratings were derived from the anthropometric measurements. Based on BMI, respondents were classified as underweight (less than 18.5 kg/m^2), normal weight (18.5 to 24.9 kg/m^2), overweight (25 to 29.9 kg/m^2), or obese (30 kg/m^2 or more).[3] Based on waist circumference, respondents' health risk was classified as low (less than 80 cm in females; less than 94 cm in males), increased (80 to 87 cm in females; 94 to 101 cm in males) or high (more than 87 cm in females; more than 101 cm in males).[3,33,43,44] An overall body composition health rating was assessed by using a combination of BMI, waist circumference and the sum of five skinfolds, as defined in the CPAFLA.[33]

Aerobic fitness was measured using the modified Canadian Aerobic Fitness Test (mCAFT). Respondents were required to complete one or more three-minute "stepping" stages (up and down steps with increasing intensity as stages increased) at predetermined speeds based on their age and sex.[33] Their heart rate was recorded after each stage. The test was completed once a respondent's heart rate reached 85% of their age-predicted maximal heart rate (220–age). The predicted maximal aerobic power (VO_2 max) was calculated based on the last completed stage.[33,45,46] (In the CPAFLA, the term "aerobic fitness score" is used, which is derived from the predicted VO_2 max.) Respondents who completed at least one stage, but stopped midway through a subsequent stage (referred to as "partials"), were assigned a score based on the last fully completed stage. Typically, "partials" were due to respondents being unable to maintain the cadence of the stepping test. Those who were unable to complete a single stage were coded as "not stated" and were not assigned an aerobic fitness score.

Muscular strength was assessed by measuring grip strength twice on each hand (alternating) using a Smedley III hand-grip dynamometer (Takei Scientific Instruments, Japan) and combining the maximum score for each hand (in kg). Muscular endurance was measured with the partial curl-ups test, which required respondents to perform as many partial curl-ups as possible in one minute, at a set pace, to a maximum of 25. Flexibility was assessed using the sit-and-reach test, for which respondents sat on a mat on the floor with their legs extended against a flexometer (a device that measures the distance of a stretch) (Fit Systems Inc., Calgary, Canada), and the best of two attempts to stretch forward as far as possible without bending the knees was recorded to the nearest 0.1 cm.

According to definitions specified in the CPAFLA,[33] respondents were assigned "health benefit ratings" of excellent, very good, good, fair or needs improvement, based on their score for each fitness test (aerobic fitness, flexibility, muscular endurance and muscular strength) and their sex and age. An overall musculoskeletal fitness health benefit rating was assessed based on the results of the grip strength, partial curl-ups and sit-and-reach tests; a back fitness health benefit rating was also calculated based on the results of the waist circumference, partial curl-ups and sit-and-reach tests.[33]

The 1981 Canada Fitness Survey[39] assessed grip strength, sit-and-reach and anthropometric measurements following collection protocols similar to those used for the CHMS.

Analytical techniques

Data were analysed separately by sex for three age groups: 20 to 39, 40 to 59, and 60 to 69 years. Estimates of means, standard deviations and medians were produced for all fitness measures (body composition measurements and fitness test scores). Estimates of the means and medians for most measures were similar, but in some cases, means were marginally higher, reflecting distributions that were somewhat positively skewed. An exception was the distribution of the number of partial curl-ups completed in one minute (to a maximum of 25). In this case, the distribution of scores was bimodal, with large percentages of respondents completing either 0 or 25 partial curl-ups. As a result, for this measure, percentage distributions are presented.

Comparisons with the 1981 CFS were made for grip strength, sit-and-reach flexibility, and all body composition measurements. Comparisons of muscular endurance could not be made between the CHMS and the CFS, because the partial curl-up test, which was used to assess this component of fitness in the CHMS, was administered as speed sit-ups in the CFS. Although the same testing modality was used to assess aerobic fitness in the two surveys, small differences in the protocols between the two surveys negate a direct temporal comparison. A full understanding of the impact of these differences requires additional analyses that are beyond the scope of this study, but which will be conducted in future research.

Percentage distributions of the health benefits ratings are presented. Ratings for aerobic and musculoskeletal fitness are based on age-specific cut-points defined in the CPAFLA[33] that account for changes in fitness that are expected to occur with age. For adults, the CPAFLA cut-points apply to 10-year age groupings (20 to 29, 30 to 39, 40 to 49, 50 to 59, and 60 to 69). CHMS respondents were assigned health benefit ratings specific to these 10-year age groupings; estimates were then aggregated to the three broader age groups (20 to 39, 40 to 59, and 60 to 69) considered in this paper. The same age-specific cut-points were applied to CFS data for historical comparisons.

As in the CHMS, CFS respondents were interviewed before undergoing any fitness tests to ensure they were physically able to perform the tests. The CFS used the same screen-out procedures for all fitness tests, which was similar to the procedures used for the mCAFT for the CHMS. Thus, for comparisons of grip strength and sit-and-reach between the two surveys, respondents who were screened out of the mCAFT were also excluded from CHMS estimates for grip strength and sit-and-reach.

Because of the potential for changes over time in the age distribution within the three age groups considered in this paper, historical age-adjusted estimates were calculated standardizing to the CHMS population (using 5-year age groupings). In all cases, the crude and age-standardized estimates for means were similar; therefore, only crude estimates are presented.

Fitness profiles of a typical 45-year-old man and woman in 1981 and in 2007-2009 are compared. Because 45 is the midpoint of the 20-to-69-year age range examined in this paper, it was chosen as the age of comparison. To ensure adequate sample sizes, estimates are based on median values for adults aged 43 to 47 years. The silhouettes used to present the comparisons are for illustration only, and are not sized to scale.

To account for the survey design effects of the CHMS, standard errors, coefficients of variation, and 95% confidence intervals were estimated using the bootstrap technique.[47,48] Estimates of sampling error for the CFS are based on formulae for simple random sampling with the incorporation of a design effect of 1.5 to account for the complex design of the CFS. Differences between estimates were tested for statistical significance, established at the level of $p < 0.05$.

Response, non-response and screen-out rates for all of the CHMS fitness tests are given in Appendix Table A. Among respondents who participated in the examination component, partial non-response (opting out of certain tests or portions of tests) to the fitness tests and anthropometric measures was rare. Appendix Table B compares screen-out rates for the mCAFT for the CHMS with screen-out rates for the CFS fitness test.

Results

Response outcomes

Virtually all adults who participated in the examination component of the CHMS completed the flexibility (sit-and-reach) and muscular strength (grip strength) tests, and were assigned scores (Appendix Table A). Some were screened out of the aerobic fitness test (mCAFT) and the muscular endurance test (partial curl-ups)—most because of health problems they reported during the screening procedures. Somewhat more than half (57% of males; 56% of females) of those aged 60 to 69 years were screened out of the mCAFT; just over one-quarter of males and females aged 40 to 59 years were screened out, as were 9% of males and 15% of females aged 20 to 39 years. The percentages of males screened out of the partial curl-up test ranged from 10% at ages 20 to 39 years to 17% at ages 60 to 69 years, and among females, from 10% to 24%, respectively.

Sample sizes for all CHMS fitness measures are given in Appendix Table C. Body composition measurements were taken for virtually all examination participants.

Fitness measures

Mean aerobic fitness levels, measured by predicted maximal aerobic power (ml•(kg•min)$^{-1}$), were highest at ages 20 to 39 years and decreased with advancing age (Table 1). Males aged 20 to 39 years had a mean aerobic fitness score of 44 ml•(kg•min)$^{-1}$; for those aged 60 to 69 years, the mean was 28 ml•(kg•min)$^{-1}$. Declines were similar among females: from 38 ml•(kg•min)$^{-1}$ to 24 ml•(kg•min)$^{-1}$, respectively. In each age group, males had higher mean scores than did females.

An age gradient was apparent for each of the three measures of musculoskeletal fitness, with younger adults having better flexibility, endurance and strength than older Canadians. At all ages, females demonstrated greater flexibility than did males. However, over one-third of females aged 20 to 39 years and the majority of those aged 40 years or older were unable to complete even one partial curl-up. Fewer than a third (31%) of females aged 20 to 39 years completed the full 25 curl-ups, and at ages 60 to 69 years, the percentage was 4%. Higher percentages of males completed the full 25 curl-ups: 55% of 20- to 39-year-olds and 12% of 60- to 69-year-olds. In each age group, males had greater grip strength than did females, and strength declined with advancing age in both sexes.

Mean BMI rose with age. Moreover, in all age groups and among both sexes, mean BMI was above 25 kg/m^2, the WHO overweight cut-point.[3] Waist circumference and waist-to-hip ratios also increased with age, and were higher in males than females. By contrast, skinfold measurements were higher in females than in males and increased with age among females. Among males, mean skinfold measurements were similar in the youngest and oldest age groups and were higher at ages 40 to 59 years.

Health benefit ratings

Health benefit rating results for each fitness measure are presented in Table 2. The "excellent" and "very good" categories and the "fair" and "needs improvement" categories were combined to ensure sufficient sample size for all measures. Health benefit ratings for aerobic and musculoskeletal fitness are based on age-specific cut-points that account for changes expected to occur with advancing age.

At ages 20 to 39 years, 27% of males and 23% of females were assigned excellent/very good *aerobic fitness* ratings; at ages 60 to 69 years, 10% of males and fewer than 5% of females received excellent/very good aerobic fitness ratings.

Table 1
Descriptive statistics for selected fitness measures, by sex and age group, household population aged 20 to 69 years, Canada, March 2007 to February 2009

	20 to 39 years			40 to 59 years			60 to 69 years		
		95% confidence interval			95% confidence interval			95% confidence interval	
Fitness measure and sex	Estimate	from	to	Estimate	from	to	Estimate	from	to
Aerobic fitness: predicted maximal aerobic power (ml • (kg • min)$^{-1}$)									
Mean									
Male	44.1	43.1	45.1	36.6†	35.5	37.6	27.6†	26.6	28.5
Female	38.4*	37.6	39.3	31.2†*	30.5	31.8	24.1†*	23.6	24.6
Standard deviation									
Male	6.6	...	...	6.1	...	...	5.0	...	...
Female	4.8	...	...	5.3	...	...	3.7	...	...
50th percentile									
Male	44.0	42.7	45.3	38.2†	36.4	40.0	27.6†	26.6	28.6
Female	38.1*	37.1	39.1	31.0†*	30.3	31.7	23.1†*	22.6	23.6
Flexibility: sit-and-reach (cm)									
Mean									
Male	25	24	27	25	24	26	17†	16	19
Female	31*	30	31	29†*	27	30	27†*	26	28
Standard deviation									
Male	10	...	...	10	...	...	10	...	...
Female	9	...	...	10	...	...	9	...	...
50th percentile									
Male	25	24	27	25	24	26	18†	16	20
Female	31*	30	31	30*	28	31	28†*	25	30
Muscular endurance: number of partial curl-ups in one minute (maximum 25)									
% completing zero									
Male	10E	6	14	29†	24	34	69†	60	77
Female	37*	31	42	59†*	51	67	85†*	77	92
% completing 1 to 24									
Male	34	28	41	35	30	40	20†	14	25
Female	33	27	38	28	20	35	12†*E	5	18
% completing 25									
Male	55	49	62	36†	33	39	12†E	8	16
Female	31*	26	35	13†*	10	17	4†*E	2	6
Muscular strength: grip strength (kg)									
Mean									
Male	97	94	99	93†	91	95	81†	79	83
Female	56*	54	58	54†*	53	55	48†*	47	49
Standard deviation									
Male	16	...	...	15	...	...	15	...	...
Female	11	...	...	10	...	...	9	...	...
50th percentile									
Male	98	95	101	92†	90	94	82†	81	83
Female	56*	54	58	54†*	53	55	47†*	46	48
Body mass index (kg/m^2)									
Mean									
Male	26.5	26.3	26.8	28.3†	27.7	29.0	28.5†	28.0	29.0
Female	25.9	24.9	26.8	27.0†*	26.3	27.7	28.7†	27.9	29.4
Standard deviation									
Male	5.0	...	...	4.6	...	...	5.0	...	...
Female	6.3	...	...	5.9	...	...	6.1	...	...
50th percentile									
Male	25.7	25.4	26.1	27.9†	27.2	28.6	28.0†	27.2	28.8
Female	24.3*	23.2	25.3	25.6†*	25.0	26.2	27.4†	26.4	28.3
Waist circumference (cm)									
Mean									
Male	91	90	92	99†	97	101	103†	101	104
Female	83*	81	85	88†*	86	90	94†*	91	96
Standard deviation									
Male	14	...	...	13	...	...	13	...	...
Female	15	...	...	15	...	...	15	...	...
50th percentile									
Male	89	87	91	98†	96	99	102†	99	105
Female	79*	76	82	86†*	83	88	93†*	90	95
Sum of five skinfolds (mm)‡									
Mean									
Male	61	59	64	67†	62	71	62	59	65
Female	82*	78	86	90†*	86	94	94†*	91	98
Standard deviation									
Male	24	...	...	23	...	...	21	...	...
Female	30	...	...	30	...	...	26	...	...
50th percentile									
Male	58	52	64	63	58	69	59	54	63
Female	77*	70	84	89†*	83	94	92†*	86	98
Waist-to-hip ratio									
Mean									
Male	0.88	0.88	0.89	0.95†	0.94	0.96	0.99†	0.98	1.00
Female	0.80*	0.79	0.81	0.84†*	0.83	0.85	0.87†*	0.86	0.88
Standard deviation									
Male	0.07	...	...	0.07	...	...	0.11	...	...
Female	0.07	...	...	0.07	...	...	0.07	...	...
50th percentile									
Male	0.88	0.87	0.89	0.95†	0.94	0.96	0.99†	0.98	1.00
Female	0.79*	0.77	0.81	0.83†*	0.82	0.84	0.87†*	0.85	0.89

* significantly different from estimate for males ($p < 0.05$)
† significantly different from estimate for 20- to 39-year-olds ($p < 0.05$)
‡ excludes respondents with BMI 30.0 kg/m^2 or higher
E use with caution (coefficient of variation 16.6% to 33.3%)
... not applicable
Source: 2007-2009 Canadian Health Measures Survey.

The most common *flexibility* rating was fair/needs improvement. Over half (55%) of females aged 20 to 39 years and just under half of those in the 40-to 69-year age range were assigned this suboptimal rating. Approximately 60% of younger and older males were in this category, compared with 42% of middle-aged males.

In all three age groups, females were more likely than males to have *muscular endurance* scores that placed them in the fair/needs improvement category. For both sexes, percentages in this suboptimal category rose with age.

The percentage of females rated as having excellent/very good *muscular strength* increased with age, while among males, 40- to 59-year-olds had the highest percentage in this category.

Scores on flexibility, muscular endurance and strength were combined into an overall musculoskeletal heath benefit rating. Approximately half of females aged 20 to 39 years were assigned musculoskeletal health in the fair/needs improvement category. The percentage fell to 43% among females aged 40 to 59 years, and to 38% at ages 60 to 69 years. Among males, just under one-third in the 20-to-59-year age range were in the fair/needs improvement category; the percentage rose to 61% at ages 60 to 69 years.

Based on BMI, 19% of males and 21% of females aged 20 to 39 years were classified as obese; at ages 60 to 69 years, the percentage was approximately one-third. On the basis of their waist circumference, 31% of females and 21% of males aged 20 to 39 years were considered to be at high risk for health problems; by ages 60 to 69 years, the percentages were more than twice as high: 65% of females and 52% of males.

Composite scores were calculated for overall body composition (based on BMI, waist circumference and skinfolds) and for back fitness (based on flexibility, abdominal muscular endurance and waist circumference). For body composition, higher percentages of females than males aged 20 to 39 years were in the fair/needs improvement category, and for both

Table 2
Percentage distribution of health benefit ratings of selected fitness measures, by sex and age group, household population aged 20 to 69 years, Canada, March 2007 to February 2009

Health benefit rating and sex	20 to 39 years %	95% confidence interval from	to	40 to 59 years %	95% confidence interval from	to	60 to 69 years %	95% confidence interval from	to
Aerobic fitness health benefit zone									
Fair/Needs Improvement									
Male	46	41	51	32†	25	39	59†	51	67
Female	37*	31	44	56†*	50	61	92†*	88	95
Good									
Male	26	20	33	40†	32	47	31	24	38
Female	40*	37	44	20†*	16	24	8†*E	5	12
Excellent/Very good									
Male	27	19	36	28	24	33	10†E	5	15
Female	23	16	29	24*	21	27	<5†*		
Flexibility (sit-and-reach) health benefit zone									
Fair/Needs Improvement									
Male	61	55	66	42†	37	47	57	52	62
Female	55	52	59	47	39	56	46†*	40	53
Good									
Male	16	12	21	19	15	22	19	14	23
Female	16	12	19	20	14	26	18	14	23
Excellent/Very good									
Male	23	19	27	39†	36	43	24	19	29
Female	29*	26	32	33	28	37	36*	29	43
Muscular endurance (partial curl-ups) health benefit zone									
Fair/Needs Improvement									
Male	19	14	23	39†	33	45	75†	69	81
Female	46*	41	52	70†*	64	76	87†*	80	94
Good									
Male	7E	4	9	5E	3	7	3†E	1	5
Female	10	7	13	9*	6	12	<6†		
Excellent/Very good									
Male	75	70	80	56†	49	62	22†	16	28
Female	44*	39	49	21†*	17	25	10†*E	5	15
Muscular strength (grip strength) health benefit zone									
Fair/Needs Improvement									
Male	42	35	49	35†	28	42	58†	52	64
Female	56*	50	61	36†	29	44	37†*	30	44
Good									
Male	24E	15	32	19E	11	27	18	12	23
Female	18	14	22	29†	24	34	13†	9	17
Excellent/Very good									
Male	34	27	42	46†	40	52	24†	17	31
Female	27	19	34	35†*	29	40	50†*	44	56
Overall musculoskeletal health benefit zone‡									
Fair/Needs Improvement									
Male	30	25	36	29	23	35	61†	54	67
Female	51*	46	56	43†*	38	47	38†*	32	44
Good									
Male	32	26	38	30	24	36	25	19	31
Female	28	23	33	36†	32	41	38†*	33	43
Excellent/Very good									
Male	38	31	44	41	36	46	14†	10	19
Female	21*	17	24	21*	17	24	24	17	31
Body mass index category§									
Obese									
Male	19	15	23	27†	21	32	34†	29	39
Female	21	16	25	24	19	29	33†	26	41
Overweight									
Male	37	30	45	52†	47	57	39	36	43
Female	23*	17	30	31*	27	35	37†	32	41
Normal weight									
Male	43	37	48	21†	15	26	26†	19	33
Female	50	41	60	45*	40	49	30†	23	37
Waist circumference health risk									
High risk									
Male	21	18	24	38†	30	45	52†	43	60
Female	31*	25	37	47†	41	53	65†*	56	74
Increased risk									
Male	14	11	18	27†	21	32	23†	18	29
Female	17E	11	23	18*	13	24	17E	11	23
Low risk									
Male	65	61	69	36†	29	42	25†	19	32
Female	52*	43	61	35†	29	41	18†*	13	23
Body composition health benefit zone††									
Fair/Needs Improvement									
Male	20	17	23	33†	27	40	40†	32	47
Female	29*	23	34	36†	31	42	47†	38	55
Good									
Male	<5			7†E	4	9	12†	8	15
Female	<6			10†	7	13	18†*	15	22
Excellent/Very good									
Male	77	73	82	60†	52	67	48†	40	57
Female	68*	61	74	54†	48	59	35†*	26	44
Back fitness health benefit zone‡‡									
Fair/Needs Improvement									
Male	22	18	25	34†	28	40	60†	53	68
Female	30*	24	36	42†	35	49	62†	55	70
Good									
Male	21	15	27	23	18	29	21	15	26
Female	17	12	22	21	17	25	17	13	22
Excellent/Very good									
Male	58	53	62	43†	37	49	19†	14	24
Female	53	47	59	37†	30	43	20†	14	26

* significantly different from estimate for males ($p < 0.05$)
† significantly different from estimate for 20- to 39-year-olds ($p < 0.05$)
‡ based on flexibility, muscular endurance and muscular strength
§ estimates for underweight not reported because of small sample sizes
†† based on BMI, waist circumference and sum of five skinfolds
‡‡ based on flexibility, muscular endurance and waist circumference
E use with caution (coefficient of variation 16.6% to 33.3%)
Note: If coefficient of variation of estimate is greater than 33%, estimate is indicated as being less than upper limit of 95% confidence interval.
Source: 2007-2009 Canadian Health Measures Survey.

sexes, the prevalence of poorer ratings increased with age. The pattern was similar for back fitness.

Historical comparisons

Historical comparisons were made with data collected in the 1981 CFS where comparable tests were administered for flexibility and muscular strength, and similar anthropometric measurements were taken. To make estimates more comparable, respondents screened out of the aerobic fitness test were excluded from CHMS estimates of flexibility and muscular strength (see *Methods*). Screen-out rates (based on the aerobic fitness test) were similar between the two surveys across age groups and for both sexes (Appendix Table B).

Between 1981 and 2007-2009, muscular strength decreased in both males and females aged 20 to 59 years (Table 3). Flexibility declined for both sexes among those aged 20 to 39 years and for males aged 60 to 69 years. Mean values for BMI, waist circumference and skinfold measurements rose for both sexes in all age groups.

The percentage of Canadians with suboptimal ratings for flexibility and muscular strength in the CFS and the CHMS are presented in Figure 1. The percentage in the fair/needs improvement category for muscular strength rose between 1981 and 2007-2009, except among 60- to 69-year-old males, for whom the increase was not significant. The percentage in the fair/needs improvement category for flexibility rose only among males and females aged 20 to 39 years. The percentages who had a waist circumference indicative of high risk, were obese, or had body composition scores in the fair/needs improvement category more than doubled in all groups except females aged 40 to 59 years, among whom obesity almost doubled (Figure 2). At ages 20 to 39 years, the percentage whose waist circumference was classified as high risk more than quadrupled, and the percentage with body composition classified as fair/needs improvement increased fourfold among males, and sevenfold among females.

A typical 45-year-old

The 1981 and 2007-2009 fitness profiles of a typical 45-year-old man and woman are presented in Figure 3 (see *Analytical techniques*). In 2007-2009, the average 45-year-old man was about 9.2 kg (20 pounds) heavier than his 1981 counterpart, though his height was not significantly different. As a result, BMI rose by more than 2 kg/m^2. Waist circumference increased by 6.4 cm (2.5 inches), which meant a change in classification from a low risk of health problems for the average man in 1981 to an increased risk in 2007-2009. The average man's grip strength rating decreased from very good to good, while his sit-and-reach score in 2007-2009 was slightly higher than in 1981. His aerobic fitness was "good" in 2007-2009.

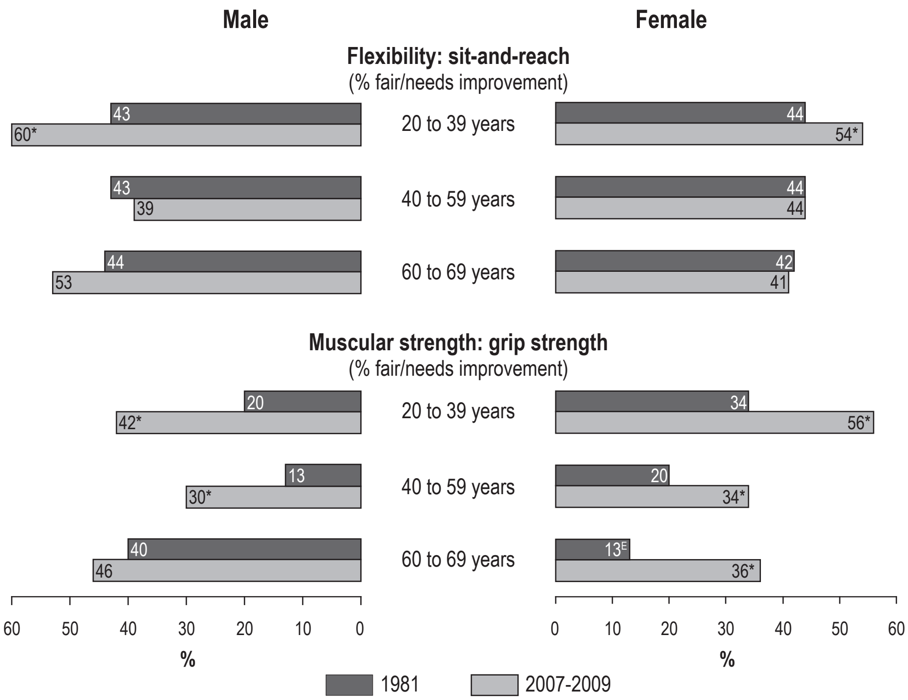
The height of a typical 45-year-old woman stayed relatively constant over the period, but her weight increased by 5.2 kg (12 pounds). Her BMI rose by close to 2 kg/m^2, moving her from the normal weight to the overweight category, and the 7.1 cm (2.8 inches) increase in her waist circumference moved her from

Table 3
Mean and median values for selected fitness measures, by sex and age group, household population aged 20 to 69 years, Canada, 1981 and 2007-2009

Fitness measure, sex and survey year	20 to 39 years		40 to 59 years		60 to 69 years	
	Mean	Median	Mean	Median	Mean	Median
Flexibility: sit-and-reach (cm)						
Male						
1981	30	30	25	25	22	23
2007-2009	25*	26*	26	26	18*	19
Female						
1981	32	33	30	31	28	28
2007-2009	31*	31*	30	30	28	29
Muscular strength: grip strength (kg)						
Male						
1981	107	107	100	100	87	87
2007-2009	97*	98*	93*	93*	84	84
Female						
1981	62	61	59	58	52	51
2007-2009	56*	56*	55*	55*	49	48
Body mass index (kg/m^2)						
Male						
1981	24.4	24.0	26.1	25.8	26.6	26.3
2007-2009	26.5*	25.7*	28.3*	27.9*	28.5*	28.0*
Female						
1981	22.5	21.8	25.0	24.3	25.8	25.4
2007-2009	25.9*	24.3*	27.0*	25.6*	28.7*	27.4*
Waist circumference (cm)						
Male						
1981	85	84	92	92	95	95
2007-2009	91*	89*	99*	98*	103*	102*
Female						
1981	72	70	78	76	82	80
2007-2009	83*	79*	88*	86*	94*	93*
Sum of five skinfolds (mm)†						
Male						
1981	51	48	56	56	56	55
2007-2009	61*	58*	67*	63*	62*	59
Female						
1981	66	63	78	77	80	80
2007-2009	82*	77*	90*	89*	94*	92*

* significantly different from estimate for 1981 ($p < 0.05$)
† excludes respondents with BMI 30.0 kg/m^2 or higher
Note: To make estimates more comparable, Canadian Health Measures Survey estimates for flexibility and muscular strength exclude respondents screened out of aerobic fitness test (see *Methods*).
Source: 1981 Canda Fitness Survey; 2007-2009 Canadian Health Measures Survey.

Figure 1
Percentage with suboptimal health benefit ratings for selected fitness measures, by sex and age group, household population aged 20 to 69 years, Canada, 1981 and 2007-2009



* significantly higher than estimate for 1981 (p<0.05)
E use with caution (coefficient of variation 16.6% to 33.3%)
Note: To make estimates more comparable, Canadian Health Measures Survey estimates for flexibility and muscular strength exclude respondents screened out of aerobic fitness test (see *Methods*).
Sources: 1981 Canada Fitness Survey; 2007-2009 Canadian Health Measures Survey.

a low to an increased risk of health problems. Her grip strength decreased, and her flexibility was approximately the same. In 2007-2009, her aerobic fitness was rated "good."

Discussion

The purpose of this article was to provide an overview of the current fitness of Canadians aged 20 to 69 years, including estimates of cardiorespiratory (aerobic) fitness, musculoskeletal fitness, and body composition. Where possible, results from the 2007-2009 CHMS were compared with findings from the 1981 CFS to illustrate temporal trends in fitness. A main observation of this study was that, independent of age and sex, a large percentage of adults in the CHMS had suboptimal health benefit ratings for all the fitness components. Most fitness scores declined across the three age groups considered. Several sex differences in fitness were noted, which likely reflect fundamental anatomical, physiological and behavioural differences between the sexes.[49] Based on comparable fitness measures in the 1981 and 2007-2009 surveys, in most instances, results were more favourable in the earlier survey, implying that the fitness of the nation has declined over the past two decades.

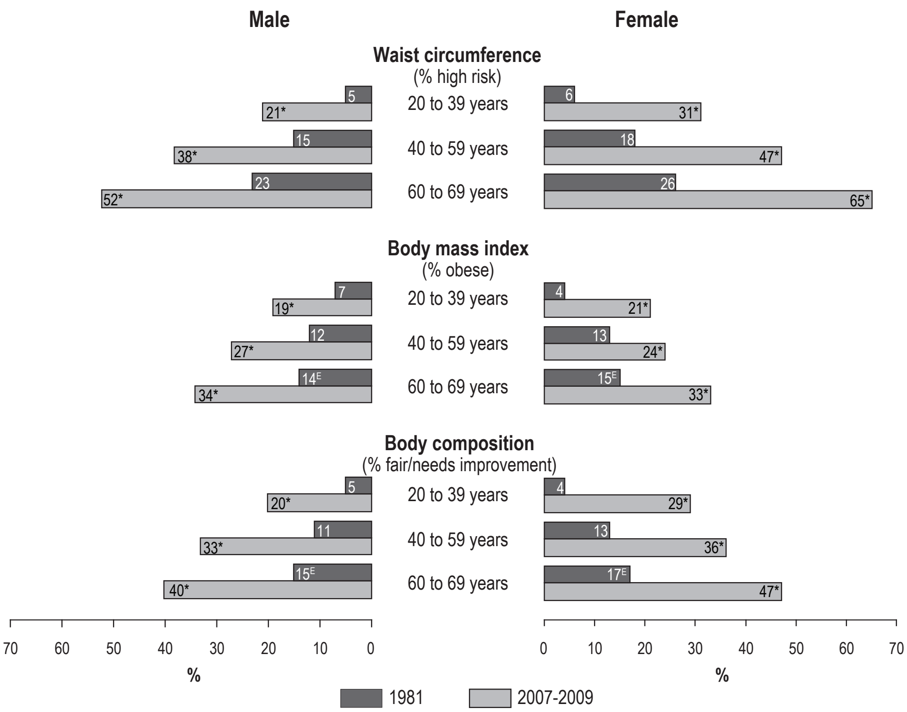
In the CHMS, middle-aged males had higher BMI values than did females, and males had higher waist-to-hip ratios than did females, independent of age. BMI and waist-to-hip ratio values were higher in older age groups, independent of sex. The patterns are consistent with those of earlier studies in Canada[50] and elsewhere.[51-53] Similarly, the higher adiposity levels based on the sum of skinfolds among females compared with males and the increase with advancing age among females are as expected, given earlier results.[50,52]

The high prevalence of overweight and obesity in the CHMS is consistent with recent data, based on measured heights and weights from the 2004 Canadian Community Health Survey.[2] Even more important than the high prevalence of overweight and obesity was the prevalence of increased health risk and high health risk, based on waist circumference. The abdominal obesity phenotype, as reflected by a high waist circumference, is now regarded as the obesity phenotype that indicates the greatest obesity-related health risk.[7,11-15] Of particular note, at ages 60 to 69, 75% of males and 82% of females had waist circumference values in the increased-to-high risk range.

