FEATURE

# Bicycling: Health Risk or Benefit?

Kay Teschke[a], Conor C.O. Reynolds[b], Francis J. Ries[c], Brian Gouge[c], Meghan Winters[d]

[a]School of Population and Public Health, University of British Columbia, Vancouver, BC
[b]Liu Institute for Global Issues, University of British Columbia, Vancouver, BC
[c]Institute for Resources, Environment & Sustainability, University of British Columbia, Vancouver, BC
[d]Faculty of Health Sciences, Simon Fraser University, Burnaby, BC

## INTRODUCTION

In the last decade, there has been new interest in promoting cycling as a mode of transportation in North America.[1] Two of the largest cities in the United States, New York and Chicago, have set aggressive targets for increased cycling, and to meet them, have launched programs to construct connected networks of bicycle infrastructure.[2] Canadian cities are also seeing changes, as illustrated in our three largest cities. Montreal has a system of separated bike lanes throughout its downtown core and implemented its pioneering BIXI bikeshare system in 2009. Toronto adopted the BIXI system in the summer of 2011, and is considering building separated lanes. Vancouver began installing separated lanes on major streets in its downtown core in 2009 as a complement to a system of designated bike routes elsewhere in the city.

The motivations for these changes are multifaceted. At the municipal level, they include the impossibility of managing traffic congestion via increased roadways, green city strategies aimed at reducing air pollution and greenhouse gases, and a recognition that the vitality of cities is better promoted by people who are not enclosed in vehicles, but walking, cycling, and interacting with each other.[3] In the public health realm, "active transportation" (physically active travel modes such as walking and cycling) has become a focus of attention following research showing that the design of cities and the connectivity of streets affect both our likelihood of walking and our health.[4] Canadians use active transport modes less than Europeans, so there is room for improvement. Bicycling offers the greatest opportunity for change. The percentage of trips via cycling in Canada (less than 2%) is very low in comparison to many northern European countries with similar climates and demographics. Cycling rates are five times higher in Finland, Germany, and Sweden, and ten or more times higher in Denmark and the Netherlands.[2] In addition, cycling offers an efficient transportation mode for short distance trips not easily made on foot.

Despite the many motivations, promotion of cycling has been controversial. Some car users have been concerned about losing road space, and bike lanes have been a prominent issue in municipal elections in both Toronto and Vancouver. In addition, there is concern about safety by both members of the public and by health professionals who have advocated helmet use.[5,6] In this article, we focus on the health elements of the controversy: what are the potential benefits of cycling; what are the risks; and do the benefits outweigh the risks?

> "The economic costs of physical inactivity and obesity in Canada in 2001 were estimated at $5.3 billion and $4.3 billion, respectively.

## METHOD

This article provides an overview of the scientific literature on these issues, based on a search that employed the following bibliographic databases: Web of Science (http://apps.isiknowledge.com); PubMed (http://www.pubmed.gov); Transportation Research Information Services (http://tris.trb.org); and Google Scholar (http://scholar.google.com). Text word searches of article titles and abstracts were conducted using combinations of the following keywords: active transportation, cyclist, bicycling, physical activity, traffic, benefit, risk, cost, safety, health, injury, accident, air pollution, exposure, and noise. Reference lists of papers were reviewed and expert colleagues were asked to identify additional references that should be included. The initial literature search was conducted up to the end of March 2010, with a search for additional risk-benefit literature up to the end of November 2011.

All papers identified were screened for relevance using the title and/or abstract. English-language literature in the following areas was sought: studies that directly examined benefits and/or risks of cycling; where direct evidence was not available, studies that provided indirect evidence; papers that reviewed the above literature; and papers that addressed research challenges. Some of the literature grouped results for cycling and walking, since both are active modes of transportation. Where separate evidence was available for cycling, it was preferred; where evidence was only available for the two modes grouped, we have included it.