The waist circumference values of Canadian males and females appear to be lower than those of Americans. The typical 45-year-old Canadian man had a waist circumference of 97.0 cm; the mean waist circumference of 40- to 49-year-old American men in 2003-2004 was 101.9 cm.[54] The corresponding values for Canadian and American women were 83.4 cm and 95.2 cm,[54] respectively. Although the waist circumference measurement sites in the CHMS (mid-point between last rib and iliac crest) and the United States (iliac crest) differed, the small disparities in waist circumference values between these two sites (0.3 cm and 1.9 cm higher at iliac crest in males and females, respectively[55]) cannot account for most of the observed differences between the Canadian and American populations.

Approximately one quarter of 20- to 39-year-olds in the CHMS had aerobic fitness values in the very good/excellent range; by ages 60 to 69 years, only 10% of males and fewer than 5% of females remained in this category. The age-related decline in aerobic fitness is a well-known phenomenon,[50-53] explained, in part, by less participation in physical activity by older adults.[56] Age-related physiological adaptations,

Figure 2
Percentage with suboptimal health benefit ratings for selected anthropometric measures, by sex and age group, household population aged 20 to 69 years, Canada, 1981 and 2007-2009



* significantly higher than estimate for 1981 (p<0.05)
E use with caution (coefficient of variation 16.6% to 33.3%)
Sources: 1981 Canada Fitness Survey; 2007-2009 Canadian Health Measures Survey.

such as a decrease in maximal heart rate and muscle mass, also likely contribute to the age difference in aerobic fitness.[57] Nationally representative data on aerobic fitness have been obtained in other countries, such as the United States,[53] but differences in study protocols (for example, exclusion criteria, fitness test employed, low fitness cut-points) make it difficult to compare CHMS results with these other countries.

For each of the three age groups examined, mean flexibility (sit-and-reach) values were higher among females, while muscular strength (grip strength) and muscular endurance (partial curl-ups) scores were better in males. This pattern is consistent with earlier studies in Canada[50] and elsewhere.[51-53]

The CHMS data on musculoskeletal fitness, at least for grip strength, appear to be comparable to those obtained in other countries. For instance, in a nationally representative cohort of 53-year-old British adults, mean grip strength values (strongest hand only) were 48 kg in males and 27 kg in females.[58] For 53-year-old CHMS participants, the mean grip strength values for the strongest hand were 47 kg in males and 26 kg in females.

All four measures of adiposity and fat distribution increased considerably since 1981. Average BMI rose by approximately 2 units for males across all age groups. The increase was similar for middle-aged females, but a larger increase of 3 units was observed for younger and older females. Males' average waist circumference increased by 5 cm or more, and females', by 10 cm or more. The apparent sex difference in changes in waist circumference among Canadian adults does not mirror trends in the United States, where changes in waist circumference since the late 1980s were similar in males and females (4.4 versus 5.0 cm).[54]

Currently, the average 20- to 39-year-old man and woman are overweight and have the same body composition profile as those who were aged 40 years or older in 1981. If these trends continue for another 25 years, half of males and females over the age of 40 years will be obese (BMI 30 kg/m^2 or more), with commensurate increases in the personal and economic burden of avoidable non-communicable disease.

Differences in the aerobic fitness test protocols used in the CFS and CHMS make direct comparisons difficult, and for this reason, results were not compared in this study. This was not the case for the flexibility and muscular strength tests. Flexibility (sit-and-reach) among males and females aged 20 to 39 years and muscular strength (grip strength) for males and females in the 20-to-59-year age range decreased. In 1981, the typical 45-year-old man and woman had grip strength values of 104 kg and 62 kg, respectively. These values are 10 kg and 6 kg (around 10%) lower in the typical 45-year-old of today. Temporal changes in grip strength of this magnitude at the population level are meaningful. To put this into context, the results of a 25-year prospective cohort study of grip strength and physical disability risk (such as slow walking speed, unable to stand from chair) in middle-aged males[27] found that between-group differences in grip strength that were comparable to the temporal changes between the CFS and the CHMS were associated with about a twofold increased risk of developing physical disability over the follow-up period.

Limitations

The two most important limitations of this study were the screening criteria used for the various CHMS fitness tests and the non-response rate.

The exclusions imposed to ensure respondent safety could have biased the sample. In particular, because of the screening questions on health conditions, unfit individuals would be more likely to have been screened out. Consequently, the fitness data may be more favourable

Figure 3
Portrait of typical 45-year-old male and female, 1981 and 2007-2009

MALE

1981	BODY COMPOSITION	2007-2009
173.0 cm (5'8")	Height	175.3 cm (5'9")
77.4 kg (171 pounds)	Weight	86.6 kg (191 pounds)*
25.7 kg/m² - overweight	Body mass index	27.9 kg/m²* - overweight
90.6 cm (35.7") - low risk	Waist circumference	97.0 cm (38.2")* - increased risk
99.0 cm (39.0")	Hip circumference	102.7 cm (40.4")*
0.91	Waist-to-hip ratio	0.95*
	FITNESS TESTS	
104 kg - very good	Grip strength	94 kg* - good
23.1 cm - fair	Sit-and-reach	26.7 cm* - good
--	Predicted maximal aerobic power (VO_2max)	39.2 ml•(kg•min)$^{-1}$ - good

FEMALE

1981	BODY COMPOSITION	2007-2009
161.5 cm (5'4")	Height	162.3 cm (5'4")
63.2 kg (139 pounds)	Weight	68.4 kg (151 pounds)*
24.1 kg/m² - normal weight	Body mass index	25.8 kg/m²* - overweight
76.3 cm (30.0") - low risk	Waist circumference	83.4 cm (32.8")* - increased risk
98.5 cm (38.8")	Hip circumference	102.5 cm (40.4")*
0.77	Waist-to-hip ratio	0.81*
	FITNESS TESTS	
62 kg - very good	Grip strength	56 kg* - good
30.2 cm - good	Sit-and-reach	31.5 cm - good
--	Predicted maximal aerobic power (VO_2max)	32.8 ml•(kg•min)$^{-1}$ - good

* significantly different from estimate for 1981 ($p<0.05$)
Note: To make estimates more comparable, Canadian Health Measures Survey estimates for flexibility and muscular strength exclude respondents screened out of aerobic fitness test (see *Methods*).
Sources: 1981 Canada Fitness Survey; 2007-2009 Canadian Health Measures Survey.

than if 100% of the eligible sample could have participated in the testing. For instance, while the mean BMI of the adults who completed the aerobic fitness test was 26.5 kg/m², the mean BMI of the 25% who were screened out of the test was 29.2 kg/m², indicating a lower level of morphological fitness. The CHMS directly measured physical activity levels with accelerometers that were provided to *all* ambulatory respondents. These data will be released later this year and will make it possible to further examine the bias associated with the screening procedures for the fitness tests.

The overall non-response rate was 49%. Although the sampling weights were adjusted to compensate for all three levels of non-response, fitness estimates could be biased if less fit individuals were more likely to opt out. In the initial contact with sampled households, potential respondents were told that they would be asked to visit an examination centre where their fitness levels and other health measures would be assessed. Thus, because of the specific nature of the survey (a heath *measures* survey), less fit individuals may have been particularly likely to be non-respondents at all three levels.

To partially assess this possibility, obesity estimates from the 2007-2009 CHMS were compared with those from the 2008 Canadian Community Health Survey (CCHS),[59] a general health survey that included measured height and weight. For adults aged 20 to 69 years, the estimated prevalence of obesity based on 2008 CCHS data was 25.4% (unpublished tabulation), not significantly different from the CHMS estimate of 24.3%. Therefore, at least for estimates of BMI, no evidence suggests that the specific nature of the CHMS had an impact on survey estimates.

The same concerns also apply to 1981 CFS estimates. Based on CFS data, 8.9% (95% confidence interval: 8.0% to 9.9%) of adults aged 20 to 69 years were obese in 1981, somewhat below the estimate of 13.0% (95% confidence interval: 11.6% to 14.4%) based on data from the Canada Health Survey (CHS) of 1978/79.[60] If the CHS is the more accurate of the two surveys, estimates of the decline in morphological fitness levels reported in this paper may be somewhat exaggerated.

As much as possible, the CHMS fitness tests and anthropometric measures were selected for their similarity to those in the CFS. However, differences in the methodology of the sample design, in educational and training requirements of survey administrators, in response rates and in weighting procedures may have weakened the comparability of survey estimates.

Conclusion

This paper presents the first comprehensive fitness assessment of Canadian adults in more than two decades. Overall, the prevalence of suboptimal fitness levels has increased markedly since 1981. Increases were

What is already known on this subject?

- Estimates of obesity based on body mass index (BMI) reveal that Canadian adults have become heavier over the past 25 years.
- Excess abdominal fat and elevated skinfold measurements are associated with adverse health outcomes, independent of BMI.
- Aerobic fitness is protective against disease, independent of BMI, and musculoskeletal fitness confers considerable health benefits, particularly at older ages.

What does this study add?

- The 2007-2009 Canadian Health Measures Survey provides objective data on fitness levels of the Canadian population for the first time in more than two decades.
- Mean scores for aerobic and musculoskeletal fitness were lower with advancing age in both sexes, while BMI, waist circumference and skinfold measurements rose at older ages.
- At ages 40 to 69 years, the percentage of males and females whose waist circumference placed them at a high risk for health problems more than doubled between 1981 and 2007-2009; at ages 20 to 39 years, percentages more than quadrupled.
- Between 1981 and 2007-2009, the percentage of Canadians aged 40 to 69 years categorized as fair or needing improvement according to their body composition (BMI, waist circumference and skinfold measurements) more than doubled. Among males aged 20 to 39 years, the increase was fourfold, and among younger females, sevenfold.
- The percentage of males and females with suboptimal health benefit ratings for muscular strength increased between 1981 and 2007-2009.

particularly pronounced for young adults, among whom the percentage with a waist circumference that placed them at a high risk for health problems more than quadrupled. Similarly, the percentage whose body composition was classified as "fair/needs improvement" rose fourfold among young males and sevenfold among young females. Increases in the percentage of young adults with suboptimal health benefit ratings of muscular strength and flexibility were also substantial. Longitudinal data reveal that once adults are overweight or obese, further weight gain is likely, and very few return to the normal weight range.[61] As these young adults with suboptimal fitness levels get older, commensurate increases in health risks and the resulting public health and economic burden of non-communicable disease are inevitable.

Data from future CHMS cycles will permit a closer and more regular assessment of temporal trends in all of the fitness measures presented here, and will allow for an ongoing assessment of intervention attempts to improve the fitness of the nation. ■

References

1. Bouchard C, Shephard RJ, Stephens T (Eds.). *Physical Activity, Fitness, and Health: Consensus Statement.* Champaign, IL: Human Kinetics, 1993.
2. Tjepkema M. Adult obesity. *Health Reports* (Statistics Canada, Catalogue 82-003) 2006; 17(3): 9-25.
3. World Health Organization. *Obesity: Preventing and Managing the Global Epidemic (WHO Technical Report Series, No. 894).* Geneva: World Health Organization, 2000.
4. Allison DB, Faith MS, Heo M, et al. Hypothesis concerning the U-shaped relation between body mass index and mortality. *American Journal of Epidemiology* 1997; 146(4): 339-49.
5. Calle EE, Thun MJ, Petrelli JM, et al. Body-mass index and mortality in a prospective cohort of U.S. adults. *New England Journal of Medicine* 1999; 341(15): 1097-105.
6. Katzmarzyk PT, Craig CL, Bouchard C. Underweight, overweight and obesity: Relationships with mortality in the 13-year follow-up of the Canada Fitness Survey. *Journal of Clinical Epidemiology* 2001; 54: 916-20.
7. Janssen I, Heymsfield SB, Ross R. Application of simple anthropometry in the assessment of health risk: implications for the Canadian Physical Activity, Fitness and Lifestyle Appraisal. *Canadian Journal of Applied Physiology* 2002; 27(4): 396-414.
8. Stevens J, Cai J, Pamuk ER, et al. The effect of age on the association between body-mass index and mortality. *New England Journal of Medicine* 1998; 338(1): 1-7.
9. Flegal KM, Graubard BI, Williamson DF, et al. Cause-specific excess deaths associated with underweight, overweight, and obesity. *Journal of the American Medical Association* 2007; 298(17): 2028-37.
10. Orpana HM, Berthelot JM, Kaplan MS, et al. BMI and mortality: Results from a national longitudinal study of Canadian adults. *Obesity* 2009; online: 1-5.
11. Chan JM, Rimm EB, Colditz GA, et al. Obesity, fat distribution, and weight gain as risk factors for clinical diabetes in men. *Diabetes Care* 1994; 17(9): 961-9.
12. Janssen I, Katzmarzyk PT, Ross R. Body mass index, waist circumference, and health risk: evidence in support of current National Institutes of Health guidelines. *Archives of Internal Medicine* 2002; 162(18): 2074-9.
13. Janssen I, Katzmarzyk PT, Ross R. Waist circumference and not body mass index explains obesity-related health risk. *American Journal of Clinical Nutrition* 2004; 79(3): 379-84
14. Kannel WB, Cupples LA, Ramaswami R, et al. Regional obesity and risk of cardiovascular disease; the Framingham Study. *Journal of Clinical Epidemiology* 1991; 44(2): 183-90.
15. Rexrode KM, Carey VJ, Hennekens CH, et al. Abdominal adiposity and coronary heart disease in women. *Journal of the American Medical Association* 1998; 280(21): 1843-8.
16. Katzmarzyk PT, Craig CL, Bouchard C. Adiposity, adipose tissue distribution and mortality rates in the Canada Fitness Survey follow-up study. *International Journal of Obesity* 2002; 26: 1054-9.
17. Blair SN, Kohl HW, III, Barlow CE, et al. Changes in physical fitness and all-cause mortality. A prospective study of healthy and unhealthy men. *Journal of the American Medical Association* 1995; 273(14): 1093-8.
18. Whaley MH, Kampert JB, Kohl HW, et al. Association between physical fitness and the metabolic syndrome in adult men and women. *Medicine and Science in Sports and Exercise* 1995; 27(5): S39.
19. Blair SN, Kampert JB, Kohl HW, III, et al. Influences of cardiorespiratory fitness and other precursors on cardiovascular disease and all-cause mortality in men and women. *Journal of the American Medical Association* 1996; 276(3): 205-10.
20. Huang Y, Macera CA, Blair SN, et al. Physical fitness, physical activity, and functional limitation in adults aged 40 and older. *Medicine and Science in Sports and Exercise* 1998; 30(9): 1430-5.
21. Wei M, Kampert JB, Barlow CE, et al. Relationship between low cardiorespiratory fitness and mortality in normal-weight, overweight, and obese men. *Journal of the American Medical Association* 1999; 282(16): 1547-53.
22. Lee CD, Blair SN, Jackson AS. Cardiorespiratory fitness, body composition, and all-cause and cardiovascular disease mortality in men. *American Journal of Clinical Nutrition* 1999; 69(3): 373-80.
23. Blair SN, Jackson AS. Guest Editorial to Accompany: Physical fitness and activity as separate heart disease risk factors: a meta-analysis. *Medicine and Science in Sports and Exercise* 2001; 33(5): 762-4.
24. Farrell SW, Kampert JB, Kohl HW III, et al. Influences of cardiorespiratory fitness levels and other predictors on cardiovascular disease mortality in men. *Medicine and Science in Sports and Exercise* 1998; 30(6): 899-905.
25. Warburton DE, Gledhill N, Quinney A. Musculoskeletal fitness and health. *Canadian Journal of Applied Physiology* 2001; 26(2): 217-37.
26. Katzmarzyk PT, Craig CL. Musculoskeletal fitness and risk of mortality. *Medicine & Science in Sports and Exercise* 2002; 34(5): 740-4.
27. Rantanen T, Guralnik JM, Foley D, et al. Midlife hand grip strength as a predictor of old age disability. *Journal of theAmerican Medical Association* 1999; 281(6): 558-60.
28. Payne N, Gledhill N, Katzmarzyk PT, et al. Health implications of musculoskeletal fitness. *Canadian Journal of Applied Physiology* 2000; 25(2): 114-26.
29. Fitzgerald SJ, Barlow CE, Kampert JB, et al. Muscular fitness and all-cause mortality: prospective observations. *Journal of Physical Activity and Health* 2004; 1:7-18.
30. Albert WJ, Bonneau J, Stevenson JM, Gledhill N. Back fitness and back health assessment considerations for the Canadian Physical Activity, Fitness and Lifestyle Appraisal. *Canadian Journal of Applied Physiology* 2001; 26(3): 291-317.
31. Tremblay MS, Connor Gorber, S. Canadian Health Measures Survey: brief overview. *Canadian Journal of Public Health* 2007; 98: 453-6.
32. Tremblay MS, Wolfson M, Connor Gorber S. Canadian Health Measures Survey: background, rationale and overview. *Health Reports* (Statistics Canada, Catalogue 82-003) 2007; 18(Suppl.): 7-20.
33. Canadian Society for Exercise Physiology (CSEP). *The Canadian Physical Activity, Fitness and Lifestyle Approach (CPAFLA) 3rd edition*. Ottawa, Canada: Canadian Society for Exercise Physiology, 2003.
34. Bryan S, St-Denis M, Wojtas D. Canadian Health Measures Survey: Clinic operations and logistics. *Health Reports* (Statistics Canada, Catalogue 82-003) 2007; 18(Suppl): 53-70.
35. Day B, Langlois R, Tremblay M, et al. Canadian Health Measures Survey: Ethical, legal and social issues. *Health Reports* (Statistics Canada, Catalogue 82-003) 2007; 18(Suppl): 37-52.
36. Giroux S. Canadian Health Measures Survey: Sampling strategy overview. *Health Reports* (Statistics Canada, Catalogue 82-003) 2007; 18(Suppl): 31-6.
37. Statistics Canada. *Canadian Health Measures Survey (CHMS) Data User Guide: Cycle 01, September 2007.* Available at: www.statcan.gc.ca.
38. Canada Fitness Survey. *A User's Guide to CFS Findings*. Ottawa: Canada Fitness Survey, 1983.
39. Canada Fitness Survey. *Fitness and lifestyle in Canada*. Ottawa: Canada Fitness Survey, 1983.

40. Canadian Fitness and Lifestyle Research Institute. *Canada Fitness Survey Household Survey: Micro-data tape documentation*. Ottawa, Canada: Canadian Fitness and Lifestyle Research Institute, 1992.

41. World Health Organization. *Physical Status: The Use and Interpretation of Anthropometry, Report of the WHO Expert Committee (WHO Technical Report Series, No. 854)*. Geneva: World Health Organization, 1995.

42. Fitness Canada. *Canadian Standardized Test of Fitness (CSTF) Operations Manual. 3rd edition.* Ottawa: Fitness and Amateur Sport, Government of Canada, 1986.

43. Lau DC, Douketis JD, Morrison KM, et al. 2006 Canadian clinical practice guidelines on the management and prevention of obesity in adults and children [summary]. *Canadian Medical Association Journal* 2007; 176(8 suppl): Online 1-12.

44. Lean ME, Han TS, Morrison CE. Waist circumference as a measure for indicating need for weight management. *British Medical Journal* 1995; 311(6998): 158-61.

45. Weller IM, Thomas SG, Corey PN, et al. Prediction of maximal oxygen uptake from a modified Canadian aerobic fitness test. *Canadian Journal of Applied Physiology* 1993; 18(2): 175-88.

46. Weller IM, Thomas SG, Gledhill N, et al. A study to validate the modified Canadian Aerobic Fitness Test. *Canadian Journal of Applied Physiology* 1995; 20(2): 211-21.

47. Rao JNK, Wu CFJ, Yue K. Some recent work on resampling methods for complex surveys. *Survey Methodology* (Statistics Canada, Catalogue 12-001) 1992; 18(2): 209-17.

48. Rust KF, Rao JNK. Variance estimation for complex surveys using replication techniques. *Statistical Methods in Medical Research* 1996; 5: 281-310.

49. Wilmore JH, Costill DL. *Physiology of Sport and Exercise. Third Edition*. Champaign Illinois: Human Kinetics Publishers, 2004: 566-602.

50. Stephens TM, Craig CL, Ferris B. Adult physical fitness and hypertension in Canada: findings from the Canada Fitness Survey II. *Canadian Journal of Public Health*, 1986; 77: 291-5.

51. Sports Council and Health Education Authority. *Allied Dunbar National Fitness Survey: Main Findings*. London, England: Sports Council and Health Education Authority, 1992.

52. Department of the Arts, Sport, the Environment and Territories. *Pilot Survey of Fitness of Australians*. Canberra, Australia: Australian Government Publishing Service, 1992: 44-8.

53. Carnethon MR, Gulati M, Greenlland P. Prevalence and cardiovascular disease correlates of low caridoresipatory fitness in adolescents and adults. *Journal of theAmerican Medical Association* 2005; 294(23): 2981-8.

54. Li C, Ford ES, McGuire LS, et al. Increasing trends in waist circumference and abdominal obesity among U.S. adults. *Obesity* 2007; 15(1):216-24.

55. Mason C, Katzmarzyk PT. Variability in waist circumference measurements according to anatomical measurement site. *Obesity* 2009; 17(9): 1789-95.

56. Craig CL, Russell SJ, Cameron C, et al. Twenty year trends of physical activity among Canadian adults. *Canadian Journal Public Health* 2004; 95(1): 59-63.

57. Shephard RJ. *Aging, Physical Activity, and Health*. Champaign, Illinois: Human Kinetics, 1997.

58. Kuh D, Bassey EJ, Butterworth S, et al. Grip strength, postural control, and functional leg power in a representative cohort of British men and women: associations with physical activity, health status, and socioeconomic conditions. *Journal of Gerontology: Medical Sciences* 2005; 60A(2): 224–31.

59. Statistics Canada. *Canadian Community Health Survey (CCHS) – Annual component - User Guide - 2008 Microdata files, June 2009.* Available at: www.statcan.gc.ca/imdb-bmdi/document/3226_D7_T9_V5-eng.pdf.

60. Health and Welfare Canada, Statistics Canada. *The Health of Canadians: Report of the Canada Health Survey* (Catalogue No. 82-538E) Ottawa: Minister of Supply and Services Canada, 1981.

61. Le Petit C, Berthelot J-M. Obesity: A growing issue. *Health Reports* (Statistics Canada, Catalogue 82-003) 2006; 17(3): 43-50.

Table A
Percentage distribution of response outcomes for fitness tests, by sex and age group, household population aged 20 to 69 years, Canada, March 2007 to February 2009

Fitness test, response outcome and sex	20 to 39 years	40 to 59 years	60 to 69 years
	%		
Aerobic fitness test (mCAFT)			
Screened in			
Test completed			
Male	88.2	72.4†	42.6†
Female	82.5*	70.9†	41.8†
Test not done: trouble maintaining cadence			
Male	1.1	0.8	0.0†
Female	2.5	0.2†	0.3†
Test not done: other reason‡			
Male	1.3	0.4	0.4
Female	0.4	2.3*	2.0
Screened out			
Male	9.4	26.4†	57.0†
Female	14.6*	26.6†	55.9†
Flexibility test (sit-and-reach)			
Screened in			
Test completed			
Male	98.0	95.6	96.0
Female	95.7	96.4	91.7*
Test not done			
Male	0.7	1.7	1.2
Female	0.3	1.3	2.9†
Screened out			
Male	1.3	2.7	2.7
Female	4.0	2.3	5.4
Muscular endurance (partial curl-ups)			
Screened in			
Test completed			
Male	88.7	85.0†	81.1†
Female	88.8	81.5†	73.6†
Test not done			
Male	1.3	1.4	1.7
Female	1.5	1.8	2.2
Screened out			
Male	10.0	13.6†	17.2†
Female	9.7	16.7†	24.1†
Muscular strength (grip strength)			
Screened in			
Test completed			
Male	98.1	99.8	98.7
Female	99.8	99.3	99.3
Test not done			
Male	1.8	0.0	1.0
Female	0.1	0.4	0.2
Screened out			
Male	0.1	0.2	0.3
Female	0.1	0.3	0.5

* significantly different from estimate for males ($p < 0.05$)
† significantly different from estimate for 20- to 39-year-olds ($p < 0.05$)
‡ includes refusal, home inteview and other reasons
Source: 2007-2009 Canadian Health Measures Survey.

Table B
Percentage screened out of aerobic fitness tests, by sex and age group, household population aged 20 to 69 years, Canada, 1981 and 2007-2009

Sex and survey year	20 to 39 years	40 to 59 years	60 to 69 years
		%	
Male			
1981	9.0	27.2	51.0
2007-2009	9.4	26.4	57.0
Female			
1981	13.7	31.4	59.1
2007-2009	14.6	26.6	55.9

Note: Differences in estimates between 1981 and 2007-2009 were not significant ($p < 0.05$)
Source: 1981 Canada Fitness Survey; 2007-2009 Canadian Health Measures Survey.

Table C
Sample sizes for fitness assessments, by age group and sex, household population aged 20 to 69 years, Canada, March 2007 to February 2009

Fitness assessment	20 to 39 years		40 to 59 years		60 to 69 years	
	Male	Female	Male	Female	Male	Female
Total sample	**524**	**661**	**582**	**654**	**342**	**339**
Total sample with score assigned for:						
Aerobic fitness (mCAFT)	466	534	418	480	150	146
Flexibility (sit-and-reach)	515	630	560	630	319	311
Muscular endurance (partial curl-ups)	480	580	492	552	268	252
Muscular strength (grip strength)	517	656	581	648	336	335
Total sample with measurements taken for:						
Body mass index	524	633	582	654	342	337
Waist circumference	524	631	581	652	341	337
Sum of five skinfolds†	412	495	418	486	229	216

† excludes respondents with BMI 30.0 kg/m^2 or higher
Source: 2007-2009 Canadian Health Measures Survey.

Blood pressure in Canadian adults

by Kathryn Wilkins, Norman R.C. Campbell, Michel R. Joffres, Finlay A. McAlister, Marianne Nichol, Susan Quach, Helen L. Johansen and Mark S. Tremblay

Abstract

Background

Hypertension is estimated to cause more than one-eighth of all deaths worldwide. In Canada, the last national surveys to include direct measures of blood pressure (BP) took place over the years 1985-1992; hypertension was estimated at 21%.

Data and methods

Data are from cycle 1 of the Canadian Health Measures Survey, conducted from March 2007 through February 2009. The survey included direct BP measures using an automated device. Weighted frequencies, means and cross-tabulations were produced to estimate levels of hypertension awareness, treatment and control in the population aged 20 to 79 years.

Results

Among adults aged 20 to 79 years, hypertension (systolic BP higher than or equal to 140 or diastolic BP higher than or equal to 90 mm Hg, or self-reported recent medication use for high BP) was present in 19%. Another 20% had BP in the pre-hypertension range (systolic 120 to 139 or diastolic 80 to 89 mm Hg). Of those with hypertension, 83% were aware, 80% were taking antihypertensive drugs, and 66% were controlled. Uncontrolled hypertension was largely due to high systolic BP.

Interpretation

Hypertension prevalence is similar to that reported in 1992. Since then, the level of hypertension control has increased considerably.

Keywords

awareness, blood pressure determination, hypertension, population surveillance

Authors

Kathryn Wilkins (1-613-951-1769; Kathryn.Wilkins@statcan.gc.ca) and Helen L. Johansen are with the Health Analysis Division at Statistics Canada, Ottawa, Ontario, K1A 0T6. Norman R.C. Campbell is with the Health Science Centre, University of Calgary. Michel R. Joffres is with the Faculty of Health Sciences, Simon Fraser University. Finlay A. McAlister is with the Department of Medicine, University of Alberta. Marianne Nichol is with the Public Health Agency of Canada. Susan Quach was formerly with the Public Health Agency of Canada. Mark S. Tremblay is with the Children's Hospital of Eastern Ontario Research Institute and Department of Pediatrics, University of Ottawa.

Hypertension is an important risk factor for cardiac, cerebrovascular and other vascular diseases.[1-5] Hypertension is also a major cause of disability and is considered to be the leading risk factor for death in the world, causing an estimated 7.5 million deaths per year (13% of all deaths).[6] Surveillance of BP in the population provides vital feedback to hypertension prevention and control efforts. With the recent Canadian Health Measures Survey (CHMS), direct, automated measures of BP were collected from a representative sample of people, allowing for the most accurate nationwide assessment of the prevalence of hypertension that has ever been undertaken.

BP control is crucial in reducing the risk of cardiovascular disease among people with hypertension. In the past 15 years, management of hypertension has improved in many Western countries, but remains less than optimal,[7] even though anti-hypertensive drugs, modifications to diet, weight and physical activity levels, and limitation of alcohol consumption can be quite effective in its control and treatment.

National data based on direct BP measures had last been collected by the Canadian Heart Health Surveys (CHHS), conducted in the provinces over the 1985 to 1992 period.[8,9] At that time, although the prevalence of hypertension was similar in Canada and the United States, levels of awareness, treatment and control were higher in the United States.[10]

Since the late 1990s, extensive efforts have been underway in Canada to improve physician and public awareness of the importance of treatment and control of hypertension.[11] Initiatives such as the Canadian Hypertension Education Program (http://www.hypertension.ca/chep), and campaigns by organizations including Blood Pressure Canada (http://

www.hypertension.ca/bpc) and the Heart and Stroke Foundation of Canada (http:www.heartandstroke.com/site) exemplify such endeavours. Perhaps not coincidentally, findings from a recent population survey in Ontario suggest that control of hypertension among those with the condition increased more than fivefold between 1992 and 2006—from 12% to 66%.[12] However, this improvement requires corroboration and assessment to determine if the Ontario results apply to Canada as a whole.

Surveillance of hypertension presents unique challenges. Unlike most other chronic conditions, hypertension is predominantly "silent," or asymptomatic. Therefore, when assessment of hypertension is limited to data from questionnaire-based health surveys, its prevalence is usually underestimated.[13] Direct BP measurement, because it is not contingent upon diagnosis or awareness, may provide more accurate estimates of the prevalence of hypertension. Furthermore, from the values obtained by direct measurement, the distribution of BP in the population can be portrayed, and comparisons can be made among subpopulations. Finally, combining data based on direct measures with self-reported information on diagnosis and treatment yields important information about hypertension awareness, treatment and control.

Cycle 1 of the CHMS was launched in 2007 by Statistics Canada, in partnership with Health Canada and the Public Health Agency of Canada.[14] As well as a detailed health-related questionnaire, the survey includes the most comprehensive set of physical measures ever collected in Canada from a population-based sample, among which is direct measurement of BP

The objectives of this preliminary study are to describe the distribution of BP in the Canadian adult population, and to provide estimates of the prevalence of hypertension by sex and age group. Levels of hypertension awareness, treatment and control are also reported.

Methods

Data source

Data for this study are from cycle 1 of the CHMS, which collected data at 15 sites across Canada from March 2007 through February 2009.[14] The survey covered the population aged 6 to 79 years living in private households. It was designed to provide sex-specific, statistically reliable national estimates of conditions for which prevalence was at least 10% for five age-groups: 6 to 11, 12 to 19, 20 to 39, 40 to 59, and 60 to 79 years.[15] This analysis is limited to respondents aged 20 to 79 years; a subsequent study will focus on BP in the age group 6 to 19 years.[16] The CHMS does not include residents of Indian Reserves or Crown lands, institutions and certain remote regions, and full-time members of the regular Canadian Forces.

Of the households selected for inclusion in the CHMS, the response rate was 69.6%—meaning that in 69.6% of the selected households, the sex and date of birth of all household members were provided by a household resident. In each responding household, one or two members were selected to participate in the survey; for the age group 20 to 79 years, 87.9% of selected household members completed the household questionnaire, and 83.6% of the responding household members participated in the subsequent examination component of the survey. The final response rate was not calculated as simply the product of these response fractions, because of the complexities involved in selecting two respondents in certain households.[16,17] The final response rate, after adjusting for the sampling strategy, was 50.9%.

Ethics approval for the CHMS was obtained from Health Canada's Research Ethics Board. Written consent was requested from respondents before participation. Respondents were informed that participation was voluntary, and that they could opt out of any part of the survey at any time. Additional information about the survey is available in previously published reports[15,17-20] and on Statistics Canada's website (http://www.statcan.gc.ca).

Measures

During a personal in-home interview, a trained interviewer administered a questionnaire covering socio-demographic characteristics, medical history, current health status and lifestyle behaviours. In the chronic conditions component of the interview, respondents were asked two yes/no questions about BP: whether they had high BP (diagnosed by a health professional and expected to last or having already lasted six months or more); and whether they had taken "medicine for high blood pressure" in the past month.

On an appointed date after the interview, physical measurements, including BP, heart rate, height, weight, and physical fitness, as well as blood and urine samples, were obtained at a mobile examination centre. To maximize response rates, respondents who were unwilling or unable to go to the centre were offered the option of a home visit. The BP protocol used to conduct measurements in the home did not differ from that used in the mobile centre.

BP and heart rate were measured with the BpTRU™ BP-300 device (BpTRU Medical Devices Ltd., Coquitlam, British Columbia) at the mobile examination centre, and with the BpTRU™ BP-100 device during home visits. The BpTRU™ is an automated electronic monitor using an upper arm cuff. The device, which automatically inflates and deflates the cuff, and uses the oscillometric technique to calculate systolic BP (SBP) and diastolic BP (DBP), has passed international validation protocols for accuracy.[21,22]

An important advantage of an automated device is that it enables BP to be measured in the absence of another person. Its use, therefore, eliminates observer errors such as digit bias, zero preference and incorrect deflation rates, and also reduces "white coat hypertension"[23]—a rise in BP associated with the presence of the health care professional and the procedures of measurement. (For more information on the procedures and protocol used, see *Resting blood pressure and heart rate* *measurement in the Canadian Health Measures Survey* by Bryan et al.[24]).

Definitions

Measures of SBP and DBP were calculated by taking the average of the first set (last five of six measures taken one minute apart) of valid BP measurements.[24] The classification scheme used to categorize measured BP was that defined in the seventh report of the Joint National Committee on Prevention, Detection, Evaluation and Treatment of High Blood Pressure (JNC 7)[25]:

JNC 7 category	Blood pressure (mm Hg)
Normal	Systolic lower than 120 and diastolic lower than 80
Prehypertension	Systolic 120 to 139 or diastolic 80 to 89
Hypertension	Systolic 140 or higher, or diastolic 90 or higher
Stage 1	Systolic 140 to 159 or diastolic 90 to 99
Stage 2	Systolic 160 or higher, or diastolic 100 or higher

For individuals whose SBP and DBP fell into different categories, the higher category was used for classification.

Normal blood pressure was defined as a measured mean SBP lower than 120 mm Hg and a measured mean DBP lower than 80 mm Hg.

Prehypertension was defined as a measured mean SBP of 120 to 139 or DBP of 80 to 89 mm Hg.

Hypertension was defined as a measured mean SBP of 140 mm Hg or higher, or a measured mean DBP of 90 mm Hg or higher, or the respondent's report of BP medication use in the past month.

Treated hypertension was defined as a respondent's report of BP medication use in the past month.

Awareness of hypertension was defined as a respondent's report of either diagnosed hypertension or BP medication use in the past month.

Controlled hypertension was defined as the respondent's report of BP medication use in the past month together with measured mean BP values lower than 140 mm Hg (systolic) and 90 mm Hg (diastolic).

Isolated systolic hypertension was defined as measured SBP of 140 mm Hg or higher, together with measured DBP lower than 90 mm Hg.

Isolated diastolic hypertension was defined as measured DBP of 90 mm Hg or higher, together with measured SBP lower than 140 mm Hg.

Analytical techniques

Based on weighted data from cycle 1 of the CHMS, frequencies, means and cross-tabulations were produced to estimate the distribution of BP, the prevalence of normal BP and hypertension, and awareness, treatment and control of hypertension in the household population aged 20 through 79 years. To account for the complex design of the survey, variance on estimates and significance testing on differences between estimates were calculated with the bootstrap technique.[26,27] Significance was specified as a p-value of less than 0.05.

Results

For cycle 1 of the CHMS, BP measures were obtained for 3,514 respondents aged 20 through 79 years: 3,493 at the mobile examination centre and 21 in their homes. The data were weighted to be representative of 23.7 million Canadian adults in this age range.

Average values of SBP and DBP differed by age and sex. In the age groups 20 to 39 and 40 to 59 years, the mean SBP values for females (101.4 and 111.7 mm Hg, respectively) were lower than those for males (109.9 and 116.5 mm Hg) (Table 1). However, in the age group 60 to 79 years, the mean SBP value was higher for females (126.9 mm Hg) than for males (122.4 mm Hg). For DBP, mean values were consistently lower in females than in males. The average values of SBP rose with age in each sex, while average DBP peaked in middle age and then declined slightly (Figure 1).

Based on measured BP and self-reported BP medication use, hypertension was present in an estimated 19% (4.6 million) of Canadian adults aged 20 to 79 years (Table 2, Figure 2). The overall prevalence of hypertension was nearly the same in males (19.7%) and females (19.0%).

The prevalence of hypertension rose with age in both sexes combined. At ages 20 to 39 years, approximately 2% had hypertension, compared with 18% of those aged 40 to 59 years, and 53% of those aged 60 to 79 years.

Three-fifths (61%) of adults had BP in the normal range, and 20% were classified as prehypertensive (Table 2). The likelihood of prehypertension was higher in males (25%) than in females (15%). At ages 60 to 79 years, the percentage with normal BP (23%) was about equal to the percentage classified as prehypertensive (24%).

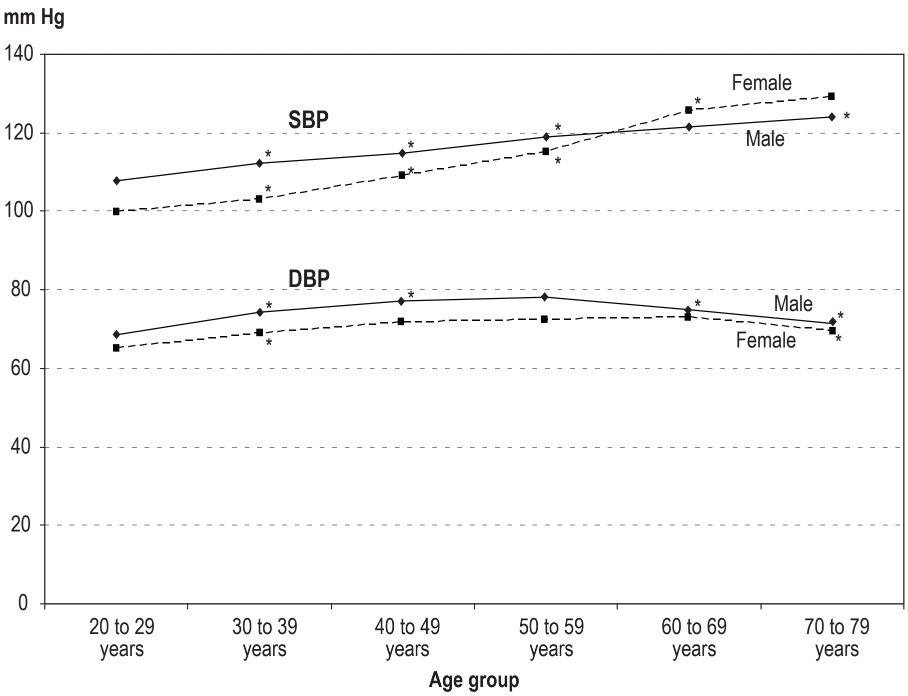
More than four-fifths (83%) of people with hypertension were aware

Table 1
Mean measured value of systolic (SBP) and diastolic blood pressure (DBP) (mm Hg), by sex and age group, household population aged 20 to 79 years, Canada, March 2007 to February 2009

Type of blood pressure and sex	Total	20 to 39 years	40 to 59 years	60 to 79 years
SBP				
Male†	115.1	109.9	116.5	122.4
Female	111.1*	101.4*	111.7*	126.9*
DBP				
Male†	74.5	71.5	77.5	73.8
Female	70.1*	67.1*	71.9*	71.7*

† reference category
* significantly different from estimate for reference category ($p<0.05$)
Note: For SBP, comparisons of sex-specific estimates by age group are all significantly different from each other ($p<0.05$) except for differences between age groups 40 to 59 and 60 to 79 in females.
Source: 2007-2009 Canadian Health Measures Survey.

Figure 1
Mean systolic (SBP) and diastolic blood pressure (DBP) (mm Hg), by sex and age group, household population aged 20 to 79 years, Canada, March 2007 to February 2009



* significantly different from sex-specific estimates for previous age group (p<0.05)
Note: All age-group-specific comparisons between males and females are significantly different (p<0.05) except for DBP in 70-to-79-year age group.
Source: 2007-2009 Canadian Health Measures Survey.

of their condition, and 80% were being treated with antihypertensive drugs (Table 3, Figure 3). Two-thirds (66%) of those with hypertension had BP that was controlled (lower than 140 mm Hg systolic and lower than 90 mm Hg diastolic) by medication. Finally, 17% of adults with hypertension were unaware of their condition, a situation more common in males (20%) than in females (14%).

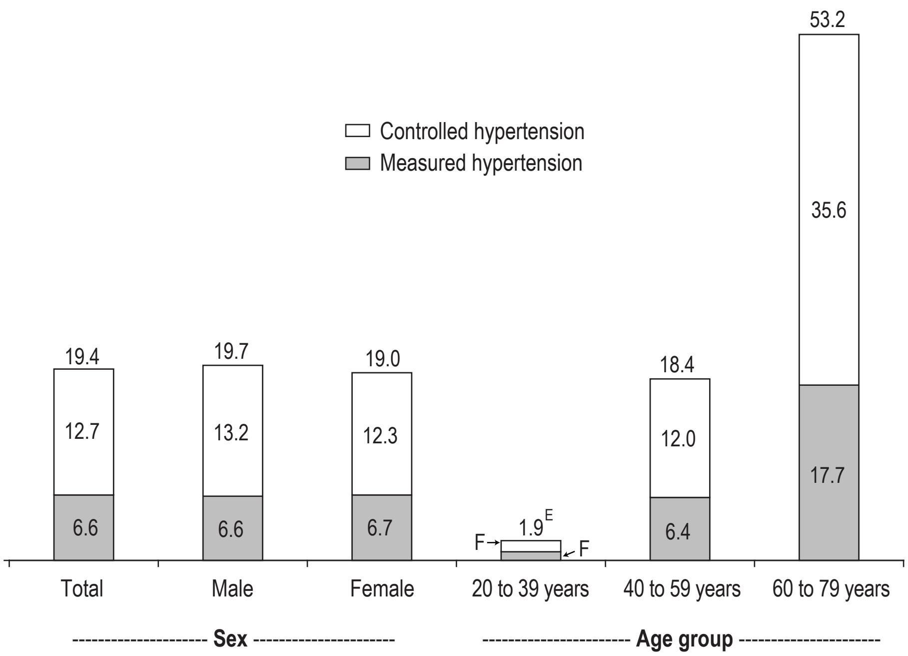
The percentages of hypertension control were similar in males (67%) and females (65%), despite the lower likelihood that males with hypertension were using antihypertensive medication (76% for males and 83% for females). Among females taking antihypertensive medication, the percentage whose BP was not controlled was higher than the corresponding figure for males (18% and 10%, respectively). Supplementary analysis revealed that the gap in BP control between the sexes was present only at older ages; in females aged 60 to 69 years who were using antihypertensive medication, the percentage not controlled was 19%, compared with 7% in males; the corresponding estimates in the age group 70 to 79 years were 37% versus 18% (data not shown).

Table 2
Percentage distribution of measured blood pressure, by hypertension status and JNC7[26] blood pressure category, by sex and age group, household population aged 20 to 79 years , Canada, March 2007 to February 2009

	Non-hypertensive				Hypertensive					
							Controlled		Uncontrolled	
Sex and age group	Sample size	Total	SBP lower than 120 and DBP lower than 80 mm Hg	SBP 120 to 139 or DBP 80 to 89 mm Hg	Sample size	Total	SBP lower than 120 and DBP lower than 80 mm Hg	SBP 120 to 139 or DBP 80 to 89 mm Hg	SBP 140 to 159 or DBP 90 to 99 mm Hg	SBP higher than or equal to 160 or DBP higher than or equal to 100 mm Hg
Total	**2,650**	**80.6**	**60.5**	**20.1**	**864**	**19.4**	**5.9**	**6.9**	**5.3**	**1.3[E]**
Sex										
Male†	1,208	80.3	55.0	25.3	441	19.7	5.6	7.6	5.9	0.7[E]
Female	1,442	81.0	65.9*	15.1*	423	19.0	6.1	6.2	4.8	1.9[E]
Age group										
20 to 39 years	1,152	98.1*	83.6*	14.5*	33	1.9[E]*	F	F	F	F
40 to 59 years†	996	81.6	58.1	23.4	238	18.4	5.3	6.8[E]	5.3	1.1[E]
60 to 79 years	502	46.6*	22.9*	23.8	593	53.2*	16.5*	19.1*	13.8*	3.9[E]

† reference category
‡ measured SBP 140 mm Hg or measured DBP higher than or equal to 90 mm Hg or self-reported use of antihypertensive medication in month before Canadian Health Measures Survey interview.
* significantly different from estimate for reference category (p<0.05)
E interpret with caution (coefficient of variation 16.6% to 33.3%)
F too unreliable to be reported (coefficient of variation greater than 33.3%)
Source: 2007-2009 Canadian Health Measures Survey.

Figure 2
Percentage with hypertension,† by sex and age group, household population aged 20 to 79 years, Canada, March 2007 to February 2009



† measured SBP higher than or equal to 140 or DBP higher than or equal to 90 mm Hg, or current use of antihypertensive medication
E interpret with caution (coefficient of variation 16.6% to 33.3%)
F too unreliable to be reported (coefficient of variation greater than 33.3%)
Note: Because of rounding, detail may not sum to total.
Source: 2007-2009 Canadian Health Measures Survey.

Table 3
Percentage with hypertension† who are aware, treated by medication, controlled, by sex and age group, household population aged 20 to 79 years with hypertension, Canada, March 2007 to February 2009

Sex and age group	Total aware	Total treated	Treated, controlled‡	Treated, not controlled§	Aware, not treated	Unaware	Total not controlled
Total	**83.4**	**79.9**	**65.9**	**14.0**	**3.5^{E}**	**16.6**	**34.1**
Sex							
Male††	80.4	76.5	66.8	9.7^{E}	3.9^{E}	19.7	33.2
Female	86.5*	83.3*	64.9	18.4^{E}*	F	13.5*	35.1
Age group							
20 to 39 years	64.4	58.4^{E}	56.8^{E}	F	F	35.6^{E}	43.2^{E}
40 to 59 years††	80.4	73.4	65.4	8.0^{E}	7.0^{E}	19.6	34.6
60 to 79 years	86.7*	85.7*	66.8	19.0*	F	13.3*	33.2

† measured SBP higher than or equal to 140 mm Hg or measured DBP higher than or equal to 90 mm Hg or self-reported use of antihypertensive medication in month before CHMS interview.
‡ measured SBP lower than 140 mm Hg and measured DBP lower than 90 mm Hg
§ measured SBP higher than or equal to 140 mm Hg or measured DBP higher than or equal to 90 mm Hg
†† reference category
* significantly different from estimate for reference category ($p<0.05$)
E interpret with caution (coefficient of variation 16.6% to 33.3%)
F too unreliable to be reported (coefficient of variation greater than 33.3%)
Note: Because of rounding, detail may not sum to total.
Source: 2007-2009 Canadian Health Measures Survey.

For both sexes combined, the likelihood of hypertension control by medication was nearly the same in the age groups 60 to 79 years (67%) and 40 to 59 years (65%). Although the point estimate of control (57%) was substantially lower in those aged 20 to 39 years, the differences compared with the other age groups were not statistically significant because of the low sample size of the younger age group.

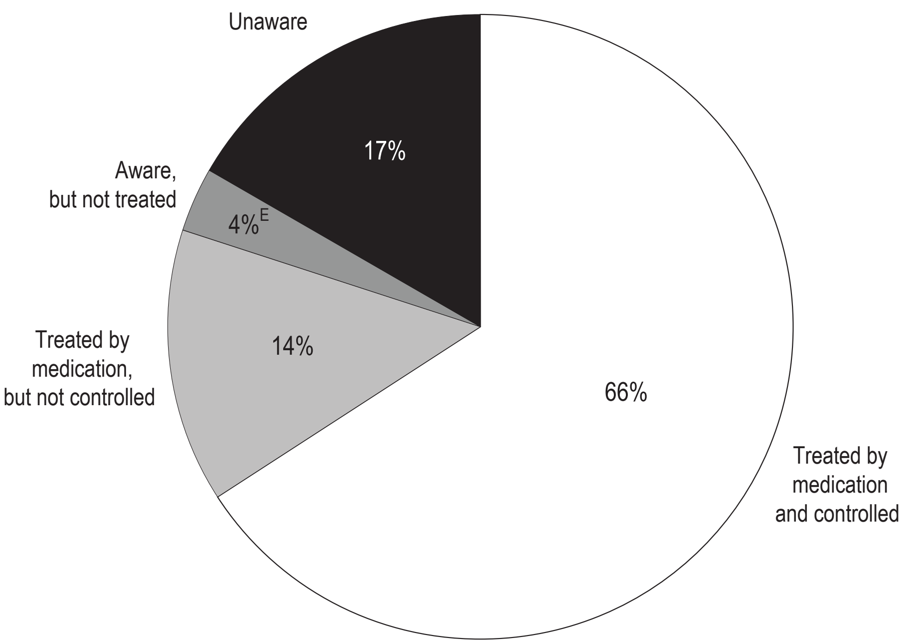
High SBP, with a prevalence of 5.4% in the adult population, was twice as common as high DBP (2.7%) (Table 4). The difference between the percentages of females (6.0%) and males (4.8%) measured as having high SBP was not statistically significant. High DBP affected a significantly lower percentage of females (2.0%) than males (3.4%). In contrast, a higher percentage of females (4.7%) than males (3.2%) were categorized as having isolated high SBP. The prevalence of high SBP and isolated high SBP increased sharply with age.

Among adults reporting current use of antihypertensive medication, 42% had measured SBP lower than 120 mm Hg; in 25%, SBP was at least 120 mm Hg but lower than 130 mm Hg, and in 17%, it was in the 130 to 139 mm Hg range (Figure 4). About one in six (16%) of those being treated with medication had a measured SBP value of 140 mm Hg or higher. DBP was lower than 80 mm Hg in 70% of adults using antihypertensive medication (Figure 5). Supplementary analysis focusing on treated but uncontrolled hypertensives revealed that nine in ten had systolic hypertension, compared with about one-quarter who had diastolic hypertension (data not shown). In summary, uncontrolled hypertension in people treated with antihypertensive medication was largely due to elevated SBP.

Discussion

The Canadian Health Measures Survey (CHMS) indicates that nearly one-fifth (19%) of adults aged 20 to 79 years have hypertension. This estimate is slightly lower than that reported from the

Figure 3
Percentage with hypertension† who are aware, treated by medication, controlled,‡ household population aged 20 to 79 years with hypertension, Canada, March 2007 to February 2009



† measured SBP higher than or equal to 140 mm Hg or DBP higher than or equal to 90 mm Hg, or current use of antihypertensive medication
‡ measured SBP lower than 140 mm Hg and DBP lower than 90 mm Hg
E interpret with caution (coefficient of variation 16.6% to 33.3%)
Note: Because of rounding, the sum of the estimates exceeds 100%.
Source: 2007-2009 Canadian Health Measures Survey.

Table 4
Percentage with measured hypertension, by type, sex and age group, household population aged 20 to 79 years, Canada, March 2007 to February 2009

Sex and age group	Total	Isolated systolic hypertension (SBP higher than or equal to 140, DBP lower than 90 mm Hg)	Isolated diastolic hypertension (SBP lower than 140, DBP higher than or equal to 90 mm Hg)	Both systolic and diastolic hypertension (SBP higher than or equal to 140 and DBP higher than or equal to 90 mm Hg)	Any systolic hypertension (regardless of DBP)	Any diastolic hypertension DBP (regardless of SBP)
Total	**6.6**	**3.9**	**1.2E**	**1.5E**	**5.4**	**2.7**
Sex						
Male†	6.6	3.2	1.7E	1.7E	4.8	3.4
Female	6.7	4.7*	F	1.3E	6.0	2.0E*
Age group						
20 to 39 years	F	F	F	F	F	F
40 to 59 years†	6.4	2.1E	F	2.2E	4.3E	4.2E
60 to 79 years	17.7*	14.3*	F	2.6E	16.9*	3.4

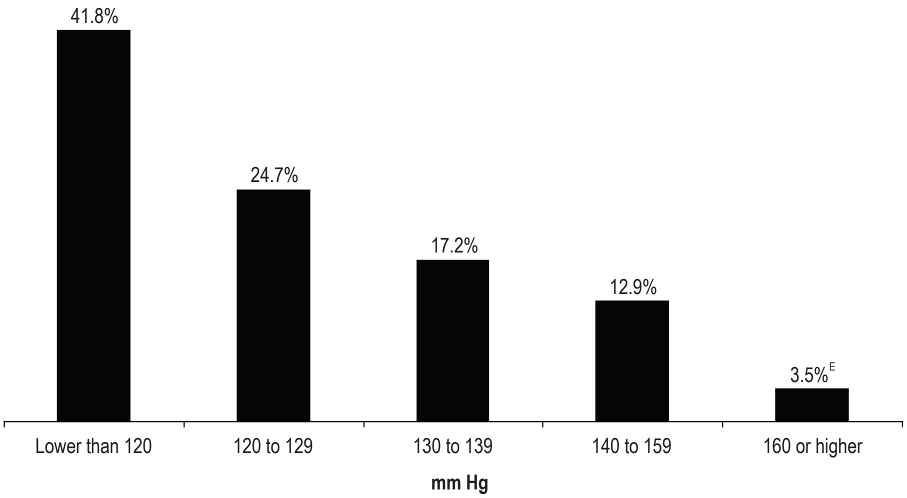
† reference category
* significantly different from estimate for reference category (p<0.05)
E interpret with caution (coefficient of variation 16.6% to 33.3%)
F too unreliable to be reported (coefficient of variation greater than 33.3%)
Note: Total is sum of estimates for isolated elevated SBP, isolated elevated DBP and both elevated SBP and DBP.
Source: 2007-2009 Canadian Health Measures Survey.

Canadian Heart Health Surveys (CHHS) (21% in 1985-1992 among people aged 18 to 74 years).[10] The average SBP of males aged 20 to 79 years (115.1 mm Hg) is considerably lower than that estimated from the CHHS for males (not including residents of Ontario) aged 18 to 74 years (126.0 mm Hg); the corresponding estimates for females are 111.1 and 118.7 mm Hg.[8] However, in view of the aging of the population, increases in obesity,[28] poor dietary habits[29] and diminishing fitness,[30] true declines of this magnitude are unlikely. The lower values in the CHMS data probably result from a combination of factors, the most important of which are differences in measurement methods between the CHHS and the CHMS.

The automated method of BP measurement that was used in the CHMS has been shown to yield BP measures 3/3 mm Hg lower than the manual method, based on readings at a single visit.[31,32] Other research suggests that the presence of an observer is associated with an even greater difference between manual and automated measures.[33] However, these studies were limited by a referral bias toward white coat hypertension, or the lack of standardized observer training or uniform measurement techniques; therefore, greater differences between manual and automated measures might be expected. BP measures for the CHHS took place during two visits (one of which was in the respondent's home), compared with only one for the CHMS, a factor that may have somewhat offset differences between the two surveys.[34] Further study of the impact of measurement mode on blood pressure values is underway in the United States, where both automated and manual measures were carried out in the 2007/2008 cycle of the National Health and Nutrition Examination Survey (NHANES).[35]

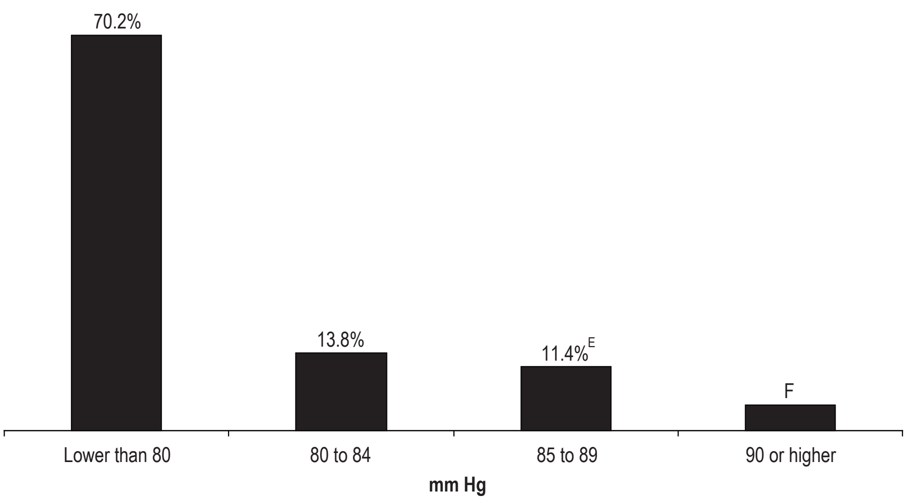
CHMS estimates of hypertension awareness and control are markedly higher than those from the earlier period; the percentages of people with hypertension who were aware of their condition increased from 57% to 83%; treated, from 34% to 80%; and controlled, from 13% to 66%.[10]

Figure 4
Percentage distribution of SBP (mm Hg), household population aged 20 to 79 years reporting current use of antihypertensive medication, Canada, March 2007 to February 2009



E interpret with caution (coefficient of variation 16.6% to 33.3%)
Source: 2007-2009 Canadian Health Measures Survey.

Figure 5
Percentage distribution of DBP (mm Hg), household population aged 20 to 79 years reporting current use of antihypertensive medication, Canada, March 2007 to February 2009



E interpret with caution (coefficient of variation 16.6% to 33.3%)
F too unreliable to be reported (coefficient of variation greater than 33.3%)
Source: 2007-2009 Canadian Health Measures Survey.

However, these comparisons may also be somewhat misleading. The use of automated measurement in the CHMS may partially account for lower values of blood pressure than were observed in the earlier survey, and thus, may also explain some of the apparently higher level of control.