Correspondence
Kay Teschke, kteschke@mac.com

## HEALTH BENEFITS OF CYCLING

**Physical activity and health**

Data from the Canadian Community Health Survey in 2005 showed that only 24% of adults were physically active, 35% were overweight, and 16% were obese.[7] Obesity and physical inactivity are strongly related. The World Health Organization (WHO) listed them as two of the five leading global risks for mortality, responsible for 16.1% of deaths in high income countries.[8] WHO estimated that obesity is responsible for the following global disease burdens: 44% of diabetes; 23% of ischaemic heart disease; and 7 to 41% of certain cancers.[8] Estimates for physical inactivity burdens were 27% of diabetes, 30% of ischaemic heart disease, and 21 to 25% of breast and colon cancers.[8]

Data at the individual and population level show that cycling for transportation can increase physical activity and reduce weight. People who cycle or walk to work are more likely to be fit and less likely to be overweight or obese than those who use motorized modes.[9] Data from national surveys of travel behaviour and health indicators show that countries with the highest levels of cycling and walking have the lowest obesity rates.[10] Active transportation is effective because it provides a means for individuals to incorporate moderate intensity activities into their daily routines. This has been shown to be more sustainable over time than structured activity programs (e.g., running or going to the gym), yet has similar health benefits.[11] This is supported by evidence that people who commute by active transport get more physical activity on average than people who use motorized transport.[12,13] Thus, increasing cycling as a mode of transportation offers a promising way to address widespread levels of inactivity and overweight in the Canadian population.

Studies have also shown direct links between transportation–related physical activity and health outcomes. People who commuted by bike or on foot experienced significant improvements in cardiovascular indicators of fitness compared to those who use motorized modes.[13,14] Men who cycled at least 25 km per week had less than half the risk of non–fatal and fatal coronary heart disease of those who were not physically active.[15] A study of physical activity and type 2 diabetes showed a 35% reduction in risk with at least 30 minutes per day of commuting by bike or on foot, a greater reduction than with physical activity during leisure time or at work.[16] A recent meta–analysis concluded that cycling or walking to work was associated with an 11% reduction in cardiovascular disease risk.[17] All–cause mortality has been found to be lower among men and women of all ages who cycled for transportation.[18] A recent meta–analysis of physical activity and all–cause mortality found reductions with all types of physical activity, including active transportation, with greater reductions in mortality with more time spent cycling and walking.[19]

In addition to physical health, increased activity benefits mental health. A meta–analysis found that exercise as a treatment for depression was more effective than no treatment, was as effective as traditional interventions in some instances, and had equivalent adherence rates to medication.[20] Regular activity at least once a week was associated with reduced risk of sleep disorders.[21]

The health issues associated with inactivity and obesity cause hardship for individuals but they also have substantial costs for society. The economic costs of physical inactivity and obesity in Canada in 2001 were estimated at $5.3 billion and $4.3 billion, respectively.[22]

**Lower levels of air pollution, greenhouse gases, noise and congestion**

One of the reasons that cities are promoting cycling is its potential to reduce air pollution and greenhouse gas emissions. Traffic–related air pollution is associated with increased non–accidental, lung cancer, and cardiovascular mortality.[23] The potential effects of climate change on health are more wide ranging. Heat episodes are one example; they consistently result in increased cardiovascular and respiratory mortality, especially among the elderly.[24] Cycling produces no in–use emissions and has low lifecycle greenhouse gas emissions.[25,26] Because it does not produce any direct emissions, it is often cited as offering opportunities to improve air quality on a neighbourhood or regional scale.[27,28] However, for such benefits to be realized, cycling needs to be a substitute for a significant proportion of motorized transportation, as it is in countries like the Netherlands and Denmark.[2,29]

Noise and congestion are additional negative consequences of motor vehicle traffic. In recent years, traffic noise has been shown to be an urban health risk that impacts childhood development and increases adult myocardial infarction and total ischemic heart disease risks.[30,31] Traffic congestion is a significant economic issue, with impacts estimated at up to 3% of gross domestic product (GDP) for many cities.[32] Cycling has been promoted as an approach for reducing both traffic noise and congestion,[2,32,33] but to our knowledge there have been no studies verifying these potential benefits.