The 66% level of hypertension control estimated from the CHMS is equivalent to that reported from the recent physical measures survey in Ontario for which automated BP measures were also employed.[12] As discussed above, various measurement factors hamper the comparability of estimates, so as would be expected, lower levels of control (defined as the percentage of hypertensives whose measured BP is less than 140/90 mm Hg) have been reported elsewhere: for example, 44% in the United States (2005-2006)[36] and 28% in England (2006).[37]

Although it is difficult to quantify the effect of differences in measurement methods on estimates of hypertension, awareness, treatment and control, it is reasonable to assume that some of the observed change over time is due to true improvement. Such progress would be consistent with large increases in diagnosis, treatment and drug prescriptions for hypertension that have occurred in Canada,[38-40] and the commensurate reductions in cardiovascular deaths and hospitalization.[39,41,42] Increases in hypertension treatment and diagnosis and subsequent reductions in cardiovascular complications may, in part, be attributed to the efforts of a variety of organizations and initiatives dedicated to raising public awareness and educating health care professionals in hypertension management.[11]

For this analysis, the definition of hypertension "treatment" was restricted to the use of medication, without consideration of other, non-pharmaceutical strategies such as dietary sodium restriction, physical activity or weight control. However, the CHMS definitions of treatment and control are the same as those used by NHANES,[36] so in this respect, the surveys are comparable.

As has been observed in other countries, awareness of hypertension was higher in females than in males.[37,43,44] Despite lower rates of awareness and treatment among males, the percentages of males and females with hypertension that was controlled by medication were nearly equal. Among those being

What is already known on this subject?

- High blood pressure (BP) is a major risk factor for heart and vascular disease and is an important cause of death around the world.
- The last nationwide surveys in Canada that included direct measures of BP took place over the period 1985 to 1992. The prevalence of hypertension (systolic BP higher than or equal to 140 or diastolic BP higher than or equal to 90 mm Hg, or self-report of recent medication use for high BP) in adults was estimated at 21%.
- According to a 2006 Ontario survey that involved direct measures of BP using an automated device, the prevalence of hypertension in adults was estimated at 19%.

What does this study add?

- Based on data from the 2007-2009 Canadian Health Measures Survey, including BP values and respondent self-report of medication use, hypertension prevalence in adults aged 20 to 79 years was estimated at 19%.
- Of people with hypertension, 83% were aware of their condition, 80% were being treated pharmaceutically, and 66% had BP below 140/90 mm Hg.
- Considerable improvements in hypertension awareness and control have been achieved in Canada over the past two decades.

treated, however, at older ages, females were less likely than males to have controlled hypertension; this finding is important and raises questions worthy of further study. Similar differences in treatment effectiveness for women have been observed in China, Spain and the United States[45]; the possible role of gender- or sex-related differences in genetic, environmental or clinical factors remains unclear. An analysis of data from the 1999-2004 NHANES revealed the same disparity, even after controlling for age, race/ethnicity and comorbidity.[46] Finally, a recently published study of over 18,000 patients with hypertension provides further evidence that although females are more often treated for hypertension, control is less successful than in males.[47]

The CHMS finding of a higher prevalence of systolic than diastolic hypertension is noteworthy in light of the greater importance of systolic hypertension as a cardiovascular risk factor in people older than 50 years.[48] The predominance of systolic hypertension may reflect the consequences of a tendency, at least until recently, for clinicians to treat it less aggressively than diastolic hypertension.[49-51] Indeed, before 1993, hypertension treatment guidelines issued by the Canadian Hypertension Society were based only on DBP levels; in that year, a SBP of 160 was added to the clinical definition of hypertension.[52] In 2001, treatment recommendations were updated to include the 140/90 mmHg cut-point for the first time, and clear diagnostic criteria for diagnosing hypertension based on SBP were set.[53,54]

The CHMS data indicated that a substantial percentage of adults had measured BP that placed them in the prehypertensive range. Although clinical guidelines do not recommend pharmacological antihypertensive therapy for people with prehypertension, strategies to modify factors including diet, weight, smoking, exercise and stress are recommended.[48,55] Prehypertension is associated with an increased risk of cardiovascular events[56] and is strongly predictive of hypertension.[27,48] About half of the health-related burden of elevated BP is estimated to occur at the level of SBP less than 145 mm Hg.[5]

Limitations

Data from the interview component of the CHMS were self-reported and not validated against external sources; the degree to which they are inaccurate is unknown. In particular, the reference period for medication use for BP was one month before the CHMS interview; inaccurate recall of the time when medication was used may have resulted in some misclassification of treatment status. As well, some respondents may have inaccurately reported the condition for which their medication was prescribed.

No information on dosage of antihypertensive medication being used or medication compliance was collected from respondents, nor were they asked about BP control measures other than pharmacotherapy. Therefore, the term "treated" was applied only to persons who reported medication use, and excluded those whose hypertension was being managed with non-pharmacologic therapy only. This may have resulted in a different percentage of hypertension control than would have been observed if the definition of treatment had been extended to non-pharmaceutical lifestyle interventions.

The overall response rate to the CHMS was 51%, meaning that in nearly half of households contacted, arrangements could not be made—for a variety of reasons—for a resident to participate. Although the survey weights were adjusted to ensure that the sample is representative of the target population according to socio-demographic characteristics, differences in health status (specifically, BP) were not accounted for. It is possible that the mean BP of those who participated in the survey differed from that of non-participants, which would compromise the external validity of the estimates. The 51% CHMS response rate compares favourably with that of the 2006 Ontario Survey on the Prevalence and Control of Hypertension (40%),[12] and is similar to that of the 1981 Canada Fitness Survey (49.5%).[30]

Conclusion

Based on highly accurate measures of BP in a representative sample of Canadian adults, this report provides a long-awaited update of the prevalence and control of hypertension in Canada. The study suggests that hypertension awareness, treatment and control have increased in the past decade, following the establishment of an ambitious program aimed at clarifying hypertension treatment guidelines and reminding clinicians of the importance of hypertension control. However, the finding that hypertension is uncontrolled in 34% of Canadians with the condition is evidence of the challenge that remains.

The rich array of data collected by the CHMS offers the opportunity for more detailed analyses focusing on BP. Forthcoming studies will identify the characteristics of subpopulations in whom hypertension is untreated or suboptimally controlled.

This study provides benchmark estimates of blood pressure distribution and hypertension in the Canadian population, based on direct automated measures. As subsequent cycles of CHMS data become available, assessments of trends over time can be made with greater precision. In addition, follow-up studies based on CHMS records linked to hospital and mortality data will provide opportunities to more accurately quantify the risks of cardiovascular disease and stroke in relation to BP level. ■

References

1. Haider AW, Larson MG, Franklin SS, et al. Systolic blood pressure, diastolic blood pressure, and pulse pressure as predictors of risk for congestive heart failure in the Framingham Heart Study. *Annals of Internal Medicine* 2003; 138: 10-6.
2. Lee DS, Massaro JM, Wang TJ, et al. Antecedent blood pressure, body mass index, and the risk of incident heart failure in later life. *Hypertension* 2007; 50: 869-76.
3. Lloyd-Jones DM, Larson MG, Leip EP, et al. Lifetime risk for developing congestive hart failure: the Framingham Heart Study. *Circulation* 2002; 106: 3068-72.
4. Kannel WB, D'Agostino RB, Silbershatz H, et al. Profile for estimating risk of heart failure. *Archives of Internal Medicine* 1999; 159: 1197-204.
5. Lawes CM, Vander HS, Rodgers A. Global burden of blood-pressure-related disease, 2001. *Lancet* 2008; 371(9623): 1513-8.
6. World Health Organization. *Global Health Risks: Mortality and Burden of Disease Attributable to Selected Major Risks*. Geneva: World Health Organization Press, 2009.
7. Kearney PM, Whelton M, Reynolds K, et al. Worldwide prevalence of hypertension: a systematic review. *Journal of Hypertension* 2004; 22(1): 11-9.
8. Joffres MR, Hamet P, Rabkin SW, et al. Prevalence, control and awareness of high blood pressure among Canadian adults. *Canadian Medical Association Journal* 1992; 146(11): 1997-2005.
9. Joffres MR, Ghadirian P, Fodor JG, et al. Awareness, treatment, and control of hypertension in Canada. *American Journal of Hypertension* 1997; 10: 1097-102.
10. Joffres MR, Hamet P, MacLean DR, et al. Distribution of blood pressure and hypertension in Canada and the United States. *American Journal of Hypertension* 2001; 14(11 Pt 1): 1099-105.
11. Campbell NRC. Hypertension prevention and control in Canada. *Journal of the American Society of Hypertension* 2008; 2(2): 97-105.
12. Leenen FHH, Dumais J, McInnis NH, et al. Results of the Ontario survey on the prevalence and control of hypertension. *Canadian Medical Association Journal* 2008; 178(11): 1441-9.
13. Connor Gorber S, Tremblay M, Campbell N, et al. The accuracy of self-reported hypertension: A systematic review and meta-analysis. *Current Hypertension Reviews* 2008; 4: 36-62.
14. Statistics Canada. *Canadian Health Measures Survey (CHMS) Data User Guide: Cycle 1, January 2010.* Available at: www.statcan.gc.ca.
15. Giroux S. Canadian Health Measures Survey: Sampling strategy overview. *Health Reports* (Statistics Canada, Catalogue 82-003) 2007; 18(Suppl): 31-6.
16. Paradis G, Chiolero A, Bushnik T, et al. Measured blood pressure among children in Canada: Findings from the Canadian Health Measures Survey. *Health Reports* (Statistics Canada, Catalogue 82-003) 2010; 21(1): (forthcoming).
17. Tremblay M, Wolfson M, Connor Gorber S. Canadian Health Measures Survey: Rationale, background and overview. *Health Reports* (Statistics Canada, Catalogue 82-003). 2007; 18(Suppl.): 7-20.
18. Tremblay M, Langlois R, Bryan S, et al. Canadian Health Measures Survey Pre-test: Design, methods, results. *Health Reports* (Statistics Canada, Catalogue 82-003) 2007; 18(Suppl.): 21-30.
19. Day B, Langlois R, Tremblay M, et al. Canadian Health Measures Survey: Ethical, legal and social issues. *Health Reports* (Statistics Canada, Catalogue 82-003) 2007; 18(Suppl): 37-52.
20. Bryan S, St-Denis M, Wojtas D. Canadian Health Measures Survey: Clinic operations and logistics. *Health Reports* (Statistics Canada, Catalogue 82-003) 2007; 18(Suppl): 53-70.
21. Mattu GS, Perry TL, Wright JM. Comparison of the oscillometric blood pressure monitor (BPM-100) with the ausculatory mercury sphygmomanometer. *Blood Pressure Monitoring* 2001; 6: 153-9.
22. Wright JM, Mattu GS, Perry TL et al. Validation of a new algorithm for the BPM-100 electronic oscillometric office blood pressure monitor. *Blood Pressure Monitoring* 2001; 6: 161-5.
23. Myers MG, Valdivieso MA. Use of an automated blood pressure recording device, the BpTRU, to reduce the "white coat effect" in routine practice. *American Journal of Hypertension* 2003; 16: 494-7.
24. Bryan S, St-Pierre Larose M, Campbell N, et al. Resting blood pressure and heart rate measurement in the Canadian Health Measures Survey, Cycle 1. *Health Reports* 2010; 21(1): (in press).
25. Chobanian AV, Bakris GL, Black HR, et al. Seventh Report of the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure. *Hypertension* 2003; 42: 1206-52.
26. Rao JNK, Wu CFJ, Yue K. Some recent work on resampling methods for complex surveys. *Survey Methodology* (Statistics Canada, Catalogue 12-001) 1992; 18(2): 209-17.
27. Rust KF, Rao JNK. Variance estimation for complex surveys using replication techniques. *Statistical Methods in Medical Research* 1996; 5: 281-310.
28. Shields M, Tjepkema M. Trends in adult obesity. *Health Reports* (Statistics Canada, Catalogue 82-003) 2006; 17(3): 53-9.
29. Garriguet D. Sodium consumption at all ages. *Health Reports* (Statistics Canada, Catalogue 82-003) 2007; 18(2): 47-52.

30. Shields M, Tremblay MS, Laviolette M, et al. Fitness of Canadian adults: Findings from the 2007-2009 Canadian Health Measures Survey. *Health Reports* (Statistics Canada, Catalogue 82-003) 2010; 21(1): (in press).

31. Myers MG, McInnis NH, et al. Comparison Between an Automated and Manual Sphygmomanometer in a Population Survey. *American Journal of Hypertension* 2008; 21: 280-3.

32. Campbell NRC, Conradson HE, Kang J, et al. Automated assessment of blood pressure using BpTRU compared with assessments by a trained technician and a clinic nurse. *Blood Pressure Monitoring* 2005; 10: 257-62.

33. Myers MG. Automated blood pressure measurement in routine clinical practice. *Blood Pressure Monitoring* 2006; 11: 59-62.

34. Parati G, Stergiou GS, Asmar R, et al. European Society of Hypertension guidelines for blood pressure monitoring at home: a summary report of the Second International Consensus Conference on Home Blood Pressure Monitoring. *Journal of Hypertension* 2008; 26: 1505-30.

35. Centers for Disease Control. *National Health and Nutrition Examination Survey (NHANES). Health Tech/Blood Pressure Procedures Manual*. May, 2009. Available at: http//www.cdc.gov/nchs/data/nhanes/nhanes_09_10/BP.pdf.

36. Ostchega Y, Sung SY, Hughes J, et al. *Hypertension Awareness, Treatment, and Control—Continued Disparities in Adults: United States, 2005-2006* (NCHS data brief, no. 3) Hyattsville, Maryland: National Center for Health Statistics, 2008.

37. Falaschetti E, Chaudhury M, Mindell J, et al. Continued improvement in hypertension management in England: results from the Health Survey for England 2006. *Hypertension* 2009; 53(3): 480-6.

38. Onysko J, Maxwell C, Eliasziw M, et al. Large increases in hypertension diagnosis and treatment in Canada following a health care professional education program. *Hypertension* 2006; 48(5): 853-60.

39. Campbell NR, Brant R, Johansen H, et al. Increases in antihypertensive prescriptions and reductions in cardiovascular events in Canada. *Hypertension* 2009; 53(2): 128-34.

40. Hemmelgarn BR, Chen G, Walker R, et al. Trends in antihypertensive drug prescriptions and physician visits in Canada between 1996 and 2006. *Canadian Journal of Cardiology* 2008; 24(6): 507-12.

41. McAlister FA, Feldman RD, Wyard K, et al. The impact of the Canadian Hypertension Education Programme in its first decade. *European Heart Journal* 2009; 30: 1434-9.

42. McAlister FA, Kelly N, Chen G, et al. *Canadian Hypertension Education Program (CHEP) Evaluation Project: A Comparison of Changes in Canadian Hypertension Treatment, Hypertension Diagnosis, and Cardiovascular Disease Rates to Other National Hypertension Management Programs. A Report submitted to the Public Health Agency of Canada Management Division, Centre for Disease Prevention and Control*. March 31, 2009.

43. Danon-Hersch N, Marques-Vidal P, Bovet P, et al. Prevalence, awareness, treatment and control of high blood pressure in a Swiss city general population: the CoLaus study. *European Journal of Cardiovascular Prevention and Rehabilitation* 2009; 16(1): 66-72.

44. Cooper RS, Wolf-Maier K, Luke A, et al. An international comparative study of blood pressure in populations of European vs. African descent. *BMC Medicine* 2005. Available at: http://www.biomedcentral.com/1741-7015/3/2.

45. Barrios V, Escobar C, Echarri R. Hypertension and women: A worldwide project [letter]. *The American Journal of Medicine* 2009; 122(2): e9.

46. Gu Q, Burt VL, Paulose-Ram R, et al. Gender differences in hypertension treatment, drug utilization patterns, and blood pressure control among US adults with hypertension: Data from the National Health and Nutrition Examination Survey 1999-2004. *American Journal of Hypertension* 2008; 21(7): 789-98.

47. Thoenes M, Neuberger H-R, Volpe M, et al. Antihypertensive drug therapy and blood pressure control in men and women: an international perspective. *Journal of Human Hypertension* advance online publication, 1 October; doi:10.1038/jhh.2009.76.

48. U.S. Department of Health and Human Services. *JNC Express. The Seventh Report on the Joint National Committee on Prevention, Detection, Evaluation and Treatment of High Blood Pressure* (NIH Publication No. 03-5233) Washington DC: National Institutes of Health, 2003.

49. Oliveria SA, Lapuerta P, McCarthy BD, et al. Physician-related barriers to the effective management of uncontrolled hypertension. *Archives of Internal Medicine* 2002; 162(4): 413-20.

50. Hyman DJ, Pavlik VN. Self-reported hypertension treatment practices among primary care physicians: blood pressure thresholds, drug choices, and the role of guidelines and evidence-based medicine. *Archives of Internal Medicine* 2000; 160(15): 2281-6.

51. McAlister FA, Laupacis A, Teo KK, et al. A survey of clinician attitudes and management practices in hypertension. *Journal of Human Hypertension* 1997; 11(7): 413-9.

52. Haynes RB, Lacourcière Y, Rabkin SW, et al. Report of the Canadian Hypertension Society Consensus Conference: 2. Diagnosis of hypertension in adults. *Canadian Medical Association Journal*. 1993; 149(4): 409-18.

53. Zarnke KB, McAlister FA, Campbell NR, et al. (Canadian Hypertension Recommendations Working Group). The 2001 Canadian recommendations for the management of hypertension: Part one—Assessment for diagnosis, cardiovascular risk, causes and lifestyle modification. *Canadian Journal of Cardiology* 2002; 18(6): 604-24.

54. Canadian Hypertension Education Program. 2009 CHEP recommendations for the management of hypertension. Available at: http://www.hypertension.ca/chep/recommendations-2009/.

55. Khan NA, Hemmelgarn B, Herman RJ, et al. The 2009 Canadian Hypertension Education Program recommendations for the management of hypertension: Part 2—therapy. *Canadian Journal of Cardiology* 2009; 25(5): 287-98.

56. Ramachandran SV, Larson MG, Leip EP, et al. Impact of high-normal blood pressure n the risk of cardiovascular disease. *New England Journal of Medicine* 2001; 345(18): 1291-7.

Vitamin D status of Canadians as measured in the 2007 to 2009 Canadian Health Measures Survey

by Kellie Langlois, Linda Greene-Finestone, Julian Little, Nick Hidiroglou and Susan Whiting

Abstract

Background
Vitamin D deficiency is a global health problem, but little is known about the vitamin D status of Canadians.

Data and methods
The data are from the 2007 to 2009 Canadian Health Measures Survey, which collected blood samples. Descriptive statistics (frequencies, means) were used to estimate 25-hydroxyvitamin D [25(OH)D] concentrations among a sample of 5,306 individuals aged 6 to 79 years, representing 28.2 million Canadians from all regions, by age group, sex, racial background, month of blood collection, and frequency of milk consumption. The prevalence of deficiency and the percentages of the population meeting different cut-off concentrations were assessed.

Results
The mean concentration of 25(OH)D for the Canadian population aged 6 to 79 years was 67.7 nmol/L. The mean was lowest among men aged 20 to 39 years (60.7 nmol/L) and highest among boys aged 6 to 11 (76.8 nmol/L). Deficiency (less than 27.5 nmol/L) was detected in 4% of the population. However, 10% of Canadians had concentrations considered inadequate for bone health (less than 37.5 nmol/L) according to 1997 Institute of Medicine (IOM) Standards (currently under review). Concentrations measured in November-March were below those measured in April-October. White racial background and frequent milk consumption were significantly associated with higher concentrations.

Interpretation
As measured by plasma 25(OH)D, 4% of Canadians aged 6 to 79 years were vitamin D-deficient, according to 1997 IOM standards (currently under review). Based on these standards, 10% of the population had inadequate concentrations for bone health.

Key words
sun exposure, milk, ethnicity

Authors
Kellie Langlois (613-951-3806; Kellie.Langlois@statcan.gc.ca) is with the Health Analysis Division at Statistics Canada, Ottawa, K1A 0T6. Linda Greene-Finestone is with the Chronic Disease Prevention Division at the Public Health Agency of Canada. Julian Little is with the Department of Epidemiology and Community Medicine at the University of Ottawa. Nick Hidiroglou is with the Health Products and Food Branch at Health Canada. Susan Whiting is with the College of Pharmacy and Nutrition at the University of Saskatchewan.

The Canadian Health Measures Survey (CHMS), launched by Statistics Canada in 2007 in partnership with Health Canada and the Public Health Agency of Canada, collected direct physical measures of health and wellness from a nationally representative sample of Canadians. It is the most comprehensive direct health measures survey undertaken in Canada at the national level. A fundamental aspect of the CHMS is the collection of blood and urine samples,[1] which were analyzed for chronic and infectious diseases, environmental toxins, and nutritional biomarkers, including glucose, cholesterol, calcium, and vitamin D. This study examines 25-hydroxyvitamin D [25(OH)D] concentrations in the Canadian population aged 6 to 79 years and factors shown to affect vitamin D status.

Vitamin D deficiency is a worldwide health problem.[2] Vitamin D promotes calcium and phosphorous absorption, which is necessary to build and maintain bones and teeth, and is also a transcription factor in most cells in the body.[3,4] Although the optimal concentration for overall health is currently under debate, lower levels of vitamin D have been associated with a greater risk of rickets in children or osteomalacia in adults;[5] increased risk of fractures,[6] falls,[7] breast cancer,[8] colorectal cancer and adenoma;[9] poor immunity;[4] and cardiovascular[10] and other diseases such as multiple sclerosis.[11]

Vitamin D activity in the body results from two conversions of the parent compound cholecalciferol, which is made in the skin in the presence of ultraviolet B (UVB) radiation.[3] Another source is ingestion of preformed cholecalciferol (often called vitamin D_3) or ergocalciferol (vitamin D_2), the latter being formed when certain fungi or yeasts are irradiated with UVB. The major circulating form of vitamin D in the blood is 25-hydroxyvitamin D [25(OH)D]. Plasma (or serum) 25(OH)D concentration is generally considered to be the best metabolite to reflect vitamin D status.[3] It represents the sum of 25(OH)D from diet and endogenous synthesis.

The determinants of vitamin D status are multifactorial and include environmental, physiological and personal characteristics. Some environmental factors can decrease synthesis of vitamin D in the skin, for example, reduced exposure to sunlight, winter season, sunscreen use, being indoors, and clothing coverage.[2] The physiologic factors associated with lower vitamin D status include pregnancy and lactation, and elevated body mass index/adiposity.[2,3] The personal characteristics include age,[12-14] level of ingestion of dietary sources,[15,16] and skin pigmentation.[2,15,16] Factors that may lead to lower vitamin D concentrations among Canadians in particular include living at a high latitude (which lessens the time for vitamin D synthesis),[17,18] a lack of dietary intake,[15,16] and for some people, darker skin pigmentation.[15,16]

The extent to which Canadians' vitamin D status has been measured and evaluated is limited. Several regional studies have reported relatively low concentrations in a high percentage of Canadian children,[17,19] adults,[18,20] pregnant women and their infants,[21-23] Aboriginal populations,[15,23] and the very old and institutionalized.[24] A small study found a disparity between Canadians of European descent and those from East Asia or South Asia, with the latter having very low levels of vitamin D in winter.[16]

Data and methods

Data for this study are from 2007 to 2009 Canadian Health Measures Survey (CHMS). This survey collected direct physical measures for the household population aged 6 to 79 years. The survey consisted of two parts: 1) an in-home interview to gather information on sociodemographic characteristics, health behaviours, environmental factors and nutrition, and 2) a subsequent visit to a mobile examination centre[25] for a series of direct measurements of height and weight, blood pressure, physical fitness, and collection of urine and blood samples. The blood samples, taken by a certified phlebotomist, measured a variety of substances and metabolites, including plasma 25(OH)D. Respondents unable to visit the mobile examination centre were given the option of having the direct measurements taken in their home.[1] Additional information about the CHMS is available in previously published reports and online from Statistics Canada's website.[1,25-27]

Sampling plan

Of the 8,772 dwellings selected in the CHMS, 6,106 agreed to participate for a household response rate of 69.6%. From these respondent households, 7,483 people were selected to participate in the survey, 6,604 of whom agreed to respond to the questionnaire for a response rate of 88.3%. Of these, 5,604 reported to the mobile examination centre for physical measurements, for a response rate of 84.9%. At the national level, the response rate was 51.7%. This overall response rate is not the result of multiplying the household and person response rates, since two people were selected in some households.[28]

Residents of Indian reserves, Crown lands, certain remote regions, and institutions, and full-time members of the Canadian Forces were excluded from the survey. Over two years, data were collected at 15 sites across the five regions of Canada: Atlantic provinces (Newfoundland and Labrador, Prince Edward Island, Nova Scotia, New Brunswick), Quebec, Ontario, the Prairies (Manitoba, Saskatchewan, Alberta; includes Yellowknife), and British Columbia (includes Whitehorse).[25] Although not every province/territory had a collection site, sites were chosen to represent the Canadian population from east to west, with larger and smaller population densities, and were ordered to take account of seasonality by region and temporal effects.[25] Approximately 97% of the Canadian population is represented.

25-hydroxyvitamin D analysis

Using the LIAISON 25-Hydroxyvitamin D TOTAL assay (Diasorin, Ltd.), plasma 25(OH)D levels were measured by a chemiluminescence assay (CLIA). The lower and upper detection limits are 10 nmol/L and 375 nmol/L, respectively. Plasma samples had been previously stored at -20°C. Analyses were performed singly rather than as paired samples. In-house Diasorin testing estimated the assay %CVs with runs as 3.2% to 8.5% and between runs as 6.9% to 12.7%. Health Canada laboratory samples were consistently within these limits, using external quality controls from BioRad and Diasorin. The Health Canada laboratory participates in the proficiency vitamin D testing through DEQAS (Vitamin D external quality assurance scheme, UK) and has received annual certification of proficiency since joining DEQAS in 2005. For more detailed information on the collection and measurement of plasma 25(OH)D in the CHMS, refer to the *Vitamin D Reference Laboratory Standard Operating Procedures Manual* at www.statcan.gc.ca.

Respondents with hemophilia or who had chemotherapy in the previous four weeks were excluded from blood collection. Also, in some cases, the respondent did not provide enough blood for the vitamin D measure (tubes were collected in priority order). Individuals whose vitamin D measurement was below the lower limit of detection (9.98 nmol/L) were assigned a value half of the lower limit (4.99 nmol/L).[29]

Measured values were compared with cut-offs for 25(OH)D. However, there is considerable controversy about what concentration of circulating 25(OH)D is optimum for health. The Institute of Medicine (IOM) is currently updating the 1997 Dietary Reference Intakes for vitamin D,[5] as new evidence indicated the need for revision.[30] The 1997 Dietary Reference Intakes were based on achieving a concentration of at least 27.5 nmol/L, values below which have been associated with vitamin D deficiency (defined as high risk of rickets in children or osteomalacia in adults).[5] Concentrations below 37.5 nmol/L are considered inadequate for bone health, based on the IOM recommendations,[5] although these are currently under review. For this analysis, vitamin D deficiency was defined as a concentration below 27.5 nmol/L. Inadequacy for bone health was defined as a concentration below 37.5 nmol/L. Nonetheless, there is growing consensus that much higher concentrations, specifically, those above 75 nmol/L, are desirable for overall health and disease prevention.[3,31-33] Consequently, this cut-off was also examined. Concentrations above 220 nmol/L correspond to intakes for adults at a proposed "no observed adverse effects levels" of 250 µg (10,000 IU) of vitamin D per day.[34] Concentrations exceeding 375 nmol/L pose a risk of adverse effects and have a potential for toxicity.[35] These cut-offs were also evaluated.

Associated factors

Concentrations of 25(OH)D are associated with skin pigmentation, but the CHMS did not collect information on skin pigmentation per se. For this analysis, racial background was used as a proxy. The CHMS asked respondents to choose among an extensive list of backgrounds; those who indicated "White" were categorized as such. Because of the low sample size of non-White respondents, racial background was defined in only two categories: White and Other.

A proxy for the effect of seasonality was based on the date respondents visited the mobile examination centre—November to March or April to October—consistent with studies based on the National Health and Nutrition Examination Survey (NHANES) in the United States.[36] This categorization represents a period during which cutaneous synthesis of vitamin D is unlikely in Canada, and a period during which cutaneous synthesis is likely.[37]

During the household interview, respondents were asked how much time each day they usually spend in the sun on "a typical weekend or day off from work/school in the summer months" between 11 a.m. and 4 p.m. For this study, daily sun exposure was defined in three categories: less than 30 minutes, 30 minutes to less than one hour, and one hour or more.

Respondents were asked how often they drink milk or enriched milk substitutes or use them on cereal. They were categorized as consuming milk less than once a day, once a day, or more than once a day.

Age was grouped according to the CHMS sampling plan: 6 to 11 years, 12 to 19 years, 20 to 39 years, 40 to 59 years, and 60 to 79 years.[25] Data on age were collected at both the household interview and the mobile examination centre visit. For this study, the respondent's age was defined based on the latter.

Statistical analysis

The sample used in this analysis consisted of 5,306 respondents (2,566 males and 2,740 females), representing 28.2 million Canadians aged 6 to 79 years from all regions throughout the two years of data collection. Respondents who refused to have their blood drawn, did not have enough blood drawn, or had medical reasons for not having their blood drawn (for example, chemotherapy) were excluded (n=298). The unweighted sample sizes with valid plasma 25(OH)D concentrations are presented by sex and age group in Appendix Table A.

Descriptive statistics (frequencies, means) were used to estimate plasma 25(OH)D concentrations by age group, sex, racial background, month of blood collection, and frequency of milk consumption (Appendix Table B). Data on other factors such as dietary supplements and sunscreen use will be examined in subsequent analyses. The prevalence of deficiency and the percentages of the population meeting different concentrations of 25(OH)D were assessed.

All estimates were based on data weighted to represent the Canadian population aged 6 to 79 years. Variance estimation (95% confidence intervals) and significance testing (chi-square or t-test) on differences between estimates were calculated using the bootstrap weights provided with the data, which account for the complex sampling design. Significance was defined as a p-value of < 0.05. The Bonferroni adjustment method was used in cases of multiple comparisons (for example, age groups). Analyses were conducted in SUDAAN v.10.

Results

The mean concentration of 25(OH)D among Canadians aged 6 to 79 years was 67.7 nmol/L (Table 1). Mean concentrations ranged from a low of 60.7

Table 1
Mean 25-hydroxyvitamin D concentrations, by age group and sex, household population aged 6 to 79 years, Canada, 2007 to 2009

Age group and sex	Mean nmol/L	95% confidence interval from	95% confidence interval to
Total 6 to 79 years	**67.7**	**65.3**	**70.1**
Male	65.7*	62.5	68.9
Female	69.7	67.8	71.7
6 to 11 years	**75.0[c d]**	**70.3**	**79.7**
Male	76.8[b c d e]	72.9	80.7
Female	73.1	67.0	79.1
12 to 19 years	**68.1**	**63.8**	**72.4**
Male	65.6*[a]	60.8	70.4
Female	70.8	65.8	75.9
20 to 39 years	**65.0[a e]**	**61.0**	**69.0**
Male	60.7*[a e]	55.3	66.1
Female	69.5	65.8	73.2
40 to 59 years	**66.5[a e]**	**63.8**	**69.2**
Male	66.0[a]	62.1	69.8
Female	67.1[e]	65.0	69.2
60 to 79 years	**72.0[c d]**	**69.4**	**74.5**
Male	70.5[a c]	67.5	73.6
Female	73.3[d]	70.3	76.4

* significantly different from estimate for females in same age group
[a] significantly different from estimate for 6 to 11 years of same sex
[b] significantly different from estimate for 12 to 19 years of same sex
[c] significantly different from estimate for 20 to 39 years of same sex
[d] significantly different from estimate for 40 to 59 years of same sex
[e] significantly different from estimate for 60 to 79 years of same sex
Source: 2007 to 2009 Canadian Health Measures Survey.

nmol/L among men aged 20 to 39 years to a high of 76.8 nmol/L among boys aged 6 to 11 years. For both sexes, the pattern of 25(OH)D concentrations by age group followed a U-shape: highest among children and seniors, and lowest at ages 20 to 39 years. Concentrations were significantly higher among females than males overall and at ages 12 to 39 years.

An estimated 4.1% of the population (5.2% of males and 3.0% of females) had concentrations below 27.5 nmol/L, indicating that they were deficient in vitamin D (Table 2). The highest prevalence of deficiency was among men aged 20 to 39 years (6.8%).

Just over 10% of Canadians (12.9% of males and 8.3% of females) had concentrations below 37.5 nmol/L—levels considered inadequate for bone health. This means that about 90% of the population (87.1% of males and 91.7% of females) had adequate concentrations for bone health (according to IOM recommendations, which are currently under review). Females were more likely than males to have adequate concentrations, overall and at ages 20 through 59 years. Boys aged 6 to 11 years were significantly more likely than older males to have adequate concentrations.

Approximately one-third of the population (33.0% of males and 37.8% of females) had concentrations above 75 nmol/L, the level proposed for optimal health. The percentage was highest at ages 6 to 11 years (48.6%) and ages 60 to 79 years (44.7%); it was lowest at ages 20 to 39 years (29.5%). Males and females were equally likely to meet this level, except at ages 20 to 39 years among whom the percentage of women was significantly higher than the percentage of men (36.3% versus 22.9%).

Fewer than 0.5% of the population had concentrations over 220 nmol/L, and no one in the CHMS sample was above the potentially toxic concentration of 375 nmol/L (data not shown).

White racial background tended to be associated with high concentrations of 25(OH)D (Table 3). The mean difference between racial groups was approximately 19 nmol/L; the smallest difference was among women aged 60 to 79 years (7.1 nmol/L), and the largest, among women aged 20 to 39 years (26.6 nmol/L).

Mean 25(OH)D concentrations varied by the month when the blood sample was taken (Table 3). Concentrations tended to be higher among people whose blood

Table 2
Percentage of household population aged 6 to 79 years meeting 25-hydroxyvitamin D concentration cut-offs, by age group and sex, Canada, 2007 to 2009

	Below 27.5 nmol/L			Below 37.5 nmol/L			Equal to or above 37.5 nmol/L			Above 75 nmol/L		
		95% confidence interval			95% confidence interval			95% confidence interval			95% confidence interval	
Age group and sex	%	from	to	%	from	to	%	from	to	%	from	to
Total 6 to 79 years	**4.1[E]**	**2.9**	**5.8**	**10.6**	**8.2**	**13.6**	**89.4**	**86.4**	**91.8**	**35.4**	**32.0**	**38.9**
Female	3.0*[E]	2.0	4.4	8.3*	6.1	11.3	91.7*	88.7	93.9	37.8	34.8	40.8
Male	5.2[E]	3.4	7.8	12.9	9.7	16.9	87.1	83.1	90.3	33.0	27.6	38.9
6 to 11 years	**F**	**...**	**...**	**F**	**...**	**...**	**95.6**	**91.2**	**97.9**	**48.6[b c d]**	**41.7**	**55.5**
Female	F	...	...	F	...	...	93.4	85.2	97.2	45.1	36.6	53.9
Male	F	...	...	F	...	...	97.8[b c d e]	95.5	98.9	51.9[b c d]	45.0	58.7
12 to 19 years	**5.0[e E]**	**3.1**	**8.0**	**11.8[E]**	**7.4**	**18.4**	**88.2**	**81.6**	**92.6**	**35.2[a]**	**30.4**	**40.3**
Female	F	...	...	8.9[E]	4.7	16.2	91.1	83.8	95.3	35.3	28.7	42.6
Male	5.0[E]	2.8	8.9	14.5[E]	9.0	22.4	85.5[a]	77.6	91.0	35.0[a c]	29.2	41.3
20 to 39 years	**5.1[E]**	**3.1**	**8.2**	**12.7[E]**	**9.1**	**17.6**	**87.3**	**82.4**	**90.9**	**29.5[a e]**	**23.6**	**36.3**
Female	3.2[E]	1.7	6.2	9.7*[E]	6.1	15.0	90.3*	85.0	93.9	36.3*	29.0	44.4
Male	6.8[E]	3.7	12.4	15.7[E]	10.8	22.2	84.3[a]	77.8	89.2	22.9[a b d e E]	16.2	31.4
40 to 59 years	**4.4[e E]**	**2.9**	**6.6**	**11.2**	**8.3**	**14.9**	**88.8**	**85.1**	**91.7**	**33.6[a e]**	**29.9**	**37.6**
Female	2.9*[E]	1.7	4.8	8.6*[E]	5.9	12.4	91.4*	87.6	94.1	34.1	30.6	37.8
Male	5.9[e E]	3.9	8.8	13.8[E]	9.8	19.0	86.2[a]	81.0	90.2	33.2[a c]	26.5	40.6
60 to 79 years	**2.1[b d E]**	**1.1**	**3.9**	**7.1**	**5.6**	**9.0**	**92.9**	**91.0**	**94.4**	**44.7[c d]**	**38.7**	**50.9**
Female	F	...	...	5.7[E]	4.0	8.1	94.3	91.9	96.0	46.0	38.7	53.6
Male	2.4[d E]	1.3	4.2	8.7	6.2	12.0	91.3[a]	88.0	93.8	43.3[c]	36.3	50.5

* significantly different from estimate for females in same age group
[a] significantly different from estimate for 6 to 11 years of same sex
[b] significantly different from estimate for 12 to 19 years of same sex
[c] significantly different from estimate for 20 to 39 years of same sex
[d] significantly different from estimate for 40 to 59 years of same sex
[e] significantly different from estimate for 60 to 79 years of same sex
[E] interpret with caution (coefficient of variation 16.6% to 33.3%)
F estimate not provided because of extreme sampling variability or small sample size
... not applicable
Source: 2007 to 2009 Canadian Health Measures Survey.

Table 3
Mean 25-hydroxyvitamin D concentrations, by racial background, month of blood collection, milk consumption, age group and sex, household population aged 6 to 79 years, Canada, 2007 to 2009

	Racial background						Month of blood collection						Milk consumption								
	White			Other†‡			April to October			November to March†			More than once a day			Once a day			Less than once a day†		
		95% confidence interval			95% confidence interval			95% confidence interval			95% confidence interval			95% confidence interval			95% confidence interval			95% confidence interval	
Age group and sex	Average nmol/L	from	to	Average nmol/L	from	to	Average nmol/L	from	to	Average nmol/L	from	to	Average nmol/L	from	to	Average nmol/L	from	to	Average nmol/L	from	to
Total 6 to 79 years	**71.2***	**68.8**	**73.7**	**52.3**	**49.1**	**55.5**	**70.0**	**65.6**	**74.4**	**64.1**	**60.3**	**67.9**	**75.0***	**72.5**	**77.5**	**68.1***	**65.3**	**71.0**	**62.7**	**60.5**	**64.9**
Female	73.3*	71.4	75.2	53.0	49.9	56.1	72.0*	68.6	75.4	66.3	63.3	69.3	75.8*	73.9	77.6	69.6*	67.2	72.1	65.9	63.4	68.3
Male	69.1*	65.7	72.6	51.6	47.3	56.0	68.1	62.4	73.7	61.7	56.5	66.9	74.2*	70.6	77.7	66.6*	61.8	71.4	59.7	56.8	62.5
6 to 11 years	**78.5***	**74.5**	**82.5**	**63.3**	**54.7**	**71.9**	**76.1**	**69.7**	**82.5**	**73.0**	**63.0**	**83.1**	**78.5***	**74.4**	**82.6**	**67.9**	**61.2**	**74.7**	**69.6**	**61.8**	**77.3**
Female	77.8*	73.0	82.6	56.7	46.0	67.4	74.1	66.7	81.6	71.4	58.7	84.1	77.5	72.4	82.6	64.0	55.0	73.0	70.1	58.9	81.2
Male	79.2*	74.8	83.6	69.4	61.8	76.9	77.9	72.2	83.6	74.8	66.3	83.3	79.4*	75.2	83.5	72.3	67.6	76.9	69.0	60.2	77.8
12 to 19 years	**72.2***	**68.3**	**76.1**	**54.8**	**48.3**	**61.2**	**73.5***	**67.5**	**79.4**	**60.1**	**53.4**	**66.9**	**74.1***	**69.0**	**79.3**	**68.1***	**62.0**	**74.3**	**58.9**	**52.8**	**65.0**
Female	76.9*	73.0	80.8	52.8	45.9	59.7	75.7*	69.9	81.4	62.4	56.8	68.1	77.7*	71.1	84.2	70.0*	63.3	76.8	62.8	56.2	69.3
Male	68.1*	62.9	73.2	56.8	47.4	66.3	71.2*	62.9	79.5	58.3	50.2	66.4	71.5*	65.1	78.0	65.7*	55.9	75.5	55.1	49.0	61.1
20 to 39 years	**70.2***	**65.7**	**74.7**	**47.8**	**44.2**	**51.3**	**69.3***	**62.2**	**76.4**	**59.6**	**54.8**	**64.4**	**71.3***	**65.4**	**77.3**	**67.9***	**62.8**	**73.0**	**58.4**	**53.9**	**62.9**
Female	75.5*	71.5	79.6	48.9	46.5	51.2	74.3*	67.5	81.1	64.2	59.7	68.8	73.8	68.4	79.2	71.5	65.8	77.1	64.9	58.0	71.8
Male	64.9*	58.4	71.4	46.8	41.2	52.4	65.0	56.0	74.1	54.6	47.8	61.3	68.8*	61.1	76.6	64.5*	57.3	71.7	52.3	47.2	57.3
40 to 59 years	**69.6***	**67.5**	**71.8**	**50.7**	**44.4**	**57.0**	**68.2**	**64.0**	**72.4**	**63.6**	**59.3**	**67.8**	**76.1***	**72.8**	**79.4**	**66.2**	**62.6**	**69.7**	**63.6**	**61.2**	**66.0**
Female	69.4*	67.8	71.1	52.4	46.5	58.2	69.2*	66.6	71.8	63.8	60.6	67.1	73.2*	67.2	79.2	66.6	63.5	69.8	65.2	62.4	67.9
Male	69.9*	66.4	73.4	49.4	41.9	57.0	67.3	61.0	73.6	63.2	56.5	69.9	79.5*	75.2	83.7	65.7	59.1	72.3	62.0	58.7	65.3
60 to 79 years	**73.1***	**70.4**	**75.8**	**62.4**	**54.6**	**70.2**	**70.2**	**66.4**	**74.0**	**75.5**	**72.7**	**78.3**	**78.9***	**75.5**	**82.2**	**72.5***	**69.5**	**75.5**	**68.8**	**65.4**	**72.2**
Female	74.1	70.7	77.4	67.0	54.9	79.1	71.1*	66.8	75.4	78.1	74.4	81.9	80.0*	75.3	84.7	73.5	67.1	79.9	69.8	65.9	73.8
Male	72.0*	68.9	75.2	57.2	52.2	62.3	69.2	64.9	73.4	72.9	67.2	78.7	77.2*	69.5	84.9	71.4	67.9	74.9	67.8	64.3	71.3

* significantly different from estimate for reference category of same age and sex
† reference category
‡ self-reported racial and cultural background, including Chinese, South Asian, Black, Filipino, Latin American, Southeast Asian, Arab, West Asian, Japanese, Korean, Aborigianal, and Other
Source: 2007 to 2009 Canadian Health Measures Survey.

was drawn in April-October rather than in November-March. The exception was women aged 60 to 79 years, who had higher concentrations in November-March. The percentage of Canadians in the adequate range (at least 37.5 nmol/L) was 91.8% in April-October, not significantly different from 85.6% in November-March. However, the percentage with concentrations above 75 nmol/L was significantly higher in April-October than in November-March: 38.6% versus 30.3% (data not shown).

Data on sun exposure during the summer indicate that people who reported an hour or less per day in the sun had lower 25(OH)D concentrations than did those who reported more than an hour (data not shown). However, because the CHMS determined sun exposure only for the summer months, the sample was not large enough to explore this relationship further.

The frequency of milk consumption tended to be positively related to 25(OH)D concentrations. People who consumed milk more than once a day had a mean concentration of 75 nmol/L versus 62.7 nmol/L among those who did so less than once a day (Table 3). The percentage of people consuming milk more than once a day declined with advancing age from about 65% of children aged 6 to 11 years to just over 20% of seniors aged 60 to 79 years (Appendix Table B).

Discussion

This study uses data from the 2007 to 2009 Canadian Health Measures Survey to examine the vitamin D status of Canadians aged 6 to 79 years. It is the first study in Canada based on direct measures of plasma 25(OH)D concentrations in a nationally representative sample. The comprehensiveness of the survey made it possible to examine several factors known to be associated with vitamin D status, including age, racial background and milk consumption.

Overall, 4% of Canadians had 25(OH)D concentrations considered deficient (less than 27.5 nmol/L). About 90% had concentrations meeting or exceeding 37.5 nmol/L, which is considered adequate for bone health by Institute of Medicine standards[5] (these standards are currently under review). Finally, a third of the population had concentrations above 75 nmol/L, the cut-off suggested in some studies[3,31-33,38] to be desirable for overall health and disease prevention.

Based on a cut-off of 25 nmol/L, countries around the world report a substantial portion of their populations as vitamin D-deficient.[2] In the United States, where measurements are taken in sunny months (summer in the northern states; winter in the southern states), the overall prevalence of concentrations under 27.5 nmol/L is about 5%.[38] In Canada, when limited to measurements taken in April-October, the prevalence of deficiency was just over 3%. Because of methodological differences, comparisons with other countries should be made with caution.

In relation to values averaged over the entire year, almost 90% of the Canadian population met the 37.5 nmol/L adequacy cut-off for bone health. This is comparable to NHANES results for the United States.[39]

Children aged 6 to 11 years and seniors aged 60 to 79 years were most likely to be above the adequacy cut-offs, although the reasons for these higher levels probably differ. According to CHMS data, young children were more likely than older people to drink milk at least once a day (Appendix Table B). Older adults may be more likely to derive more vitamin D from supplements. This will be analyzed in a subsequent paper.

The necessity of classifying respondents into only two racial categories assumes that those identified as White have light skin pigmentation, and that the Other group consists of those with darker skin pigmentation. For the most part, this grouping revealed a significant difference, with the latter having lower 25(OH)D concentrations than the former. Data from the United States[13] show that non-Hispanic Black Americans have much lower concentrations than non-Hispanic White Americans across all age/sex groups, even when measured in the summer. A small Canadian study reported a similar finding,[16] but was not able to determine if lower concentrations among those with darker skin pigmentation (which was measured directly in that study) were confounded by their lower intake of vitamin D from foods and supplements.

The month in which the blood sample was taken for the CHMS was moderately associated with 25(OH)D concentrations, notably among females and people aged 12 to 39 years. (Factors such as supplement use may have prevented the emergence of a seasonal effect in some age groups.) Similarly, Vieth et al.[20] found higher concentrations in summer than in winter among women in the Toronto area. Rucker et al.[18] showed seasonal effects in adults aged 27 to 89 years, with lower concentrations in winter and fall than in spring and summer. Moreover, their results controlled for winter travel to southern destinations, an adjustment that could not be made to the CHMS data.

The frequency of milk consumption was significantly related to vitamin D status among Canadians of all ages; those consuming milk more than once a day had an average increase of 12 nmol/L, compared with those doing so less than once a day. This is similar to the 7 nmol/L difference among non-Hispanic White Americans aged 20 to 59 years who consumed fortified milk "often/sometimes," compared with "never or rarely."[36] Fortified milk consumption has been shown to be lower among Asians, First Nations and northern and southern Indians, likely because of dietary customs and/or a higher prevalence of lactose intolerance.[16] In fact, analyses of the CHMS data revealed that Canadians in the Other racial group consumed milk signficantly less frequently than did those classified as White ($p < 0.05$, data not shown). Nonetheless, the Other racial group shared the general pattern of higher 25(OH)D concentrations with more frequent milk consumption: 60.6 nmol/L for those consuming milk more than once a day, compared with 47.5 nmol/L for those reporting less than once a day ($p < 0.05$, data not shown).

Optimal concentrations of 25(OH)D have not been established, although some researchers have proposed 75 nmol/L as desirable for overall health and disease prevention.[3,31-33,38] Concentrations above that level are known to reduce fracture risk and improve calcium absorption.[6,7,40] Also, concentrations below 75 nmol/L are associated with a greater risk of breast cancer,[8] colorectal cancer and adenomas;[9] evidence of an association with other types of cancer is less clear.[41] Because of the uncertainty about optimal levels, this analysis examined concentrations in relation to higher cut-offs. More than a third (35%) of Canadians were above the 75 nmol/L cut-off; few other countries have reported a similarly high percentage.[2] Only 0.5% of Canadians had levels over 220 nmol/L, and no respondent to the CHMS had a concentration above 375 nmol/L, a potentially toxic level.[35]

This analysis has several limitations. Not all factors that may contribute to variations in 25(OH)D concentration were examined. The examination of interactions between potentially confounding factors was restricted by small sample sizes. No direct information on skin pigmentation was available, and information on milk consumption pertained to the frequency of consumption, not the amounts consumed. Not all regions were represented or compared by month of blood collection.

What is already known on this subject?

- Data from other countries report a high prevalence of vitamin D deficiency.
- Small studies have indicated that some Canadian subgroups have relatively low vitamin D concentrations.

What does this study add?

- This analysis examines vitamin D status in a nationally representative sample of Canadians.
- About 4% of Canadians aged 6 to 79 are vitamin D-deficient, and more than 10% do not have concentrations adequate for bone health. However, 35% are above the cut-off (75 nmol/L) recently suggested as desirable for overall health and disease prevention.
- Low milk consumption and non-White racial background are associated with lower plasma 25(OH)D concentrations.

Conclusion

This study identifies population groups that are likely to have lower concentrations of vitamin D and factors associated with vitamin D status. The factors related to low concentrations are winter season, racial backgrounds other than White, and less frequent intake of milk. Future analyses of CHMS data will investigate additional factors that may influence vitamin D concentrations, such as supplement consumption, body mass index, pregnancy, fish consumption and sunscreen use. ■

References

1. Tremblay M, Wolfson M, Connor Gorber S. Canadian Health Measures Survey: Rationale, background and overview. *Health Reports* (Statistics Canada, Catalogue 82-003) 2007; 18 (Suppl.): 7-20.
2. Mithal A, Wahl DA, Bonjour JP, et al. Global vitamin D status and determinants of hypovitaminosis D. *Osteoporosis International* 2009. Aug 19 [Epub ahead of print].
3. Holick MF. Vitamin D deficiency. *New England Journal of Medicine.* 2007; 357(3): 266-81.
4. White JH. Vitamin D signaling, infectious diseases, and regulation of innate immunity. *Infectious Immunology* 2008; 76: 3837-43.
5. Institute of Medicine. *Dietary Reference Intakes for Calcium, Phosphorus, Magnesium, Vitamin D, and Fluoride.* Washington DC: National Academy Press, 1997.
6. Bischoff-Ferrari HA, Willett WC, Wong JB, et al. Prevention of nonvertebral fractures with oral vitamin D and dose dependency: a meta-analysis of randomized controlled trials. *Archives of Internal Medicine* 2009; 169(6): 551-61.
7. Bischoff-Ferrari HA, Dawson-Hughes B, Staehelin HB, et al. Fall prevention with supplemental and active forms of vitamin D: a meta-analysis of randomised controlled trials. *British Medical Journal* 2009; 339: b3692 doi: 10.1136/bmj.b3692.
8. Lin J, Manson JE, Lee I-M, et al. Intakes of calcium and vitamin D and breast cancer risk in women. *Archives of Internal Medicine* 2007; 167(10): 1050-9.
9. Gorham ED, Garland CF, Garland FC, et al. Optimal vitamin D status for colorectal cancer prevention: a quantitative meta analysis. *American Journal of Preventive Medicine* 2007; 32: 210-6
10. Giovannucci E, Liu Y, Hollis BW, Rimm EB. 25-hydroxyvitamin D and risk of myocardial infarction in men: a prospective study. *Archives of Internal Medicine* 2008; 168: 1174-80.
11. Ramagopalan SV, Maugeri NJ, Handunnetthi L, et al. Expression of the multiple sclerosis-associated MHC class II allele HLA-DRB1*1501 is regulated by vitamin D. *PLOS Genetics*. 2009; 5(2): e1000369. Epub 2009 February 6.
12. Dixon T, Mitchell P, Beringer T, et al. An overview of the prevalence of 25-hydroxy-vitamin D inadequacy amongst elderly patients with or without fragility fracture in the United Kingdom. *Current Medical Research and Opinion*. 2006; 22: 405-15.
13. Ginde AT, Liu MC, Camargo CA Jr. Demographic differences and trends of vitamin D insufficiency in the US population, 1988-2004. *Archives of Internal Medicine* 2009; 169(6): 626-32.
14. Mansbach JM, Ginde AA, Camargo CA. Serum 25-hydroxyvitamin D levels among US children aged 1 to 11 years: do children need more vitamin D? *Pediatrics* 2009; 124: 1404-10.
15. Weiler HA, Leslie WD, Krahn J, et al. Canadian Aboriginal women have a higher rate of vitamin D deficiency than non-Aboriginal women status despite similar dietary vitamin D intakes. *Journal of Nutrition* 2007; 137: 461-5.
16. Gozdzik A, Barta JL, Wu C, et al. Low wintertime vitamin D levels in a sample of healthy young adults of diverse ancestry living in the Toronto area: Associations with vitamin D intake and skin pigmentation. *BMC Public Health* 2008 8: 336.
17. Roth DE, Prosser C, Martz P, et al. Are national guidelines sufficient to maintain adequate blood levels in children? *Canadian Journal of Public Health* 2005; 96: 443-9.
18. Rucker D, Allan JA., Fick GH, Hanley DA. Vitamin D insufficiency in a population of healthy western Canadians. *Canadian Medical Association Journal* 2002; 166: 1517-24.
19. Mark S, Gray-Donald K, Delvin EE, et al. Low vitamin D staus in a representative sample of youth from Quebec, Canada. *Clinical Chemistry* 2008; 54: 1283-9.
20. Vieth R, Cole DE, Hawker GA, et al. Wintertime vitamin D insufficiency is common in young Canadian women and their vitamin D intake does not prevent it. *European Journal of Clinical Nutrition* 2001; 55: 1091-7.
21. Weiler H, Fitzpatrick-Wong S, Veitch R, et al. Vitamin D deficiency and whole-body and femur bone mass relative to weight in healthy newborns. *Canadian Medical Association Journal.* 2005; 172(6): 757-61.
22. Newhook LA, Sloka S, Grant M, et al. Vitamin D insufficiency common in newborns, children and pregnant women living in Newfoundland and Labrador, *Canada Maternal and Child Nutrition* 2009; 5(2): 186-91.
23. Waiters B, Godel JC, Basu TK. Perinatal vitamin D and calcium status of northern Canadian mothers and their newborn infants. *Journal of the American College of Nutrition* 1998; 18: 122-6.
24. Liu BA, Gordon M, Labranche JM, et al. Seasonal prevalence of vitamin D deficiency in institutionalized older adults. *Journal of the American Geriatric Society* 1997; 45: 598-603.
25. Giroux S. Canadian Health Measures Survey: Sampling strategy overview. Health Reports (Statistics Canada, Catalogue 82-003) 2007; 18 (Suppl.): 31-6.
26. Day B, Langlois R, Tremblay M, Knoppers B-M. Canadian Health Measures Survey: Ethical, legal and social issues. Health Reports (Statistics Canada, Catalogue 82-003) 2007; 18 (Suppl.): 37-51.
27. Bryan S, St-Denis M, Wojtas D. Canadian Health Measures Survey: Clinical operations and logistics. Health Reports (Statistics Canada, Catalogue 82-003) 2007; 18 (Suppl.): 53-70.
28. Statistics Canada. *Canadian Health Measures Survey (CHMS) Data User Guide: Cycle 1*. Available at: www.statcan.gc.ca.
29. Cole SR, Chu H, Nie L, Schisterman EF. Estimating the odds ratio when exposure has a limit of detection. *International Journal of Epidemiology* 2009; 38: 1674-80.

30. Yetley EA, Brule D, Cheney MC, et al., Dietary reference intakes for vitamin D: justification for a review of the 1997 values. *American Journal of Clinical Nutrition* 2009; 89: 719-27.

31. Vieth R, Bischoff-Ferrari H, Boucher BJ, et al. The urgent need to recommend an intake of vitamin D that is effective. *American Journal of Clinical Nutrition* 2007; 85: 649-50.

32. Bischoff-Ferrari HA, Giovannucci E, Willett WC, et al. Estimation of optimal serum concentrations of 25-hydroxyvitamin D for multiple health outcomes. *American Journal of Clinical Nutrition* 2006; 84: 18-28.

33. Dawson-Hughes B, Heaney RP, Holick MF, et al. Estimates of optimal vitamin D status. *Osteoporosis International* 2005; 16: 713-6

34. Hathcock JN, Shao A, Vieth R, Heaney RP. Risk assessment for vitamin D. *American Journal of Clinical Nutrition* 2007; 85: 6-18.

35. Jones G. Pharmacokinetics of vitamin D toxicity. *American Journal of Clinical Nutrition* 2008; 88: 582S-6S.

36. Looker AC, Pfeiffer CM, Lacher DA, et al. Serum 25-hydroxyvitamin D status of the US population: 1988-1994 compared with 2000-2004. *American Journal of Clinical Nutrition* 2008; 88: 1519-27.

37. Webb AR, Engelsen O. Calculated ultraviolet exposure levels for a healthy vitamin D status. *Photochemistry and Photobiology* 2006; 82: 1697-703

38. Yetley EA. Assessing the vitamin D status of the US population. *American Journal of Clinical Nutrition* 2008; 88: 558S– 64S.

39. Looker AC, Dawson-Hughes B, Calvo MS, et al. Serum 25-hydroxyvitamin D status of adolescents and adults in two seasonal subpopulations from NHANES III. *Bone* 2002; 30: 771-7.

40. Lips P, Bouillon R, van Schoor NM, et al. Reducing fracture risk with calcium and vitamin D. Clinical Endocrinology (Oxford) 2009 Sep 10. [Epub ahead of print]

41. IARC Working Group on Vitamin D. Vitamin D and Cancer (IARC Working Group Reports; 5) Lyon: International Agency for Research on Cancer, 2008. Available at: http://www.iarc.fr/en/publications/pdfs-online/wrk/wrk5/Report_VitD.pdf. Accessed November 2, 2009.

Appendix

Table A
Unweighted sample sizes of participants with valid vitamin D concentrations, by age group and sex, household population aged 6 to 79 years, Canada, 2007 to 2009

Age group	Male	Female
Total 6 to 79 years	**2,566**	**2,740**
6 to 11 years	453	450
12 to 19 years	489	456
20 to 39 years	514	650
40 to 59 years	576	642
60 to 79 years	534	542

Source: 2007 to 2009 Canadian Health Measures Survey.