## HEALTH RISKS OF CYCLING

**Injury risk**

Unfortunately, trips by bicycle face higher risks of fatality and injury per trip and per distance travelled than trips by automobile. In the United States from 1999 to 2003, the fatality rate per bike trip was about 2.3 times that for automobile trips, and the police-reported injury rate per bike trip was about 1.8 times that for automobile trips.[34] The greater distances travelled on motor vehicle trips (bike trips are about half the distance of motor vehicle trips) mean that the difference in risk per distance travelled would be greater still. Canadian data suggest a similar pattern. In 2006, there were 2125 deaths among motor vehicle drivers and passengers (74% of all traffic-related deaths), and 73 deaths among cyclists (2.5% of all traffic-related deaths).[35] Census data in the same year indicated that 80% of trips to work were by car and 1.3% of trips to work were by bicycle,[36] suggesting that proportionately more fatalities happen during travel by bicycle.

However, Canadian data over a 2-decade period provide encouraging news: traffic fatalities by all modes have declined at a steady pace, and cycling deaths appear to have declined at a slightly faster rate (Figures 1a and 1b).[37-40]

In addition, there is evidence that injury and fatality rates decrease as cycling mode share increases, an effect that has

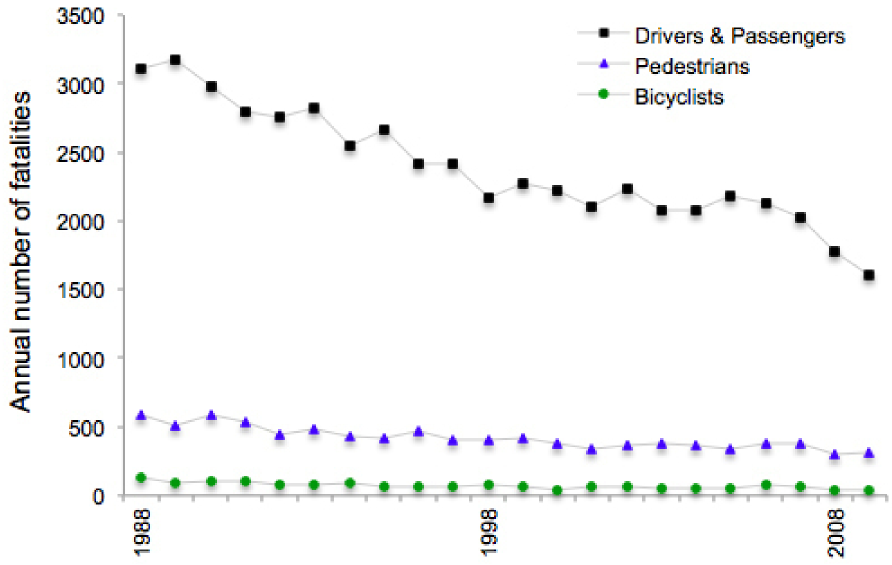


**Figure 1a.** Traffic collision fatalities by road user class, in Canada, 1988 to 2009.

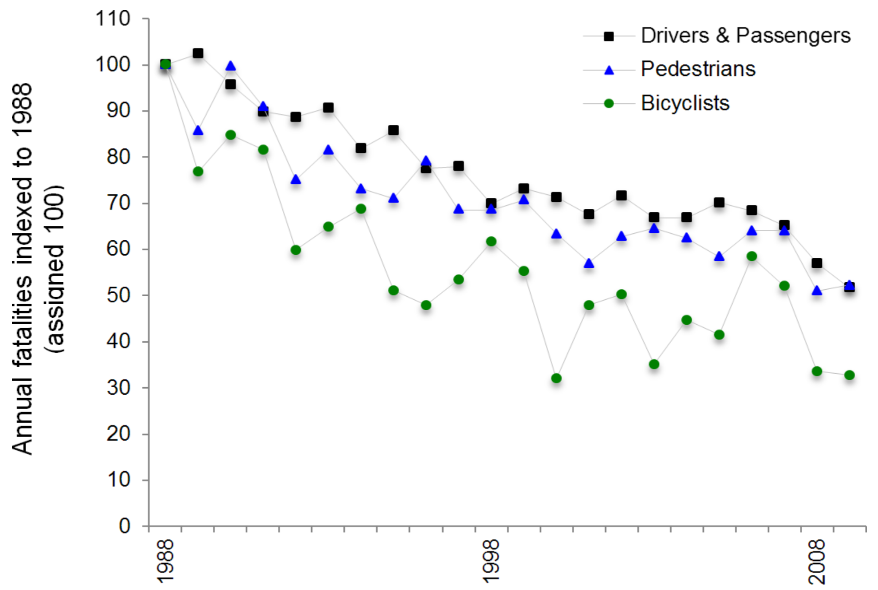


**Figure 1b.** Trend in number of traffic collision fatalities in Canada indexed to 1988 (assigned 100), by road user class, 1988 to 2009..

been dubbed "safety in numbers".[41,42] In the Netherlands, where almost 30% of trips are by bicycle, the fatality risk was 1.1 per 100 million km cycled, versus 3.6 and 5.8 per 100 million km cycled in the UK and the US, respectively, where about 1% of trips are by bicycle.[2] There remains concern that, with increased cycling mode share, there may be a net increase in the absolute number of traffic injuries, because of the shift from a lower risk to a higher risk mode of transport. However, Elvik suggested that if enough trips were converted from driving to cycling or walking, reductions in overall traffic fatalities might be observed, because of the safety in numbers effect and the lower volume of automobile traffic.[43] This effect may be operating in the Netherlands; the overall traffic fatality rate in 2009 was much lower in the Netherlands (3.9/100,000 population) than in Canada (6.3/100,000 population).[44]

**Risk from exposure to air pollution**

Although population–level reductions in air pollution have been suggested as a potential benefit of major shifts from driving to bicycling, air pollution exposure can present a risk to individual cyclists. Results of personal exposure studies are mixed. Cyclists generally experience lower exposures to fine and ultrafine particulate matter, volatile organic compounds, and carbon monoxide compared to those inside vehicles.[45,46] The benefits of lower exposure levels may be offset to some degree by longer travel times and increased pollutant uptake due to increased respiratory ventilation, approximately 2 to 4 times that of motor-vehicle occupants.[47-49] There is some evidence that cyclists may experience higher exposures than car drivers if they travel on busy routes.[50,51] However, they can reduce their pollution exposure significantly by choosing low-traffic routes.[52-54]

## WEIGHING THE BENEFITS AND RISKS

One of the earliest efforts at quantifying the tradeoffs between benefits and risks of cycling was completed by the British Medical Association 20 years ago.[55] It enumerated a benefit to risk ratio (years of life gained versus lost) of 20 to 1 and concluded that "in spite of the hostile environment in which most cyclists currently ride, the benefits in terms of health promotion and longevity far outweigh the loss of life years in injury on the roads."[55]

Over the last few years, a number of teams have synthesized more recent evidence.[27,28,56-58] Table 1 summarizes the results of these studies, examining one North American setting and four European settings. All studies considered the benefits of increased physical activity, and all but one considered the risks of traffic injuries. All studies considered the impact of air pollution, though two considered its impact only on risk and two only on benefit. The benefits and risks were calculated in different ways (deaths prevented, reductions in disability-adjusted life years, and monetary costs of premature death).

The conclusions of all studies supported that of the British Medical Association: there is a large net health benefit of increased cycling, since the risk of fatal injury is greatly outweighed by the reductions in mortality afforded by increased physical activity. Air pollution risks and benefits had smaller impacts in either direction. Benefit to risk ratios ranged between 9 to 1 and 96 to 1.