Table B
Selected characteristics of sample (weighted), by sex and age group, household population aged 6 to 79 years, Canada, 2007 to 2009

	Total 6 to 79			6 to 11 years			12 to 19 years			20 to 39 years			40 to 59 years			60 to 79 years		
		95% confidence interval			95% confidence interval			95% confidence interval			95% confidence interval			95% confidence interval			95% confidence interval	
Characteristic	%	from	to	%	from	to	%	from	to	%	from	to	%	from	to	%	from	to
Male																		
Racial background																		
White	80.3	70.4	87.5	75.6	59.7	86.7	78.4	66.3	87.0	76.6	66.7	84.2	80.9	68.6	89.2	89.7	82.0	94.3
Other	19.7E	12.5	29.6	24.4E	13.3	40.3	21.6E	13.0	33.7	23.4E	15.8	33.3	19.1E	10.8	31.4	10.3E	5.7	18.0
Month of collection																		
November to March	37.3E	17.3	62.8	F	...	...	43.3E	20.5	69.4	41.7E	21.4	65.3	F	...	...	F	...	...
April to October	62.7E	37.2	82.7	64.9E	37.8	85.0	56.7E	30.6	79.5	58.3E	34.7	78.6	67.4E	38.9	87.1	64.6E	38.2	84.4
Milk consumption																		
Less than once a day	41.3	38.8	43.9	8.4	6.2	11.3	28.7	23.1	35.0	40.2	34.9	45.7	49.3	43.9	54.7	49.2	43.0	55.3
Once a day	32.8	30.6	35.0	24.0	19.5	29.1	20.4	16.1	25.6	34.9	31.4	38.5	35.5	30.9	40.4	35.1	28.7	42.0
More than once a day	25.9	23.2	28.8	67.6	61.3	73.3	50.9	44.5	57.3	25.0	18.8	32.3	15.2	11.4	20.0	15.8	11.4	21.3
Female																		
Racial background																		
White	82.4	74.3	88.4	76.2	61.6	86.4	75.4	66.6	82.4	77.5	69.0	84.2	86.3	77.1	92.2	89.7	83.6	93.7
Other	17.6E	11.6	25.7	23.8E	13.6	38.4	24.6	17.6	33.4	22.5E	15.8	31.0	13.7E	7.8	22.9	10.3E	6.3	16.4
Month of collection																		
November to March	40.0E	19.9	64.3	F	...	...	F	...	...	47.6E	23.4	72.9	39.1E	19.2	63.4	F	...	...
April to October	60.0E	35.7	80.1	61.5E	34.0	83.2	63.5E	36.3	84.2	52.4E	27.1	76.6	60.9E	36.6	80.8	68.4	45.2	85.0
Milk consumption																		
Less than once a day	40.0	37.5	42.7	9.2E	6.3	13.4	31.3	25.9	37.3	39.1	34.3	44.1	47.9	44.2	51.6	42.6	37.1	48.2
Once a day	33.6	31.9	35.4	27.7	22.9	33.1	28.5	24.0	33.5	34.6	30.3	39.1	34.3	29.8	39.1	35.9	30.7	41.4
More than once a day	26.3	23.4	29.4	63.0	57.6	68.1	40.2	34.5	46.2	26.3	21.7	31.6	17.8	13.5	23.2	21.6	18.5	25.0

E interpret with caution (high sampling variability; coefficient of variation 16.6% to 33.3%)
F estimate not provided because of extreme sampling variability or small sample size
... not applicable
Source: 2007 to 2009 Canadian Health Measures Survey.

ELECTRONIC PUBLICATIONS AVAILABLE AT

www.statcan.ca

The effect of supplement use on vitamin C intake

by Didier Garriguet

Abstract
According to results from the 2004 Canadian Community Health Survey–Nutrition, Canadians get an average of 132 milligrams of vitamin C a day from food. About one adult in five has inadequate dietary intake of vitamin C. A third of Canadians take vitamin C supplements, which add 100 milligrams to total average daily intake. Supplement use lowers the overall percentage of adults with inadequate intake by 5 percentage points to 17%. Smokers, people who eat fruit and vegetables infrequently, and members of households with low income and low educational attainment tend to have relatively low vitamin C intake.

Keywords
ascorbic acid, diet, fruit, nutrition, vegetables

Author
Didier Garriguet (1-613-951-7187; Didier.Garriguet@statcan.gc.ca) is with the Health Analysis Division at Statistics Canada, Ottawa, Ontario, K1A 0T6.

Vitamin C is a powerful antioxidant that contributes to the formation and health of blood vessels, tendons, ligaments, bones, teeth and gums.[1] It helps the body absorb iron and recover from wounds and burns. Serious deficiency can lead to scurvy, which is now a rare condition in the Western world.

Fruit and vegetables are the main dietary sources of vitamin C, but it can also be taken as a supplement. In fact, vitamin C is taken more often than other supplements.[2]

This article provides an overview of vitamin C intake among Canadians and how levels are affected by supplement use.

According to the Institute of Medicine, the estimated average requirements for vitamin C range from 13 milligrams for toddlers aged 1 to 3 to 75 milligrams for adult men and 60 milligrams for adult women (Table 1). Because smokers have below-normal antioxidant levels and their bodies use vitamin C more quickly, their requirements are 35 milligrams higher than those of non-smokers. The recommended intake level maintains a near-maximum concentration of neutrophil (a type of leukocyte) in the blood, and minimizes the loss of vitamin C in the urine. The Institute of Medicine recommendations are not nearly as high as those of some other sources, which advocate intake as high as 400 or even 2,000 milligrams per day.[3] This analysis, however, examines vitamin C intake in relation to the Institute of Medicine recommendations, which were set jointly by Canada and the United States and are used by Health Canada.[4]

Table 1
Estimated average daily vitamin C requirements, by age group and sex

	Milligrams per day†	
Age group	Male	Female
1 to 3	13	13
4 to 8	22	22
9 to 13	39	39
14 to 18	63	56
19 or older	75	60

† 35 milligrams higher for smokers.
Note: Excludes pregnant and breastfeeding women.
Source: Reference 1.

Vitamin C from food

Three sources—fruit juice, fruit drinks and citrus fruits—accounted for 50% of the vitamin C that Canadians got from food in 2004; fruit juice alone made up 32% (Table 2).

Regardless of their age, sex, household income, level of education or province of residence, Canadians' average dietary intake of vitamin C was well above the Institute of Medicine recommendations. In 2004, Canadians averaged 132 milligrams of vitamin C a day from food alone (Table 3). Quebec residents, whose fruit and vegetable consumption is highest,[5] had the highest provincial dietary intake of vitamin C: a daily average of 144 milligrams.

High averages, however, hide the substantial percentages of various groups whose vitamin C intake from food left them below the recommended levels. When smokers' greater vitamin C requirements are factored in, 21% to 35% of men aged 19 or older had inadequate dietary intake; among women, the percentages ranged from 17% to 26%. Fewer than 10% of children and teens had inadequate dietary intake of vitamin C (Table 3).

Not surprisingly, a high percentage—46%—of people who reported that they ate fruit and vegetables infrequently (no more than three times a day) had inadequate dietary intake of vitamin C. The percentages were also significantly high among people in the lowest income (25%) and education (35%) households and among those who were inactive during their leisure time (30%). Partly because smokers' recommended intake is greater, over half (52%) of them had inadequate vitamin C intake from food. In fact, despite their greater requirements, smokers' average dietary intake of vitamin C was lower than that of non-smokers.

The people who took supplements containing vitamin C also tended to get more vitamin C from their diet than those who did not: a daily average of 142 milligrams, compared with 126 milligrams. Thus, based on diet alone, those who did not take supplements were more likely than supplement consumers to have inadequate vitamin C intake (25% versus 17%) (data not shown).

Table 2
Main dietary sources of vitamin C, household population aged 1 or older, Canada excluding territories, 2004

		Percentage of dietary vitamin C intake		
			95% confidence interval	
Rank	Food	%	from	to
1	Fruit juice	31.8	30.8	32.9
2	Fruit drinks	10.5	9.9	11.2
3	Citrus fruits (orange, grapefruit, lemon, etc.)	7.0	6.6	7.4
4	Tomatoes	5.8	5.5	6.0
5	Broccoli	5.1	4.7	5.6
6	Red and green peppers	4.8	4.5	5.2
7	Potatoes	3.5	3.2	3.7
8	Melons (cantaloupe, honeydew melon, watermelon, etc.)	2.8	2.3	3.4
9	Strawberries	2.6	2.3	2.8
10	Lettuce and green leafy vegetables (spinach, mustard greens, etc.)	1.9	1.7	2.1
11	Other fruits (blueberries, dates, kiwis, fruit salad, dried fruit, etc.)	1.9	1.6	2.1
12	Other vegetables (cucumber, Brussels sprouts, beets, turnip, etc.)	1.8	1.6	2.0
13	Bananas	1.8	1.7	1.9
14	Tomato and vegetable juice	1.7	1.4	2.0
15	Potato chips	1.7	1.5	1.8

Source: 2004 Canadian Community Health Survey—Nutrition

Supplements

Just under a third (31%) of Canadians took supplements containing vitamin C in 2004 (Table 3). In general, the groups that had higher average dietary intake of vitamin C were also the most likely to take supplements—36% of people who ate fruit and vegetables more than six times a day did so, as did 38% of those with the highest household incomes, 34% of those who belonged to a household with at least one postsecondary graduate, 35% who were physically active, and 32% of non-smokers.

Quebec differed from the other provinces in that it had the highest dietary intake of vitamin C, but the lowest percentage of consumers of vitamin C supplements (Table 3).

Impact on intake

For the population as a whole, supplements provided 43% of vitamin C intake, twice as much as the main dietary source, fruit juice. And for the minority of the population (31%) who were supplement consumers, the percentage was nearly 70%.

Supplement consumption raised Canadians' overall vitamin C intake by 100 milligrams to an average of 233 milligrams a day. Among supplement consumers, total daily intake averaged 463 milligrams.

Despite the substantial increase in average milligrams a day, the overall effect of supplements was relatively modest, reducing the percentage of the total population with inadequate vitamin C intake by just 5 percentage points. This is because more than two-thirds of Canadians did not take supplements, and those who did take them were likely to already have adequate dietary intake of vitamin C. Nonetheless, except among the age groups from 1 to 30, the reductions in inadequate vitamin C intake due to supplement consumption were significant (Table 3). The impact of supplement consumption was greater for smokers and for people who eat fruit and vegetables infrequently: almost a 10-percentage-point reduction.

As might be expected, few supplement consumers had inadequate vitamin C

Table 3
Vitamin C intake by supplement consumption and selected characteristics, household population aged 1 or older, Canada excluding territories, 2004

	Dietary vitamin C intake				Percentage taking supplement containing vitamin C		Total vitamin C intake (dietary and supplements)			
Characteristics	Average (milligrams)	Standard error	Inadequate† (%)	Standard error	%	Standard error	Average (milligrams)	Standard error	Inadequate† (%)	Standard error
Total	**132**	**1**	**22.5**	**0.5**	**31.4**	**0.5**	**233**	**3**	**17.7**	**0.5**
Age group and sex										
1 to 3	135	3	<3	...	36.2	1.6	169	5	<3	...
4 to 8	144§	3	<3	...	43.7§	1.4	189§	4	<3	...
9 to 13										
Boys	156	5	<3	...	31.9§	1.8	218§	8	<3	...
Girls	147	4	<3	...	30.4§	1.8	203	7	<3	...
14 to 18										
Boys	163††	5	9.6§	1.8	20.9§	1.4	221	8	8.1§E	1.7
Girls	147	4	8.1§	1.6	24.2§	1.4	214	7	7.3§E	1.5
19 to 30										
Men	158††	7	21.2§	3.3	25.1	1.7	242††	10	16.9§E	3.1
Women	132§	5	17.2§	3.0	29.2§	1.7	215	9	16.1§	2.5
31 to 50										
Men	128§ ††	4	31.8§	2.7	24.7††	1.5	214††	9	26.1§††	2.5
Women	117§	4	26.2§	2.1	34.7 §	1.6	247§	12	18.2	1.9
51 to 70										
Men	130	5	30.1††	2.3	31.9§††	1.4	261§	12	23.7††	1.9
Women	121	3	19.7§	1.8	37.4	1.5	271	11	15.1	1.6
71 or more										
Men	111§	4	34.6††	2.8	31.6††	2.0	237	12	28.8††	2.4
Women	107§	3	22.8	1.9	38.1	1.6	254	11	17.1	1.7
Times per day fruit /vegetables consumed										
3 or less	87*	2	46.2*	1.4	26.6*	0.9	167*	5	36.7*	1.2
3.01 to 6‡	136	2	15.7	0.7	32.6	0.7	240	4	11.8	0.6
More than 6	194*	4	4.8*	0.5	36.3*	1.1	320*	9	3.7*	0.5
Household income quintile										
First (lowest)	125*	3	25.0*	1.3	25.5*	1.1	201*	7	21.2*	1.2
Second	124*	3	23.4	1.4	28.9*	1.1	209*	6	18.5*	1.2
Third	133*	3	21.7	1.3	32.1*	1.3	236*	8	17.5	1.2
Fourth	136	3	21.3	1.1	35.0	1.1	259	9	15.6	1.1
Fifth (highest)‡	143	3	19.8	1.2	37.6	1.3	265	8	14.5	1.1
Highest level of household education										
Less than secondary	102*	2	35.2*	1.8	24.1*	1.2	185*	8	29.0*	1.6
Secondary graduation	117*	4	27.9*	1.8	25.8*	1.2	196*	7	23.5*	1.7
Some postsecondary	125*	4	24.3*	1.9	29.7*	1.6	214*	9	19.0*	1.9
Postsecondary graduation‡	139	2	19.1	0.6	33.7	0.6	247	4	14.7	0.6
Smoker (aged 12 or older)										
No‡	136	2	14.6	0.7	32.0	0.6	253	4	11.2	0.6
Yes	110*	3	52.2*	2.5	24.7*	1.1	195*	7	42.9*	2.1
Level of physical activity (aged 12 or older)										
Active	152*	3	14.9*	1.3	34.5*	1.2	284*	9	12.5*	1.2
Moderately active	139*	3	16.4*	1.6	31.9*	1.1	257*	8	11.7*	1.5
Inactive‡	118	2	29.9	1.1	28.0	0.8	214	5	24.1	1.0
Province										
Newfoundland and Labrador	120*	4	30.0*	2.2	20.5*	1.5	178*	10	25.9*	2.0
Prince Edward Island	107*	4	29.0*	2.2	28.1	1.9	198*	11	23.7*	2.0
Nova Scotia	109*	3	27.2*	2.2	28.1	2.0	191*	10	21.1	2.1
New Brunswick	113*	5	31.0*	2.7	24.7*	1.7	188*	11	24.8*	2.6
Quebec	144*	3	18.3*	1.2	21.6*	1.1	202*	6	15.6*	1.1
Ontario	131	2	22.3	1.0	33.8*	0.8	241*	6	17.7	0.9
Manitoba	118*	3	27.8*	1.6	32.9	1.2	224	9	20.5*	1.4
Saskatchewan	127	7	24.3	2.2	39.3*	1.9	282*	18	16.8	1.9
Alberta	125	4	25.2	1.7	39.0*	1.4	247	11	17.3	1.5
British Columbia	134	3	21.0	1.5	37.5*	1.4	267*	10	15.0*	1.3

† below estimated average requirement
‡ reference category; for provinces, reference category is Total
* significantly different from estimate for reference category (p<0.05)
§ significantly different from estimate for preceding age group of same sex (p<0.05)
†† significantly different from estimate for females of same age (p<0.05)
E use with caution (coefficient of variation 16.6% to 33.3%)
<3 coefficient of variation more than 33.3%, but limits of confidence interval included within interval (0.0, 3.0)
... not applicable
Notes: All averages that include supplement intake are significantly different from those for dietary intake only. Percentages with inadequate dietary and total intake are not significantly different for ages 1 to 13 and for women aged 14 to 30; in all other cases, differences are significant.
Source: 2004 Canadian Community Health Survey—Nutrition.

The data

The 2004 Canadian Community Health Survey—Nutrition collected information about the food and nutrient intake of the household population at the national and provincial levels. Information about the use of vitamin and mineral supplements was also collected. The survey excluded members of the regular Canadian Forces; residents of the three territories, Indian reserves, institutions and some remote areas; and all residents (military and civilian) of Canadian Forces bases. Detailed descriptions of the survey design, sample and interview procedures are available in a published report.[6]

A total of 35,107 people responded to an initial 24-hour dietary recall, and a subsample of 10,786 took part in a second dietary recall three to ten days later. The response rates were 76.5% and 72.8%, respectively.

Canadians' intake of food and nutrients was estimated with a 24-hour dietary recall. To help respondents remember what and how much they ate and drank the previous day, interviewers used the automated multiple-pass method (AMPM),[7,8] which consists of five steps:

- a quick list (respondents reported all foods and beverages consumed);
- questions about specific food categories and frequently forgotten foods;
- questions about the time and occasion of consumption;
- questions seeking more detail about the foods and beverages and the quantities consumed; and
- a final review.

Questions about vitamin and mineral supplements pertained to consumption frequency in the last 30 days. Respondents were asked the number of days that they had taken supplements and the average quantity consumed. More information about these derived variables is available in the survey documentation.[9]

The nutrient content of the food that respondents reported was derived from Health Canada's Canadian Nutrient File (Supplement 2001b).[10] The composition of supplements was taken from the Drug Product Database (DPD)[11] for September 2003 in the case of drug identification numbers listed at the time of collection, and for spring 2005 if the drug identification numbers were missing or incorrect.

This study examined data for 34,386 people aged 1 or older, 10,591 of whom responded to the second 24-hour dietary recall. Children younger than 1 year (288), pregnant (175) and nursing (92) women, breastfed children (104), and respondents with no dietary intake (16) or invalid dietary intake (45) were excluded from the analysis.

SIDE (Software for Intake Distribution Estimation)[12,13] was used to determine the usual distribution, and in particular, the percentage of the population with inadequate vitamin C intake (below the estimated average requirement). To compensate for within-individual intake variability, the daily distribution of the intake of a nutrient was adjusted with the second dietary recall. Because the vitamin C requirements of children, teens, adults, males, females and smokers differ, intake is expressed in relation to the requirements of the group to which the respondent belongs. Hence, the percentage of the population with inadequate vitamin C intake is the proportion for which the ratio is less than 1.

The distribution of vitamin C intake that includes both dietary sources and supplements was determined by combining estimated intake from food alone for the respondents who do not take supplements and the total estimate (intake from food plus average daily intake from supplements) for respondents who take supplements. Details about the methods are available in an accompanying article.[2]

To account for the complex design of the Canadian Community Health Survey, the bootstrap method[14-16] was used to estimate standard errors, coefficients of variation and confidence intervals. The statistical significance level was set at 0.05.

Fruit and vegetable consumption frequency is not based on the 24-hour dietary recall; it refers to the reported number of times per day that respondents ate fruit and vegetables, not the quantities that they consumed.

Household income is income from all sources in the previous 12 months. The ratio of total household income to the low-income cut-off for the relevant household size and community size was calculated for each household. The ratios were adjusted by dividing them by the highest ratio for all Canadian Community Health Survey respondents. The adjusted ratios were grouped into quintiles, the first quintile containing the lowest incomes, and the fifth, the highest.

Highest level of household education refers to the highest level of educational attainment of at least one household member.

Smoker refers to people who reported that they smoked daily or occasionally. *Level of physical activity* (inactive, moderately active, active) is based on average daily energy expenditure derived from the reported frequency and duration of all leisure-time physical activity in the three months before the interview and each activity's metabolic energy expenditure (non-leisure activity is not included). These two variables are not available for respondents younger than 12.

intake—2% overall, 5% among those who ate fruit and vegetables no more than three times a day, and 7% among smokers (Table 4). However, if the people who took supplements had not done so, based on their diet alone the percentages with inadequate intake would have been 17% overall, and 40% for smokers and infrequent consumers of fruit and vegetables.

Conclusion

More than 20% of Canadians do not get sufficient vitamin C from their diet. Roughly a third of the population takes vitamin C in the form of supplements. While supplements virtually eliminate inadequate intake among those who take them, the impact on the population as a whole is minimal. ■

Table 4
Percentage with inadequate vitamin C intake, by supplement consumption and selected characteristics, household population aged 1 or older who take vitamin C supplements, Canada excluding territories, 2004

Characteristics	Percentage with inadequate† vitamin C intake based on: Diet %	Diet Standard error	Diet and supplements %	Diet and supplements Standard error
Total	**17.3**	**0.9**	**1.7**	**0.2**
Age group and sex				
1 to 3	<3	...	<3	...
4 to 8	<3	...	<3	...
9 to 13				
Boys	<3	...	<3	...
Girls	<3	...	<3	...
14 to 18				
Boys	F	...	<3	...
Girls	F	...	2.1^E	0.6
19 to 30				
Men	19.0^E	5.4	3.7^E	1.2
Women	F	...	2.2^E	0.7
31 to 50				
Men	26.8^E	5.3	3.0^E	1.0
Women	25.4	3.5	2.3^E	0.6
51 to 70				
Men	23.6^E	4.6	2.0^E	0.6
Women	12.4^E	2.4	1.3^E	0.4
71 or more				
Men	23.7^E	4.8	F	...
Women	15.8	2.2	<3	...
Times per day fruit/vegetables consumed				
3 or less	40.1	3.0	4.6	0.7
3.01 to 6	13.5	1.1	1.2^E	0.2
More than 6	3.4^E	0.8	<3	0.1
Household income quintile				
First (lowest)	17.4	2.1	2.0^E	0.5
Second	18.3	2.3	1.9^E	0.4
Third	14.6	1.9	1.3^E	0.3
Fourth	18.0	1.8	1.3^E	0.3
Fifth (highest)	16.4	1.9	2.1^E	0.6
Highest level of household education				
Less than secondary	29.3	3.1	2.5^E	0.7
Secondary graduation	20.1	2.5	2.4^E	0.7
Some postsecondary	18.0^E	3.0	1.9^E	0.5
Postsecondary graduation	15.0	1.0	1.5	0.2
Smoker (aged 12 or older)				
No	11.8	1.2	1.0^E	0.2
Yes	44.2	6.3	7.3^E	1.2
Level of physical activity (aged 12 or older)				
Active	8.4^E	1.7	1.0^E	0.3
Moderately active	16.4	2.5	1.8^E	0.4
Inactive	23.8	2.0	3.2	0.5
Province				
Newfoundland and Labrador	19.8^E	4.1	F	...
Prince Edward Island	19.1^E	4.4	<3	...
Nova Scotia	23.8^E	4.1	<3	...
New Brunswick	27.0^E	5.1	F	...
Quebec	13.7	2.2	1.7^E	0.5
Ontario	16.1	1.6	1.5	0.2
Manitoba	24.8	3.0	2.2^E	0.5
Saskatchewan	19.9^E	3.3	2.0^E	0.6
Alberta	21.6	2.7	2.0^E	0.6
British Columbia	17.2	2.2	1.5^E	0.4

† below estimated average requirement
E use with caution (coefficient of variation 16.6% to 33.3%)
F too unreliable to be published (coefficient of variation more than 33.3%)
<3 coefficient of variation more than 33.3%, but limits of confidence interval included within interval (0.0, 3.0)
... not applicable
Note: Estimates of percentage with inadequate dietary and total intake are not significantly different for ages 1 to 18 and for women aged 19 to 30; in all other cases, differences are significant.
Source: 2004 Canadian Community Health Survey—Nutrition.

References

1. Institute of Medicine. *Dietary Reference Intake for Vitamin C, Vitamin E, Selenium and Carotenoids*. Washington DC: National Academy Press, 2000.

2. Garriguet D. Combining nutrient intake from food and from vitamin and mineral supplements. *Health Reports* (Statistics Canada, Catalogue 82-003) 2010; 21 (forthcoming).

3. Higdon J, Linus Pauling Institute Micronutrient Information Center, vitamin C, 2008. Available at : http://lpi.oregonstate.edu/infocenter/vitamins/vitaminC. Accessed May 7, 2009.

4. Health Canada. *Canadian Community Health Survey, Cycle 2.2, Nutrition (2004) – A Guide to Accessing and Interpreting the Data* (Catalogue H164-20/2006E) Ottawa: Health Canada, 2006.

5. Garriguet D. *Overview of Canadians' Eating Habits. Nutrition: Findings from the Canadian Community Health Survey (*Statistics Canada, 82-620-MIE2006002) 2006. Available at: http://www.statcan.gc.ca/pub/82-620-m/82-620-m2006002-eng.htm.

6. Béland Y, Dale V, Dufour J, Hamel M. The Canadian Community Health Survey: Building on the success from the past. *Proceedings of the American Statistical Association Joint Statistical Meeting, Section on Survey Research Methods, August 2005.* Minneapolis: American Statistical Association, 2005.

7. Moshfegh AJ, Borrud L,Perloff B, et al. Improved method for the 24-hour dietary recall for use in national surveys . *The FASEB Journal: Official Publication of The Federation of American Societies for Experimental Biology* 1999; 13: A603 (Abstract).

8. Moshfegh AJ, Raper N, Ingwersen L, et al. An improved approach to 24-hour dietary recall methodology. *Annals of Nutrition and Metabolism* 2001; 45(suppl): 156 (abstract).

9. Statistics Canada. *Canadian Community Health Survey (CCHS): Cycle 2.2, Nutrition: General Health Component Including Vitamin and Mineral Supplements, and 24-hour Dietary Recall Component,* Derived variables documentation, 2008.

10. Health Canada. 2005. *Canadian Nutrient File, 2005 Version*. Available at: http://www.hc-sc.gc.ca/fnan/nutrition/fiche-nutri-data/index_e.html.

11. Health Canada. *Drug Product Database.* Available at: http://www.hc-sc.gc.ca/dhp-mps/prodpharma/databasdon/index-eng.php. Accessed January 26, 2009.

12. Nusser SM, Carriquiry AL, Dodd KW, et al. A semiparametric transformation approach to estimating usual daily intake distributions. *Journal of the American Statistical Association* 1996; 91(436): 1440-9.

13. Novenario MJ. *User's Guide to SIDE, A, August 1996*. Available at: http://www.card.iastate.edu/publications/DBS/PDFFiles/96tr32.pdf. Accessed September 12, 2005.

14. Rao JNK, Wu CFJ, Yue K. Some recent work on resampling methods for complex surveys. *Survey Methodology* (Statistics Canada, Catalogue 12-001) 1992; 18(2): 209-17.

15. Rust KF, Rao JNK. Variance estimation for complex surveys using replication techniques. *Statistical Methods in Medical Research* 1996; 5: 281-310.

16. Yeo D, Mantel H, et T.P. Liu TP. Bootstrap Variance Estimation for the National Population Health Survey. *Proceedings of the Annual Meeting of the American Statistical Association: Survey Research Methods Section*. American Statistical Association: Baltimore, August 1999.

Quality control and data reduction procedures for accelerometry-derived measures of physical activity

by Rachel Colley, Sarah Connor Gorber and Mark S. Tremblay

Abstract

Background
This article describes four key quality control and data reduction issues that researchers should consider when using accelerometry to measure physical activity: monitor reliability, spurious data, monitor wear time, and number of valid days required for analysis.

Data source and methods
Exploratory analyses were conducted on an unweighted subsample (n=987) of the accelerometry data from the Canadian Health Measures Survey. Participants were asked to wear an accelerometer for 7 consecutive days. Calibration, reliability, biological plausibility and compliance issues were explored using descriptive statistics.

Results
Ongoing calibration is an effective method for identifying malfunctioning accelerometers. The percentage of files deemed viable for analysis depends on participant compliance, the allowable interruption period chosen and the minimum wear-time-per-day criterion. A 60-minute allowable interruption period and 10-hours-per-day wear time criteria resulted in 95% of the subsample having at least 1 valid day, and 84% having at least 4 valid days.

Interpretation
Before the derivation of physical activity outcomes, accelerometry data should undergo standardized quality control and data reduction procedures to prevent mis-representation of the results. Incomplete accelerometry data should be handled carefully, and strategies to improve compliance in the field are warranted.

Keywords
ambulation, data quality, error, health measurement, quality control

Authors
Rachel Colley (1-613-737-7600x4118; Rachel.Colley@statcan.gc.ca) and Mark Tremblay are with the Healthy Active Living and Obesity Research Group, Children's Hospital of Eastern Ontario Research Institute, Ottawa, Ontario; Rachel Colley and Sarah Connor Gorber are with the Health Analysis Division at Statistics Canada, Ottawa, Ontario.

Considerable evidence indicates that sedentary behaviour is a major risk factor for obesity and several other chronic conditions. Population-level surveillance of physical activity has historically relied on questionnaires,[1] a method of assessing lifestyle behaviours that can be affected by measurement bias.[2-4] Objective measurement devices, notably accelerometers, have the potential to overcome many problems associated with self-reports, and they provide robust and detailed information about physical activity.[5,6] However, because small inconsistencies can have a substantial impact on outcome variables,[6-8] stringent quality control and data reduction procedures are necessary.

This article considers four critical quality control and data reduction procedures that should be addressed before physical activity information is derived from accelerometry data. The results are based on early experience gained in cycle 1 of the Canadian Health Measures Survey, a comprehensive direct health measures survey of a national sample of Canadians, which used accelerometry to collect data on physical activity.

Intra- and inter-monitor variability[9,10] and the possibility that accelerometers will malfunction warrant the development and maintenance of rigorous calibration procedures. In 2006, Esliger and Tremblay[11] reported the results of a technical reliability assessment of three accelerometer models: Actical (Mini Mitter - Respironics, Oregon, USA), Actigraph model 7164 (Actigraph, Fort Walton Beach, FL), and RT3 (Stayhealthy, Inc., Monrovia, CA). The Actical had the best intra- and inter-monitor reliability, but discrepancies were observed, which confirms the need for ongoing calibration checks.

Accelerometers are designed to record counts within a defined range of movement that is plausible for humans.

Even so, monitor malfunctions and random spurious data points do occur during field measurements and must be managed. The threshold for defining spurious data must be low enough to exclude incorrect high values (for example, monitor aberrations), but high enough to include legitimate values that reflect vigorous activity. The maximum saturation value for the Actigraph is 32,767 counts per minute (cpm), and the recommended threshold for biological plausibility is less than 15,000 cpm.[6] According to the manufacturer, the maximum saturation value for the Actical is 28,404 cpm, and to the authors' knowledge, a threshold for biological plausibility has yet to be suggested.

Minimum daily wear time is another critical data reduction issue, because it affects the proportion of files that can be included in analyses. The minimum must be high enough to eliminate days when the monitor was clearly not worn long enough to accurately depict physical activity, but low enough to prevent too many days from being eliminated, which would bias the sample and reduce sample size and statistical power. Several studies have used 10 hours per day as a minimum requirement,[7] an approach that appears to be common in the broader research community.[6,8,12-14]

Calculation of wear time is complicated by the fact that inactivity is part of normal behaviour. Instead of simply deleting zero count values from the dataset, it is necessary to apply a decision rule that allows for a certain number and pattern of consecutive zeros throughout the day in order to capture and assess true inactivity. This is referred to as the "allowable interruption period" and ranges from 10 to 60 minutes.[7]

Population-level surveillance studies typically ask participants to wear an accelerometer for 7 full days, but because of non-compliance, the number of valid days varies among participants. To achieve some consistency, researchers have used various minimums for the number of valid days recommended for inclusion in analyses, ranging from fewer than 3[15-17] up to 7 full days.[6,18] No consensus has been reached on the minimum number of days required to gain an accurate picture of an individual's physical activity.

The information in this article will contribute to the development of quality control and data reduction procedures for researchers measuring physical activity with accelerometry, particularly those wishing to work with or compare their results to Canadian Health Measures Survey data. The hypothesis is that variations in quality control and data reduction procedures can have a substantial impact on which files are deemed acceptable for inclusion in analyses. This, in turn, affects physical activity outcomes.

Methods

Data source

From March 2007 through February 2009, cycle 1 of the Canadian Health Measures Survey collected data from a representative sample of Canadians aged 6 to 79 years. The survey was conducted by Statistics Canada in partnership with Health Canada and the Public Agency of Canada. Details on the background and rationale are available elsewhere.[19]

The survey involved an interview in the participant's household and a visit to a mobile examination centre where he or she underwent a series of physical measurements. Afterwards, ambulatory participants aged 6 years or older were asked to wear an Actical accelerometer over their right hip on an elasticized belt for 7 days. They were to wear the device during their waking hours and take it off only for bathing and swimming. The monitors were returned to Statistics Canada, where the data were downloaded and the monitor was checked to determine if it was still within the manufacturer's calibration specifications. An Actical calibrator was custom built for the Canadian Health Measures Survey.

The estimated sample for cycle 1 was about 5,000 individuals. An unweighted subsample (1,033) from the first four sites was used in the current study of accelerometer performance. As a result of monitor malfunctions, 46 files were unsuitable for analysis, reducing the sample to 987.

The measurement device

The Actical (dimensions: 2.8 x 2.7 x 1.0 centimetres; weight: 17 grams) is designed to measure and record acceleration in all directions, providing an indication of the intensity of physical activity. The digitized values are summed over a user-specified interval of 1 minute, resulting in a count value per minute (cpm). Accelerometer signals were also converted into steps accumulated per minute.[20]

Intra- and inter-monitor reliability

The Canadian Health Measures Survey calibration system simulates a dynamic motion that elicits a known value of 1,950 cpm from the Actical. Between each field measurement, the monitors were re-tested to ensure they recorded values within ±10% of 1,950 cpm. Those that failed the calibration procedures three times were returned to the manufacturer for repair or replacement.

Although 16 monitors can be placed on the calibration wheel at once, study flow meant that the calibration sometimes had to be performed with fewer than 16. Four different conditions were tested to compare the results of conducting the calibration with 16, 12, 8 and 4 monitors. The monitors were evenly distributed for each measurement, and each monitor underwent three testing cycles for each condition.

Identifying and managing spurious data

To determine a spurious data threshold, additional analyses were completed on previously published data that described the accuracy of the step-count function in the Actical.[20] The data were from a convenience sample of 38 participants aged 9 to 59 years with body mass indices from 19.9 to 36.6 kg/m^2. They were asked to walk or jog at three different speeds on a treadmill. The highest treadmill speed used in this study was 8 km/h, a speed representative of slow jogging and certainly not the fastest that could be obtained within a population sample. To account for this, the present study used linear regression to extrapolate the accelerometer counts to a high-level running speed (approximately 14 to 15 km/h) to determine a plausible upper threshold for identifying spurious data.

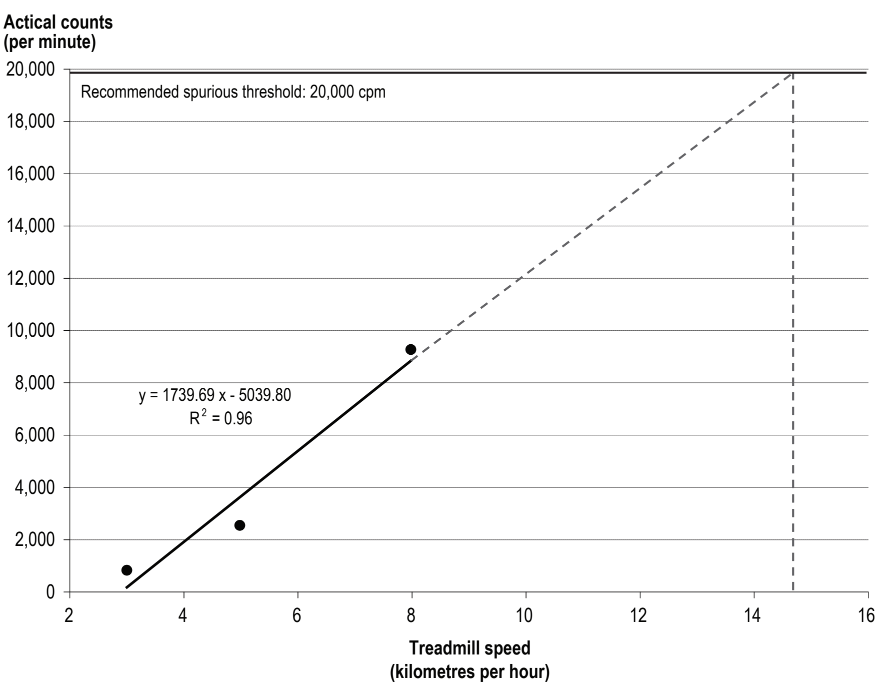
Defining wear time

Previously reported data reduction procedures were used in the present study. Troiano et al.[14] defined a valid day as 10 or more hours of monitor wear. Wear time was defined by subtracting nonwear time from 24 hours. Nonwear was defined as a period of a least 60 consecutive minutes of zero counts, with allowance for 1 to 2 minutes of counts between 0 and 100. A range of interruption periods (10, 20, 30, 60 minutes) was compared to demonstrate the effect of altering this value on the wear time obtained and the percentage of files deemed viable for analysis. A range of wear time criteria (6, 8, 10, 12, 14 hours per day) was also compared to demonstrate the effect that altering this value would have on the percentage of files that would be accepted for analysis.

Defining minimum number of days required for analysis

The data reduction procedures used by Troiano et al.[14] were applied to the Canadian Health Measures Survey subsample to determine what proportion of participants would have data available for further physical activity analyses, specifically, the percentages of participants with 1 valid day and 4 or more valid days, as this is consistent with how data have been published from the 2003-2004 National Health and Nutritional Examination Survey.[14]

Figure 1
Extrapolation of a linear regression relationship created between treadmill speed and Actical accelerometer counts



Source: 2007 to 2009 Canadian Health Measures Survey, first four sites.

Results

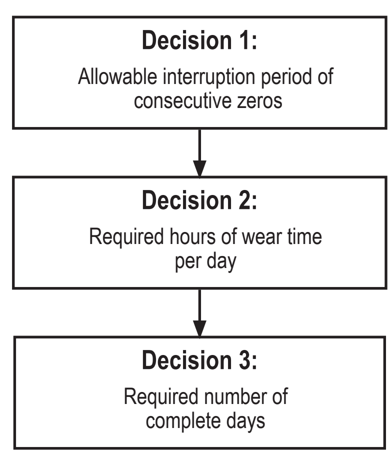
Intra- and inter-monitor reliability

As long as the monitors were evenly distributed, no differences in calibration results emerged between using 16, 12, 8 or 4 monitors on the calibration wheel. Cycle 1 of the calibration study found that 6 of the 16 monitors were outside the acceptable limits of ±10%. Two more cycles were completed (maximum number of cycles allowed was 3), which resulted in 4 of the failed monitors passing and 2 being identified as malfunctioning and requiring repair.

Spurious data threshold

A review of the literature on the Actical revealed that no spurious data threshold has been suggested. Initial quality control procedures used 15,000 cpm, but this proved to be too low, given that it can be obtained by some individuals jogging at a moderate pace. According to the extrapolation procedure, a count value of 15,000 cpm corresponded to a running speed of approximately 12 km/h. A more appropriate spurious data threshold that would capture high-speed running, yet still exclude biologically implausible

Figure 2
Sequence of decisions for determining viability of accelerometry data for further analysis



movement, was needed. The count value attained when a linear regression line was extrapolated to a high-level running speed (14 to 16 km/h) was approximately 20,000 cpm (Figure 1).

Wear time

Defining acceptable wear time involves a series of decisions about allowable interruption periods and the number of hours needed for a valid day (Figure 2). The goal is to preserve both true activity and inactivity.

Lengthening the allowable interruption period increases average wear time (Table 1). Similarly, shortening the allowable interruption period decreases the number of files attaining the 10-hours-per-day wear time criterion. For example, if 4 out of 7 days are required for analysis, the difference between setting the allowable interruption period at 10 minutes (38% of individuals have at least 4 viable days) rather than 60 minutes (84% of individuals have at least 4 viable days) is substantial.

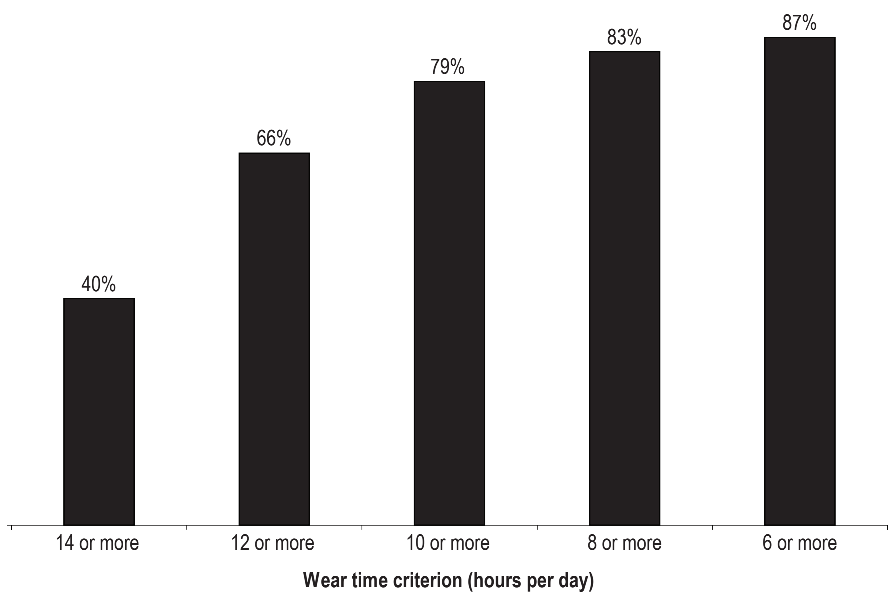
Figure 3 shows the percentages of individuals meeting the wear-time criteria when the minimum number of hours for a valid day is altered (with an allowable interruption period of 60 minutes). The gain in acceptable files between 14 and 10 hours of wear time per day is larger than between 10 and 6 hours per day. In other words, lowering the minimum number of hours needed for a valid day from 14 to 10 hours resulted in a marked increase of acceptable files; lowering the minimum from 10 to 6 hours yielded a smaller difference.

Table 1
Mean calculated accelerometer wear time, by allowable interruption period

Allowable interruption period (minutes)	Mean wear time (hours per day)
10	8.5 ± 4.4
20	9.7 ± 4.7
30	10.6 ± 4.9
60	12.0 ± 5.1

Source: 2007 to 2009 Canadian Health Measures Survey, first four sites.

Figure 3
Percentage of individuals with acceptable files when minimum criterion (hours) for “valid day” is altered



Note: Allowable interruption period is 60 minutes.
Source: 2007 to 2009 Canadian Health Measures Survey, first four sites.

Valid days suitable for analysis

Overall, 95% of the participants had at least 1 valid day, and 84% had 4 or more (Table 2). Thus, if researchers are satisfied that 1 valid day is sufficient to answer their question, they would only have to exclude approximately 5% of the sample.

Table 2
Percentage distribution of participants, by number of valid days of accelerometer wear, group and sex

Age group and sex	Valid days of accelerometer wear: 0	1	2	3	4	5	6	7	1 or more	4 or more
6 to 11										
Male	3	3	5	3	11	13	27	35	97	86
Female	2	6	3	1	10	15	21	42	98	88
12 to 19										
Male	10	4	1	8	12	12	26	27	90	77
Female	11	1	6	1	11	13	23	34	89	81
20 to 39										
Male	7	6	0	8	4	17	11	47	93	79
Female	6	6	6	4	10	9	17	42	94	78
40 to 59										
Male	3	2	3	4	2	15	22	49	97	88
Female	4	4	2	5	4	9	19	53	96	85
60 to 79										
Male	0	2	3	4	9	19	19	44	100	91
Female	7	4	2	3	4	5	17	58	93	84
Overall group means	...	...	...	...	...	...	...	...	95	84

... not applicable
Note: A valid day is defined as 10 or more hours of accelerometer wear time with allowed interruption period of 60 minutes
Source: 2007 to 2009 Canadian Health Measures Survey, first four sites.

The percentage of participants achieving 7 valid days varied by age group from 27% to 58%. Complete nonwear (0 valid days) was most common among 12- to 19-year-olds; the highest compliance was among participants aged 40 to 79 years. No consistent sex difference was evident in any age group.

Discussion

The quality of accelerometry-derived data can be maximized through systematic, consistent quality control and data reduction procedures. This article presents four issues that researchers should address when establishing physical activity measurement and analysis protocols: intra- and inter-monitor reliability, spurious data thresholds, derivation of wear time, and number of valid days required for analysis.

Few studies have examined the technical reliability of accelerometers, largely because of the lack of commercially available calibration units. Unless researchers have the resources to design and build custom calibration equipment, they must trust that their accelerometers provide stable within- and between-monitor measurements of physical activity. However, apparent reliability issues suggest that calibration procedures are warranted. For example, in the present study, 2 out of the 16 monitors measured outside an acceptable reliability range. Without a way to identify these out-of-calibration monitors, they would have been sent back into the field and potentially contaminated physical activity outcomes. The 2006 study by Esliger and Tremblay[11] outlined calibration recommendations based on their work using a hydraulic shaker table to test the reliability of the Actical, Actigraph and RT3 accelerometers. They found that all three were susceptible to reliability problems, and of relevance to the present study, 7 out of 39 Acticals were too variable for use in the field.[11] The calibration protocol in place for the Canadian Health Measures Survey will decrease the likelihood that contaminated data are included in any analyses, thereby strengthening the quality of the physical activity measure.

The present study found that a spurious data threshold of 15,000 cpm (recommended for the Actigraph) is too low for the Actical and that 20,000 cpm is more appropriate. For instance, high-performance runners could legitimately accumulate accelerometer counts close to 20,000 cpm. Unless such data are captured, the level of activity of these participants would be underestimated.

A quality control step that detects spurious data can identify and manage both malfunctioning monitors and biologically implausible data. While most Canadian Health Measures Survey files contained no spurious data (more than 20,000 cpm), an occasional file had a small number (fewer than 5) of spurious observations. In rare circumstances, excessive spurious data appeared in a file, and upon further investigation, these files were found to be completely unusable because of a monitor malfunction. Thus, a simple quality control step that sums spurious observations by participant is a useful way of identifying monitors that may require technical attention. When occasional spurious observations occur in appropriately functioning monitors, they can be managed by techniques such as replacing the elevated observations with the mean of the two closest non-spurious data points on either side.[14]

Observations equal to zero pose a special problem. Excluding them would discard important information about inactivity. However, maintaining all these observations may lead to the inclusion of non-wear time in the final analysis and dilute physical activity outcomes. The assumption is that periods of consecutive zeros lasting longer than the allowable interruption period represent times when the accelerometer has been removed. Intervals of continuous zero counts that are shorter than the allowable interruption period are preserved as wear time, and are believed to indicate sedentary behaviour.

This study compared the impact of various allowable interruption periods on the likelihood that a file would

What is already known on this subject?

- Accelerometry-derived measures of physical activity continue to be published in the research literature. However, the implementation and reporting of data reduction and analytical methods is inconsistent.
- Given the potential impact that data reduction procedures can have on physical activity outcomes, consensus is needed among researchers using these devices.
- Publication of recommendations about processing accelerometry data from the National Health and Nutritional Examination Survey facilitated the establishment of consistent procedures for the Canadian Health Measures Survey.

What does this study add?

- One of the primary challenges in using accelerometers to derive information about physical activity is low compliance with wearing the devices. The resultant incomplete data create interpretation issues and require consistent quality control and data reduction procedures.
- Four important quality control and data reduction steps are presented that help address incomplete accelerometry data and should be considered before deriving physical activity information: intra- and inter-monitor reliability, spurious data thresholds, derivation of wear time, and number of valid days required for analysis.
- The information is particularly relevant for researchers who work with or compare their results to Canadian Health Measures Survey accelerometry data.

achieve the daily wear time criterion. As expected, longer interruption periods resulted in higher mean wear time values and a higher percentage of files being deemed acceptable for analysis. Earlier studies have used interruption periods ranging from 10[21,22] to 60[7,14] minutes. Masse et al.[7] found that a less restrictive interruption period (60 minutes) results in more minutes of inactivity being reported than a shorter interruption period (20 minutes). Changing the interruption period may affect power and sample size because this affects the number of days that reach the wear time criterion. However, consensus on a single allowable interruption period is unlikely. Rather, it appears that this decision should be made *a priori,* based on the research design (population surveillance versus intervention monitoring) and the age of the population being studied. Researchers measuring physical activity in children have used shorter interruption periods, possibly reflecting an assumption that children are more active than adults. For example, the European Youth Heart Study uses a 10-minute interruption period when reducing accelerometry data collected from children and youth.[13,22,23]

The finding that at least one valid day was available for 95% of the sample is encouraging and suggests that the data reduction procedures tested are not so stringent as to dramatically reduce sample size. Like the National Health and Nutritional Examination Survey 2003-2004 accelerometry analysis, the present study found compliance in wearing a monitor was highest among older adults, and lowest among adolescents. This demonstrates the need to encourage compliance among adolescents when accelerometers are used to measure physical activity.

This article presents practical issues for researchers to consider when using accelerometers. It also provides methodological information on the survey accelerometer procedures, which will be useful to researchers working with or comparing their own data with Canadian Health Measures Survey results. A limitation is the small sample size on which recommendations about an appropriate spurious data threshold are based. This value should be tested on a larger sample to confirm that it is appropriate for all ages and abilities. Future investigations might explore whether lower thresholds should be used for children, the elderly or people with known physical limitations. Conversely, higher thresholds might be appropriate for individuals who self-identify as high-performance athletes.

Conclusions

A number of issues must be considered to ensure that valid data are reported when using accelerometers to measure physical activity. A limitation of many studies that report accelerometry-based estimates of physical activity is that they lack a description of the procedures used to calibrate the accelerometers and the data reduction procedures used before derivation of physical activity information. Monitor malfunctions can and do occur. Therefore, it is essential that researchers continually check the reliability of the measurement tool itself. A series of steps can be followed during data collection to prevent defective monitors from being sent into the field for data collection. Similarly, before analysis of derived variables, it is important to have procedures in place to confirm that the data are biologically plausible and that compliance with wearing the device is acceptable. ■

References

1. Katzmarzyk P, Tremblay M. Limitations of Canada's physical activity data: implications for monitoring trends. *Applied Physiology, Nutrition and Metabolism / Canadian Journal of Public Health* 2007; 32 / 98: S185-S194.
2. Adamo K, Prince S, Tricco A, et al. A comparison of indirect versus direct measures for assessing physical activity in the pediatric population: A systematic review. *International Journal of Pediatric Obesity* 2009; 4(1): 2-27.
3. Prince S, Adamo K, Hamel M, et al. A comparison of direct versus self-report measures for assessing physical activity in adults: a systematic review. *International Journal of Behavioral Nutrition and Physical Activity* 2008; 5: 56.
4. Walsh M, Hunter GR, Sirikul B, Gower B. Comparison of self-reported with objectively assessed energy expenditure in black and white women before and after weight loss. *American Journal of Clinical Nutrition* 2004; 79: 1013-9.
5. Montoye HJ, Kemper HCG, Saris WHM, Washburn RA. *Measuring Physical Activity and Energy Expenditure.* Champaign, Illinois: Human Kinetics, 1996.
6. Esliger D, Copeland J, Barnes J, Tremblay M. Standardizing and optimizing the use of accelerometer data for free-living physical activity monitoring. *Journal of Physical Activity and Health* 2005; 3: 366-83.
7. Masse L, Fuemmeler B, Anderson C, et al. Accelerometer data reduction: A comparison of four reduction algorithms on select outcome variables. *Medicine and Science in Sports and Exercise* 2005; 37: S544-S554.
8. Esliger D, Tremblay M. Physical activity and inactivity profiling: the next generation. *Applied Physiology, Nutrition and Metabolism/Canadian Journal of Public Health* 2007; 32/98: S195-S207.
9. Powell SM, Jones DI, Rowlands AV. Technical variability of the RT3 accelerometer. *Medicine and Science in Sports and Exercise* 2003; 35: 1773-8.
10. Powell SM, Rowlands AV. Intermonitor variability of the RT3 accelerometer during typical physical activities. *Medicine and Science in Sports and Exercise* 2004; 36: 324-30.
11. Esliger D, Tremblay M. Technical reliability assessment of three accelerometer models in a mechanical setup. *Medicine and Science in Sports and Execrise* 2006; 38: 2173-81.
12. Mattocks C, Ness A, Leary S, et al. Use of accelerometers in a large field-based study of children: protocols, design issues, and effects on precision. *Journal of Physical Activity and Health* 2008; 5: S98-S111.
13. Moller N, Kristensen P, Wedderkopp N, et al. Objectively measured habitual physical activity in 1997/1998 vs 2003/2004 in Danish children: The European Youth Heart Study. *Scandinavian Journal of Medicine and Science in Sports* 2009; 19(1): 19-29.
14. Troiano R, Berrigan D, Dodd K, et al. Physical activity in the United States measured by accelerometer. *Medicine and Science in Sports and Exercise* 2008; 40: 181-8.
15. Ness A, Leary S, Mattocks C, et al. Objectively measured physical activity and fat mass in a large cohort of children. *PLoS Medicine* 2007; 4: e97.
16. Moore L, Gao D, Bradlee M, et al. Does early physical activity predict body fat change throughout childhood? *Preventive Medicine* 2003; 37: 10-7.
17. Stevens J, Suchindran C, Ring K, et al. Physical activity as a predictor of body composition in American Indian children. *Obesity Research* 2004; 12: 1974-80.
18. Trost S, Pate R, Freedson P, et al. Using objective physical activity measures with youth: how many days of monitoring are needed. *Medicine and Science in Sports and Exercise* 2000; 32: 426-31.
19. Tremblay M, Wolfson M, Connor Gorber S. Canadian Health Measures Survey: Background, rationale and overview. *Health Reports* (Statistics Canada, Catalogue 82-003) 2007;18 (Suppl.): 7-20.
20. Esliger D, Probert A, Connor Gorber S, et al. Validity of Actical accelerometer step count function. *Medicine and Science in Sports and Exercise* 2007; 39: 1200-4.
21. Ekelund U, Yngve A, Brage S, et al. Body movement and physical activity energy expenditure in children and adolescents: how to adjust for differences in body size and age. *American Journal of Clinical Nutrition* 2004; 79: 851-6.
22. Riddoch C, Andersen LB, Wedderkopp N, et al. Physical activity levels and patterns of 9- and 15-yr-old European children. *Medicine and Science in Sports and Exercise* 2004; 36: 86-92.
23. Nilsson A, Anderssen S, Andersen LB, et al. Between- and within-day variability in physical activity and inactivity in 9- and 15-year-old European children. *Scandinavian Journal of Medicine and Science in Sports* 2009; 19(1): 10-8.

Resting blood pressure and heart rate measurement in the Canadian Health Measures Survey, cycle 1

by Shirley Bryan, Mathieu Saint-Pierre Larose, Norm Campbell, Janine Clarke and Mark S. Tremblay

Abstract

Background
Directly measured blood pressure (BP) data have not been collected in Canada since the Canadian Heart Health Surveys, conducted between 1985 and 1992. Because hypertension is often asymptomatic, a large proportion of those with the condition are unaware of it.

Data and methods
These analyses use BP and heart rate (HR) data from cycle 1 of the 2007-2009 Canadian Health Measures Survey (CHMS) for respondents aged 6 to 79 years. Methods and quality assurance and control procedures are explained. Logistical and feasibility issues that arose during data collection are discussed. The reasons for repeating a series of measures are given. Between- and within- series variations and inter-tester variability are assessed.

Results
The BP and HR of almost all respondents who attended the examination centre were measured. Only one series of measurements was taken for 88% of respondents. The series was repeated for around 5% with variability in their BP or HR measurements. About 3% had HR or BP values above the screening cut-offs for the fitness tests. Almost 35% of respondents with HR or BP values above the screening cut-offs after their first series had values below the cut-points after the second series; a further 3% had values below after the third series. Within a series of six measurements, BP decreased until about the fourth measure, after which it remained stable. Mean BP and HR values indicated no inter-tester variability.

Interpretation
The protocol for measuring BP and HR by oscillometry in the CHMS appears to have produced reliable estimates. No benefit to repeating the series of six measurements a third time for screening purposes is evident. Four measurements may be sufficient to provide reliable BP and HR data. Oscillometry appears to eliminate inter-tester variability.

Keywords
direct measurement, health survey, oscillometric measurement

Authors
Shirley Bryan (613-951-4968; Shirley.Bryan@statcan.gc.ca), Mathieu St-Pierre Larose and Janine Clarke (613-951-7598; Janine.Clarke@statcan.gc.ca) are with the Physical Health Measures Division, Statistics Canada, Ottawa, Ontario K1A 0T6. Norm Campbell is with the University of Calgary and Libin Cardiovascular Institute. Mark S. Tremblay is with the Healthy Active Living and Obesity Research Group at the Children's Hospital of Eastern Ontario Research Institute.

Elevated blood pressure (BP) is a leading risk factor for mortality, cardiovascular disease and kidney disease.[1,2] The World Health Organization estimates that elevated BP is responsible for approximately 7.1 million premature deaths annually and 4.4% of the global disease burden,[3] with two-thirds of stroke and half of ischemic heart disease attributable to suboptimal BP levels.[4] Worldwide, in 2000, an estimated 26.4% of adults had hypertension (high BP), a figure projected to increase to 29.2% by 2025.[5]

Population surveys in Canada (for example, the Canadian Community Health Survey) have long relied on self-reported questionnaires to determine the prevalence of chronic conditions. Hypertension, however, tends to be asymptomatic, and a large proportion of people who are affected are unaware of it. The potential for underreporting, and thereby underestimating, the prevalence of a condition with such a high public health burden necessitates the collection of directly measured BP.[6]

In Canada, the last comprehensive directly measured BP data were gathered between 1985 and 1992 as part of the Canadian Heart Health Surveys.[7] The surveys used standard mercury sphygmomanometers. Information was collected from adults during home interviews and clinic visits in the 10 provinces.[7] From these data, the prevalence of hypertension (average systolic BP ≥140 mmHg or average diastolic BP ≥90 mmHg, or current treatment with prescription medicine or non-pharmacological treatment) among adults was estimated at 22%; 42% of these hypertensive adults were unaware of their condition.[8]

In March 2007, Statistics Canada launched the first cycle of the Canadian Health Measures Survey (CHMS). The CHMS is a nationally representative, cross-sectional direct measures survey that includes the concurrent direct measurement of resting BP and heart rate (HR) using oscillometry.

The threefold objectives of this paper are to provide:

- an overview of the BP and HR collection method used for cycle 1 of the CHMS;
- information about methodological and analytical issues faced during the collection and analysis of the BP and HR data; and
- information about protocol changes implemented in cycle 2 in response to the experience gained in cycle 1.

Data source

Cycle 1 of the CHMS involved a nationally representative sample of approximately 5,600 Canadians aged 6 to 79 years. Data were collected from March 2007 through February 2009. The survey comprised an in-home interview about general health followed by a visit to a mobile examination centre where direct physical measures were conducted.[9]

The cycle 1 sample represented 96.3% of the Canadian population; full-time members of the Canadian Forces, and residents of Crown lands or Indian reserves, institutions and certain remote regions were excluded.[10] Measurement of resting HR and BP was completed on almost all respondents who participated in the physical measures portion of the survey (N=5,610; 2,709 males and 2,901 females). Test exclusion criteria for HR and BP included double-arm amputation, rashes, gauze dressings, casts, oedema, paralysis, tubes, open sores or wounds, and withered arms or v-shunts on both arms. No respondents were screened out of this component.

Equipment

BP and HR were measured electronically with an automated oscillometric device: the BpTRU™ BPM-300 at the mobile examination centre and with the BpTRU™ BPM-100 during home visits (BpTRU™ Medical Devices Ltd., Coquitlam, British Columbia). The BPM-300 allows electronic transfer of data; the BPM-100 does not.

The decision to use an automated oscillometric device was based on recommendations from a committee of hypertension and survey experts.[11] The BpTRU™ meets the Association for the Advancement of Medical Instrumentation standard and the British Hypertension Society protocol.[12] The committee recommended oscillometry rather than auscultation because oscillometric devices require less training to operate, improve the reproducibility and standardization of readings, and eliminate common problems associated auscultation such as ausculatory gaps, hearing acuity, interpretation of Korotkoff sounds, changes in technique over time, differences in technique between staff, and terminal digit bias. Oscillometry has been used in large surveys in several other countries.[11,13,14] As well, oscillometric devices allow HR and BP to be taken in the absence of survey personnel, which minimizes observer-subject interactions that can influence results (for example, white-coat effect).[11]

The oscillometric measurement protocol was assessed during a comprehensive pre-test of the CHMS and was found to meet the needs of the survey.[15] A review of the CHMS data revealed no terminal end-digit bias when using the BpTRU™. Oscillometric BP measurement was taken on more than 99% of respondents . If a respondent refused to have BP measured with the BpTRU™, or to confirm multiple series of results with excessive variability (see *Measurement procedures*), BP was taken manually using a Littman Classic II SE stethoscope and an ALMEDIC 490 mercury sphygmomanometer.