The degree of uncertainty in the estimates was illustrated by some large differences between studies. This research area faces a number of methodological challenges: identifying the population affected by a change; assessing behaviour changes; and quantifying health outcomes. There are also potential risks and benefits that were not considered in the analyses to date: for

> If enough trips were converted from driving to cycling or walking, reductions in overall traffic fatalities might be observed.

example, skin cancer risk or increased vitamin D production from sun exposure; and the benefits associated with mitigation of global climate change.[59] Rabl and de Nazelle made some initial estimates for non–fatal injuries, noise, and congestion.[57] These suggested relatively minor increases in cost from non–fatal injuries and large benefits from reduced noise and congestion (comparable to those from increased physical activity).

## REAPING THE BENEFITS, MANAGING THE RISKS

Given the substantial health benefits that accrue from bicycling as a mode of transportation, the new public health focus on promoting its use is well founded. It is also reasonable to promote means to mitigate any risks. A number of evidence-based strategies for managing risks exist. Cyclists can be encouraged to wear helmets, which reduce the chance of head and face injuries in the event of a crash.[6,60] However, helmets do not prevent crashes from happening in the first place. The methods used to protect cyclists in the Netherlands, where helmet use is rare and injury rates are low, appear to have been successful in this regard.[2] Their approach has been to construct bicycle–specific facilities, the design of which varies depending on motor vehicle traffic volumes and speeds.[2,44] Typically, on major streets, "cycle tracks" are used to physically separate cyclists from faster (motor vehicle) and slower (pedestrian) traffic. On residential streets, motor vehicle traffic is restricted and kept slow, with speed limits of 30 km/h. A recent review and other emerging evidence show that bicycle–specific facilities (e.g., cycle tracks, residential street bike routes, on–road marked bike lanes, and off–road bike paths) reduce crashes and injuries to cyclists.[61-63] Most of these route types are favoured by all types of people, from young men to older adults with children, from regular cyclists to those who are just considering cycling.[64] They should help motivate cycling and thus help induce safety in numbers. In addition, route types separated from traffic are likely to have lower air pollution and noise exposures.

The good news is that developments in North American cities are much more focussed on creating favourable environments for cycling, similar to the Dutch model. Whether we reap the benefits depends on all of us.

## ACKNOWLEDGEMENT

CCOR, FJR and MW acknowledge support from the University

**Table 1.** Summary of some recent studies of the health risks and benefits of increased bicycline or bicycling and walking.

| Authors | Location | Changes / effects being considered | Risk Estimate | Benefit Estimate | Balance of Risk and Benefit |
|---|---|---|---|---|---|
| Grabow et al, 2011 [27] | USA, 11 metropolitan areas in the mid-west | Conversion of 50% of automobile round trips of ≤ 8 km to cycling. | None evaluated | More physical activity: 687 fewer deaths.<br>Reductions in ozone air pollution: 9 fewer deaths.<br>Reductions in particulate air pollution: 433 fewer deaths. | Combined effect: 1,129 fewer deaths in 31.9 million population = 35 fewer deaths per million population per year.<br>Benefit to risk ratio: cannot be calculated, no risks considered. |
| Woodcock et al., 2009 [28] | London, England | Increased active transportation: 2 times as much walking & 8 times as much cycling.<br>Effects on cardiovascular disease, breast cancer, colon cancer, dementia, depression, and diabetes. | More traffic crashes: 11 more premature deaths and 519 fewer disability-adjusted life-years (DALYs) per million population. | More physical activity: 528 fewer premature deaths and 7,742 more DALYs per million population.<br>Reductions in air pollution: 21 fewer premature deaths and 200 more DALYs per million population. | Combined effect: 530 fewer premature deaths and 7,332 more disability-adjusted life-years per million population per year.<br>Benefit to risk ratio: ~ 49:1 for premature deaths; ~ 15:1 for DALYs |
| Johan de Hartog et al., 2010 [56] | Netherlands | 500,000 adults switch from car to bicycle for trips < 7.5 km.<br>Effect on life years. | More traffic crashes: loss of 9,639 life years.<br>More air pollution inhaled: loss of 28,135 life years. | More physical activity: gain of 337,896 life years. | Combined effect: gain of 7 months of life per person = 583,333 years per million population over the life course.<br>Benefit to risk ratio: ~ 9:1 |
| Rabl & de Nazelle, 2012 [57] | Europe | Driver who switches to 5 km of cycling.<br>Effect on all cause mortality. | More traffic crashes: loss of 53 Euros/yr.<br>More air pollution inhaled: loss of 19 Euros/yr. | More physical activity: gain of 1310 Euros/yr.<br>Reductions in air pollution: gain of 33 Euros/yr. | Combined effect: gain of 1,271 Euros/yr per car driver who switches to cycling = 1.3 billion Euros/yr per million car drivers who switch.<br>Benefit to risk ratio: ~ 19:1 |
| Rojas-Rueda et al., 2011 [58] | Barcelona, Spain | 181,982 subscribers to a public bike share program compared to car drivers.<br>Effect on all cause mortality. | More traffic crashes: 0.03 more deaths.<br>More air pollution inhaled: 0.13 more deaths. | More physical activity: 12.5 fewer deaths. | Combined effect: 12.3 fewer deaths per year = 67 fewer deaths per million population per year.<br>Benefit to risk ratio: ~ 96:1 |