The accuracy of each BpTRU™ was verified by staff three times during the six-week period at each CHMS collection site or when a problem was suspected (for example, questionable readings, suspected damage) following standardized procedures recommended by the manufacturer (Table 1).[16] A reference gauge calibration check, including a static and dynamic accuracy test, was also performed by the manufacturer (BpTRU™ Medical

Table 1
Verification procedures, purpose and repeat criteria for verifying BpTRU™,[16] Canadian Health Measures Survey, cycle 1, 2007 to 2009

Verification procedure	Purpose	Repeat criteria
Zero calibration check	Verifies that BpTRU™ accurately measures zero pressure when no pressure is being applied	If value in PULSE display not equal to 0 or if value in READING display >10.
Reference gauge calibration check	Compares accuracy of BpTRU™'s pressure transducer against reference pressure gauge (for example, mercury sphygmomanometer) of known accuracy when pressure applied to device	Repeat based on difference between expected and actual readings at each pressure tested as follows: 275 > ± 5.5 mmHg 200 > ± 4 mmHg 50, 100 and 150 > ± 3 mmHg
Over pressure test	Verifies BpTRU™'s safety mechanism that automatically releases air in cuff and displays error code should pressure surpass 330 mmHg	Error code E2 should be displayed in SYSTOLIC display window; if not, repeat test.
Over inflation time test	Verifies BpTRU™'s safety mechanism that automatically releases air in cuff if it stays pressurized over 10 mmHg for more than 180 seconds	Error code E11 should be displayed in SYSTOLIC display window; if not, repeat test.

Services) once per year. The mercury sphygmomanometer was verified three times at each collection site using a zero calibration check. Results of all verifications were recorded in a database, and staff followed a set of repeat criteria (Table 1) to determine if a second verification was necessary. The results were reviewed by the on-site manager and sent to Statistics Canada's head office in Ottawa for review and documentation. During collection, three devices did not pass verification and were sent to the manufacturer for repair and calibration.

In addition to regular verification, the staff maintained the BpTRU™ devices. This included cleaning the cuffs after each use, cleaning and disinfecting the unit weekly, and performing a visual inspection and battery check at the beginning and end of the period spent at each collection site (approximately six weeks).

The BpTRU™ BPM-300 was chosen because it allows automated downloading of data through a USB connection. A customized data transfer program was developed to download data from the BpTRU™ to the data capture application. Occasional random communication problems prevented automatic data transmission. In 182 instances, staff had to manually enter values into the data capture application.

Training

All staff conducting the physical measures were accredited members of the Canadian Society for Exercise Physiology (CSEP). These health measures specialists completed a one-day calibration/training session for HR and BP measurement with registered nurses from the Ottawa Hospital (Ottawa, Canada) who specialize in this measure. Training included basic theory; review and practice of both the oscillometric and auscultatory protocols; in-class demonstrations on how to use the equipment, prepare a respondent for measurement, select the appropriately sized cuff and fasten it on various arm sizes and shapes (for instance, large or conical-shaped arms); and the effect of arm and body position on the measurement. Staff watched a video that described proper technique for calculating maximal inflation rate when performing measurements by auscultation. Staff were evaluated using a double-headed stethoscope. Time was also dedicated to reviewing equipment maintenance and verification procedures. During a dress rehearsal before the start of cycle 1 data collection, staff practised measurement techniques, became familiar with protocols, and addressed equipment and protocol problems. A retraining session took place nine months after collection started. During collection, time was allocated for weekly practice performing auscultation so that staff were prepared to use this technique if needed.

Staff were periodically observed by external experts (for example, with expertise in BP measurement in a clinical setting), head office staff and mobile examination centre managers. Observation guidelines and an observation checklist were developed in consultation with measurement experts to aid in the assessment and documentation of staff performance. In total, 16 observation reports were completed for each staff member conducting the BP component, and based on these reports, feedback and retraining were provided. Two protocol items that required retraining were ensuring the BpTRU™ screen could not be viewed by respondents during the measurement and ensuring that the arm was at the correct height.

Measurement procedures

During the household interview, respondents were asked: "Do you have high blood pressure?" (diagnosed by a health professional) and "In the past month have you taken any medicine for high blood pressure?"[17] These questions are consistent with those in other Statistics Canada surveys (for example, Canadian Community Health Survey).[18] Respondents were also asked about their use of prescription and over-the-counter medications, including dosage and the last time they took the medication.

At the beginning of respondents' mobile examination centre visit, the health measures specialist asked them screening questions, during which the list of medications (including BP medications) provided during the home interview was reviewed and updated. Questions were also asked about acute and chronic conditions that could result in a respondent being screened out of other physical measures.[19]

HR and BP measurement was the fourth component in the mobile examination centre visit, after screening, anthropometry, and urine collection.[20] It was administered in quiet, temperature-controlled rooms (21ºC ± 2ºC) with the lights on at all times. Respondents were asked if they needed to use the washroom before the test. They were seated in a comfortable chair with the back and arms supported and with both feet on a flat surface. The antecubital fossa (elbow crease) of the right arm was positioned at the apex of the heart (the junction of the fourth intercostal space and the lower left sternal border) with the palm facing down for oscillometric measurement or up for auscultation. Staff could use use arm pads of two different thicknesses, and chairs with adjustable height were provided to assist with arm height positioning. The left arm was used only when it was impossible to use the right arm. An appropriately sized cuff was chosen using the marked ranges on the inner side as a guideline. The cuff was fastened tightly around the bare upper part of the arm such that only two fingers could be slid under the cuff, with the center of the bladder over the brachial artery and the lower margin of the cuff 2 to 3 cm above the antecubital fossa. Because respondents had been asked to wear clothing appropriate for exercise for their mobile examination centre visit, most wore a short-sleeved shirt. On some occasions (more often among older adults), respondents were given a short-sleeved shirt to wear during the measurement to ensure that clothing did not impede blood flow in the arm. Respondents were left alone to rest for five minutes before the measurement. The health measures specialist asked them to sit quietly, relax and refrain from moving or talking during this rest period. After the rest period, the health measures specialist re-entered the room to start the BpTRU™.

The test consisted of six oscillometric measurements taken at one-minute intervals. The health measures specialist remained in the room for the first measurement to ensure proper functioning of the BpTRU™ and that the respondent was following test instructions. The BpTRU™ digital display was positioned so that the respondent could not see the results during the test. In the case of young children who had difficulty complying with the testing procedures (for example, sitting quietly), the health measures specialist remained in the room throughout the measurement series. This practice was implemented based on experience at the first collection site where some children were anxious and tended to move during the measurement, and as a result, errors were recorded on the BpTRU™. Having health measures specialists in the room improved data quality, as they could ensure that children followed proper test protocol.

Of the six measurements taken in a series, only the last five were used to calculate average BP and HR. The health measures specialist reviewed the first series of measurements. The series was repeated a second time, after five more minutes of rest, if:

1. average BP was >144/94 mmHg; or
2. average heart rate was ≥100 bpm; or
3. fewer than three valid measurements were recorded because of BpTRU™ error codes; or
4. variability between two systolic measurements in the series was >30 mmHg; or
5. variability between two diastolic measurements in a series was >20 mmHg; or
6. variability between two heart rate measurements in a series was >30 bpm.

If the series was repeated because of BP >144/94 mmHg or HR ≥100 bpm, the results of subsequent series were used only as a screening tool to assess eligibility to participate in the aerobic fitness (modified Canadian Aerobic Fitness Test) and muscular endurance (partial curl-ups) components of the survey. These cut-points were set according to the guidelines in the Canadian Physical Activity, Fitness and Lifestyle Approach.[21]

A third series of measurements was taken if the second series indicated any of the six problems listed above. If the problem was related to variability or to too many errors, the health measures specialist would take the BP by auscultation (fewer than 1% of cases) to ensure the problem was not a malfunctioning BpTRU™. The health measures specialists could also re-do a series of measurements if, after review, they considered the validity of the measurements to be in question. In such instances, average systolic and diastolic BP and average HR were not calculated, and the values were set to "not stated" (996) in the data set for that series. More information about the survey design and data layout is available in the *CHMS Data User's Guide*.[22]

At the end of their examination centre visit, respondents received a printed report of the results of their physical measures tests. Average BP and HR were based on the last series of valid BP measurements recorded, and a comment about the result was included on the report. For adults aged 18 years or older, the classification of hypertensive status was taken from the guidelines developed by the Canadian Coalition for High Blood Pressure Prevention and Control.[23] For respondents aged 6 to 17 years, the classification was taken from the guidelines developed by the National High Blood Pressure Education Program Working Group on High Blood Pressure in Children and Adolescents.[24] Respondents with a BP above the normal range received a letter to give to their health care provider, which included the test result and information about how the data had been collected.

Evaluation of cycle 1 data

An evaluation of some aspects of the BP collection protocol was undertaken to determine if adjustments were required, specifically, the number of times the series was repeated, the reason for the repeat, and the effect of the third series of measurements on the overall screen-out rate for the fitness tests. In addition, the data were reviewed to detect inter-tester variability in the measurements and to determine the difference between measures within a series and thereby assess if six repeated measurements were necessary to produce reliable average values.

Series repeats

All repeated series of measurements were assessed to determine how many times and why a series had been repeated based on the six repeat criteria. Particular attention was paid to the variability check. This was an automated procedure performed on the first and second series to assess whether a subsequent series should be performed because of too much variability between measurements that might indicate invalid data. The variability limits (30 mmHg for systolic BP, 20 mmHg for diastolic BP, 30 bpm for HR) were based on an evaluation of the CHMS pre-test data. In the pre-test, fewer than 3% of the overall sample had a range greater than these cut-points in their measurements within a single series. The 97th percentile for the maximum range in the first series was determined by age group and sex.

Between-series evaluation

The measurement of BP and HR served two distinct purposes: 1) to assess the respondent's BP and HR status, and 2) as a screening tool to exclude respondents aged 15 to 69 years from certain fitness tests (those with BP >144/94 mmHg or HR≥100 bpm were excluded from the aerobic fitness test and partial curl-up test). Respondents whose BP or HR was above the screening cut-off on their first series of measurements were assessed to determine if repeating the series a second or a third time yielded results below the cut-points, and thus, allowed them to participate in the fitness tests.

Within-series evaluation

Six BP and HR measurements were recorded at one-minute intervals within each series of measurements. To assess whether six measurements were needed for a reliable estimate of resting values, the mean of each measurement in the series and the difference between measurements within the series was determined by age group using the series that was included as part of the derived variable calculation of the averages.[25]

Inter-tester variability

To detect inter-tester variability, the means and 95% confidence intervals of all first series measures taken by each health measures specialist were calculated.

Results

Reasons for repeating series

For a large majority of respondents (88.8%), only one series of six measurements was taken; for approximately 11% , a second series was taken; and 13.7% of those who had a second series also had a third. The most common reason for repeating a series was too much variability for both the second and third repeat (Table 2).

An assessment of the maximum range between measures in the first series showed that the 97th percentile varied widely between age groups and tended to be highest and over the variability cut-points among 12- to 19-years-olds for HR and systolic BP (Table 3).

Between-series evaluation

A total of 95 respondents aged 15 to 69 years had BP or HR above the screening cut-points (BP >144/94 mmHg; HR ≥100 bpm) during the first series of six measurements. Of these, 33 (34.7%) had average values below these limits during the second series, but only 3 (3.2%) had values below the limits during the third series. Thus, 59 (62.1%) remained screened out of the fitness components of the survey as a result of BP or HR that exceeded the screening cut-points.

Within-series evaluation

Table 4 displays the mean of each measurement within a series, the

Table 2
Reason for performing second and third series of blood pressure (BP) and heart rate (HR) measurements, Canadian Health Measures Survey, cycle 1, 2007 to 2009

First set			Second set		
Reason for second set	Number	Percent	Reason for third set	Number	Percent
First set accepted	4,980	88.8	Second set accepted	544	9.7
Elevated BP and HR	4	0.1	Elevated BP and HR	0	0.0
Elevated BP only	164	2.9	Elevated BP only	1	0.0
Elevated HR only	52	0.9	Elevated HR only	2	0.0
More than 3 errors	24	0.4	More than 3 errors	2	0.0
Variability	270	4.8	Variability	64	1.1
Option to re-do	116	2.1	Option to re-do	17	0.3

Table 3
97th percentiles of range (maximum-minimum) within first series for resting systolic and diastolic blood pressure (BP) and for resting heart rate, by age group, household population aged 6 to 79 years, Canadian Health Measures Survey, cycle 1, 2007 to 2009

Age group	Systolic BP	Diastolic BP	Heart rate
	(mmHg)	(mmHg)	(bpm)
6 to 11 years	25	26	22
12 to 29 years	30	20	33
20 to 39 years	24	17	16
40 to 59 years	24	14	11
60 to 79 years	28	20	17

What is already known on this subject?

- In Canada, the last comprehensive directly measured blood pressure (BP) data were gathered between 1985 and 1992 as part of the Canadian Heart Health Surveys using standard mercury sphygmomanometers.
- The 2007-2009 Canadian Health Measures Survey (CHMS) included direct measurement of resting BP and HR using oscillometry.
- Compared with auscultation, oscillometric devices require less training to operate, improve the reproducibility and standardization of readings, and eliminate problems associated auscultation such as changes in technique over time, differences in technique between staff, terminal digit bias, and observer-subject interactions.

What does this study add?

- The protocol used for measuring BP and HR by oscillometry in the CHMS produces reliable estimates for the Canadian population.
- Measurement of BP and HR using oscillometry eliminates inter-tester variability.
- Ocsillometry is suitable for population surveys, provided that rigorous quality assurance, quality control and calibration procedures are in place.

Table 4
Mean and 95% confidence intervals of each measurement in a series and mean difference between measurements within the series (in relation to last measurement used in creation of derived variable), by age group, household population aged 6 to 79 years, Canadian Health Measures Survey, cycle 1, 2007 to 2009

		Mean						Mean difference				
			95% confidence interval			95% confidence interval			95% confidence interval			
Measurements and age group	Number	Mean	from	to	Mean	from	to	Estimate	from	to	Minimum	Maximum
Second/Sixth		**Second measurement**			**Sixth measurement**							
6 to 11 years												
Systolic BP (mmHg)	952	94	81	108	92	80	106	2	-8	12	-22	25
Diastolic BP (mmHg)	951	63	51	76	60	48	74	3	-6	12	-18	20
Heart rate (bpm)	954	77	61	96	81	65	100	-3	-12	5	-30	22
12 to 19 years												
Systolic BP (mmHg)	968	100	84	11	98	83	115	2	-5	10	-26	46
Diastolic BP (mmHg)	968	64	52	77	61	49	75	3	-6	10	-19	25
Heart rate (bpm)	968	72	54	94	76	57	99	-3	-14	8	-32	28
20 to 39 years												
Systolic BP (mmHg)	1,166	106	89	126	104	87	123	2	-7	13	-22	29
Diastolic BP (mmHg)	1,166	70	57	86	68	54	84	2	-5	9	-17	18
Heart rate (bpm)	1,165	68	52	87	70	54	88	-2	-9	4	-28	24
40 to 59 years												
Systolic BP (mmHg)	1,224	115	94	143	112	92	138	3	-9	15	-22	30
Diastolic BP (mmHg)	1,224	75	60	92	74	59	90	1	-5	8	-17	21
Heart rate (bpm)	1,224	67	51	84	68	52	86	-1	-6	3	-19	12
60 to 79 years												
Systolic BP (mmHg)	1,090	127	100	160	123	98	152	4	-8	18	-27	30
Diastolic BP (mmHg)	1,090	73	57	90	72	55	88	1	-5	8	-16	22
Heart rate (bpm)	1,090	65	49	84	66	50	84	-1	-5	4	-32	21
Third/Sixth		**Third measurement**			**Sixth measurement**							
6 to 11 years												
Systolic BP (mmHg)	946	93	81	108	92	80	106	1	-9	12	-22	21
Diastolic BP (mmHg)	945	62	49	75	60	48	74	1	-8	10	-20	18
Heart rate (bpm)	949	79	62	97	81	65	100	-2	-12	6	-27	24
12 to 19 years												
Systolic BP (mmHg)	973	99	84	116	98	83	115	2	-11	14	-28	27
Diastolic BP (mmHg)	973	63	50	76	61	49	75	1	-7	9	-37	19
Heart rate (bpm)	974	74	55	98	76	57	99	-2	-12	7	-30	29
20 to 39 years												
Systolic BP (mmHg)	1,165	105	89	125	104	87	123	1	-9	12	-22	28
Diastolic BP (mmHg)	1,165	69	56	85	68	54	84	1	-5	8	-17	20
Heart rate (bpm)	1,165	69	54	88	70	54	88	-1	-8	5	-29	22
40 to 59 years												
Systolic BP (mmHg)	1,222	114	93	141	112	92	138	2	-8	13	-24	30
Diastolic BP (mmHg)	1,222	75	60	91	74	59	90	1	-5	7	-19	19
Heart rate (bpm)	1,222	67	51	85	68	52	86	-1	-5	4	-17	16
60 to 79 years												
Systolic BP (mmHg)	1,083	126	99	158	123	98	152	3	-10	15	-28	30
Diastolic BP (mmHg)	1,083	73	56	90	72	55	88	1	-5	7	-16	20
Heart rate (bpm)	1,083	66	50	85	66	50	84	0	-4	4	-20	25
Fourth/Sixth		**Fourth measurement**			**Sixth measurement**							
6 to 11 years												
Systolic BP (mmHg)	956	93	80	107	92	80	106	1	-9	11	-23	30
Diastolic BP (mmHg)	955	61	48	75	60	48	74	1	-8	10	-18	19
Heart rate (bpm)	959	80	63	100	81	65	100	-1	-10	7	-29	19
12 to 19 years												
Systolic BP (mmHg)	976	99	84	115	98	83	115	1	-10	12	-26	29
Diastolic BP (mmHg)	976	62	50	76	61	49	75	1	-7	9	-32	19
Heart rate (bpm)	975	75	56	96	76	57	99	-1	-10	8	-25	28
20 to 39 years												
Systolic BP (mmHg)	1,174	105	88	124	104	87	123	1	-9	11	-26	24
Diastolic BP (mmHg)	1,174	69	55	84	68	54	84	1	-5	7	-18	18
Heart rate (bpm)	1,174	70	54	88	70	54	88	0	-7	6	-26	20
40 to 59 years												
Systolic BP (mmHg)	1,227	113	93	140	112	92	138	1	-9	12	-20	22
Diastolic BP (mmHg)	1,227	74	60	90	74	59	90	1	-5	6	-17	15
Heart rate (bpm)	1,227	68	51	86	68	52	86	0	-5	4	-15	17
60 to 79 years												
Systolic BP (mmHg)	1,091	125	100	157	123	98	152	2	-9	14	-27	29
Diastolic BP (mmHg)	1,091	73	56	89	72	55	88	1	-6	6	-15	18
Heart rate (bpm)	1,091	66	50	85	66	50	84	0	-4	3	-15	18
Fifth/Sixth		**Fifth measurement**			**Sixth measurement**							
6 to 11 years												
Systolic BP (mmHg)	941	93	80	106	92	80	106	0	-10	10	-19	21
Diastolic BP (mmHg)	940	61	48	74	60	48	74	0	-8	9	-18	33
Heart rate (bpm)	943	80	64	100	81	65	100	-1	-9	7	-24	20
12 to 19 years												
Systolic BP (mmHg)	972	98	83	115	98	83	115	1	-11	12	-28	24
Diastolic BP (mmHg)	972	62	48	76	61	49	75	0	-7	8	-35	19
Heart rate (bpm)	972	75	56	98	76	57	99	-1	-10	8	-33	24
20 to 39 years												
Systolic BP (mmHg)	1,168	104	88	123	104	87	123	0	-9	10	-29	27
Diastolic BP (mmHg)	1,168	68	55	84	68	54	84	0	-7	7	-19	20
Heart rate (bpm)	1,168	70	54	88	70	54	88	0	-6	6	-28	28
40 to 59 years												
Systolic BP (mmHg)	1,221	113	92	138	112	92	138	0	-10	11	-23	23
Diastolic BP (mmHg)	1,221	74	59	91	74	59	90	0	-5	6	-21	18
Heart rate (bpm)	1,221	68	52	86	68	52	86	0	-5	4	-19	14
60 to 79 years												
Systolic BP (mmHg)	1,088	124	99	155	123	98	152	1	-10	12	-30	28
Diastolic BP (mmHg)	1,088	73	57	89	72	55	88	0	-6	6	-19	19
Heart rate (bpm)	1,088	66	50	84	66	50	84	0	-3	3	-16	15

difference between the means for each measurement relative to the sixth, and the maximum and minimum difference for each age group. Among all age groups, both systolic and diastolic BP tended to decrease over the six measurements, while HR tended to increase. The greatest differences were between the second and sixth measurements and the third and the sixth, after which the difference was minimal. The highest maximum and minimum differences for blood pressure were in the youngest age group; these differences narrowed with subsequent measures.

An analysis of the values in the first series of six measurements revealed instances of large differences (potential outliers) between two measurements. However, assessment of the means produced using the derived variable did not show large differences (data not shown). Consequently, no process for removing outliers is needed when calculating mean BP. More details on the determination of the derived variables can be found in the *CHMS Derived Variable Document*.[25]

Inter-tester variability

The means and 95% confidence intervals for staff performing HR and BP measurements on more than 100 respondents indicate consistent results between testers (Table 5). The results for testers who performed more than 500 tests were equally consistent, with means ranging from 107 to 109 mmHg (systolic BP), from 67 to 69 mmHg (diastolic BP), and from 70 to 71 bpm (HR).

Discussion

Analysis of the measurement procedures described in this study led to some modifications to the measurement protocol for cycle 2 of the CHMS. The most common reason for repeating a series of BP measurements was related to variability in HR or BP values between measures within a series. Because this variability was age-dependent and there was no way to determine how much of it

Table 5
Mean and 95% confidence interval for resting systolic and diastolic blood pressure (BP) and for resting heart rate, by tester, Canadian Health Measures Survey, 2007 to 2009

Tester	Number	Systolic BP Mean (mmHg)	Systolic BP 95% confidence interval from	Systolic BP 95% confidence interval to	Diastolic BP Mean (mmHg)	Diastolic BP 95% confidence interval from	Diastolic BP 95% confidence interval to	Heart rate Mean (bpm)	Heart rate 95% confidence interval from	Heart rate 95% confidence interval to
1	538	108	87	137	69	53	87	71	53	93
2	705	108	88	138	69	54	86	70	53	90
3	864	107	86	138	68	53	85	71	54	91
4	579	107	86	138	69	53	84	71	53	90
5	556	107	86	138	68	53	85	71	53	91
6	583	108	88	139	68	53	85	71	53	93
7	536	107	86	140	67	52	83	70	54	88
8	186	109	85	146	68	54	88	72	53	91
9	194	107	84	140	66	49	85	72	54	90
10	212	104	83	132	66	52	81	73	56	96
11	195	108	87	148	68	53	88	71	56	93
12	228	106	86	133	67	52	83	71	55	89

was biologically plausible, the variability check was eliminated for cycle 2.

The BP and HR measurement protocol allowed for up to three series of measurements for each respondent in order to obtain values below the fitness test screening cut-offs. Evaluation of the means between the first and subsequent series of measurements showed only minimal advantage in the third series for screening respondents into the fitness tests, and therefore, the third series of measurements was removed from the procedures for cycle 2.

Unquestionably, it is important to include BP in a comprehensive direct measures health survey, since many people with hypertension are unaware of it.[8] However, the current protocol of performing six measurements up to three times in order to collect this information takes considerable time and places an additional burden on respondents. Analysis of the data in a set of six measurements revealed that by the fourth measure within a set, there appears to be no further change, suggesting that this may be the point of diminishing returns, and that the cost and inconvenience of the fifth and sixth measurements may not merit the effort. Even so, the BpTRU™ was designed and validated when six repeated measures are performed, so no changes have been made to this protocol for cycle 2 of the CHMS. Nonetheless, the potential for improved efficiency should be explored for subsequent cycles.

No inter-tester variability was evident when the staff used the BpTRU™. This is to be expected, since oscillometric devices are designed to be used in the absence of test personnel. However, because of procedural changes during the collection of cycle 1 data, it is not possible to determine the effect of a tester being present in the room with younger children. Since measurement staff stayed in the room only when a child had difficulty following the testing procedures, research on the effect of tester-respondent interaction in the younger age group is warranted to determine if a systematic difference exists between measurements taken in the presence versus the absence of a staff member. Continued monitoring of staff is important to ensure that factors that could affect BP and HR (for example, incorrect arm position) are avoided.

Conclusions

The protocol used to measure BP and HR in cycle 1 of the CHMS was found to be suitable for cycle 2, with only minor modifications based on the findings in this study. These findings indicate no apparent advantage to performing a third series of six BP measurements, since very few respondents with initial values above the screening cut-points were subsequently screened into the fitness testing. Further methodological work is needed to determine the optimal rest period and the number of blood pressure measurements required to obtain valid and reliable estimates, while minimizing respondent burden. The BP equipment and protocol resulted in no detectable inter-tester variability, indicating that the procedures effectively eliminate this variability. The ocsillometric BP procedure appears to be suitable for population surveys, provided that rigorous quality assurance, quality control and calibration procedures are in place. ■

References

1. He J, Whelton PK. Epidemiology and prevention of hypertension. *The Medical Clinics of North America* 1997; 81: 1077–97.
2. Whelton PK. Epidemiology of hypertension. *Lancet* 1994; 344: 101-6.
3. World Health Organization. *The World Health Report 2002, Reducing Risks, Promoting Healthy Life*. Geneva: World Health Organization, 2002.
4. Lawes CM, Vander Hoorn S, Rodgers, A. Global burden of blood-pressure-related disease, 2001. *Lancet* 2008; 371: 1513-8.
5. Kearney PM, Whelton M, Reynolds K, et al. Global burden of hypertension: analysis of worldwide data. *Lancet* 2005; 365: 217-23.
6. Connor Gorber S, Tremblay MS, Campbell N, Hard J. The accuracy of self-reported hypertension: a systematic review and meta-analysis. *Current Hypertension Reviews* 2005; 4: 36-62.
7. MacLean DR, Petrasovits A, Nargundkar M. Canadian Heart Health Surveys: a profile of cardiovascular risk. Survey methods and data analysis. *Canadian Medical Association Journal* 1992; 146(11): 1969-2029.
8. Joffres MR, Ghadirian P, Fodor JG, et al. Awareness, treatment, and control of hypertension in Canada. *American Journal of Hypertension* 1997; 10: 1097-102.
9. Tremblay M., Wolfson M., Gorber SC. Canadian Health Measures Survey: Rational, background and overview. *Health Reports* (Statistics Canada, Catalogue 82-003) 2007;18(supplement): 7-20.
10. Giroux S. Canadian Health Measures Survey: Sampling strategy. *Health Reports* (Statistics Canada, Catalogue 82-003) 2007; 18(supplement): 31-6.
11. Campbell NRC, Joffres MR, McKay DW. Hypertension surveillance in Canada. Minimum standards for assessing blood pressure in surveys. *Canadian Journal of Public Health* 2005; 96: 217-20.
12. Wright JM, Mattu GS, Perry Jr TL, et al. Validation of a new algorithm for the BPM-100 electronic oscillometric office blood pressure monitor. *Blood Pressure Monitoring* 2001; 6: 161-5.
13. Pan American Hypertension Initiative. Working meeting on blood pressure measurement: suggestions for measuring blood pressure to use in population surveys. *Pan American Journal of Public Health* 2003; 14(5): 300-2.
14. Pereira M, Lunet N, Azeved H, Barros H. Differences in prevalence, awareness, treatment. and control of hypertension between developing and developed countries. *Journal of Hypertension* 2009; 27: 963-75.
15. Tremblay M., Langlois R., Bryan S., et al. Canadian Health Measures Survey Pre-test: Design, methods and results. *Health Reports* (Statistics Canada, Catalogue 82-003) 2007; 18(supplement): 21-30.
16. VSM MedTech Ltd. *BpTRU™ Operator's Manual*. 2004.
17. Statistics Canada. *Canadian Health Measure Survey (CHMS) Household Questionnaire*. Available at: http://www.statcan.gc.ca/imdb-bmdi/instrument/5071_Q1_V1-eng.pdf.
18. Statistics Canada. *Canadian Community Health Survey (CCHS) Questionnaire*. 2007. Available at: http://www.statcan.gc.ca/imdb-bmdi/instrument/3226_Q1_V4-eng.pdf. Accessed March 5, 2009].
19. Statistics Canada. *Canadian Health Measures Survey (CHMS) Clinic Questionnaire*. Available at: http://www.statcan.gc.ca/imdb-bmdi/instrument/5071_Q2_V1-eng.pdf.
20. Bryan SN, St-Denis M, Wojtas D. Canadian Health Measures Survey: Clinic operations and logistics. *Health Reports* (Statistics Canada, Catalogue 82-003) 2007; 18(supplement): 53-70.
21. Canadian Society for Exercise Physiology. *The Canadian Physical Activity, Fitness & Lifestyle Approach, Third Edition*. Ottawa: Canadian Society for Exercise Physiology, 2004.
22. Statistics Canada. *Canadian Health Measures Survey (CHMS) Data Users' Guide: Cycle 0.1, September 2007*. Available at: www.statcan.gc.ca.
23. Abbott D, Campbell N, Carruthers-Czyzewski P, et al. Guidelines for measurement of blood pressure, follow-up, and lifestyle counselling. *Canadian Journal of Public Health*. 1994; 85(Suppl 2): S29-S35.
24. National High Blood Pressure Education Program Working Group on High Blood Pressure in Children and Adolescents. The fourth report on the diagnosis, evaluation, and treatment of high blood pressure in children and adolescents. *Pediatrics* 2004; 114: 555-76.
25. Statistics Canada. *Canadian Health Measures Survey (CHMS) Derived Variable Document*. Available at: www.statcan.gc.ca.