of British Columbia Bridge Program. This paper was based in part on an Evidence Review prepared for the National Collaborating Center for Environmental Health of the Public Health Agency of Canada:

Conor CO Reynolds, Meghan Winters, Francis J. Ries, Brian Gouge. 2010. Active transportation in urban areas: Exploring health benefits and risks. http://www.ncceh.ca/sites/default/files/Active_Transportation_in_Urban_Areas_June_2010.pdf

## REFERENCES


1. Mapes J. Pedaling revolution - how cyclists are changing American cities. Corvallis, OR: Oregon State University Press; 2009.
2. Pucher J, Buehler R. Making cycling irresistible: lessons from the Netherlands, Denmark and Germany. Transport Rev 2008;28:495-528.
3. Gehl J. Cities for people. Washington, DC: Island Press; 2010.
4. Frank L, Engelke P, Schmid T. Health and community design: the impact of the built environment on physical activity. Washington, DC: Island Press; 2003.
5. Winters M, Davidson G, Kao D, Teschke K. Motivators and deterrents of bicycling: comparing influences on decisions to ride. Transport 2011;38:153-168
6. Thompson D, Rivara F, Thompson R. Helmets for preventing head and facial injuries in bicyclists. Cochrane Database Syst Rev 2000:CD001855.
7. CFLRI. 2007 physical activity monitor. Ottawa, ON: Canadian Fitness and Lifestyle Research Institute; 2008.
8. WHO. Global health risks: mortality and burden of disease attributable to selected major risks. Geneva: WHO Press; 2009 [cited December 13, 2011]. Available from: http://www.who.int/healthinfo/global_burden_disease/global_health_risks/en/index.html
9. Gordon-Larsen P, Nelson MC, Beam K. Associations among active transportation, physical activity, and weight status in young adults. Obes Res 2005;13:868-875
10. Bassett DR, Pucher J, Buehler R, Thompson DL, Crouter SE. Walking, cycling, and obesity rates in Europe, North America, and Australia. J Phys Act Health 2008;5:795-814.
11. Dunn A, Marcus B, Kampert J, Garcia M, Kohl HR, Blair S. Comparison of lifestyle and structured interventions to increase physical activity and cardiorespiratory fitness: a randomized trial. JAMA 1999;281:327-34.
12. Buehler R, Pucher J, Merom D, Bauman A. Active travel in Germany and the U.S. Contributions of daily walking and cycling to physical activity. Am J Prev Med 2011;41:241-50.
13. Oja P, Vuori IM, Paronen O. Daily walking and cycling to work: their utility as health-enhancing physical activity. Patient Educ Couns 1998;33:S87-S94.
14. Gordon-Larsen P, Boone-Heinonen J, Sidney S, Sternfeld B, Jacobs Jr DR, Lewis CE. Active commuting and cardiovascular disease risk: the CARDIA study. Arch Intern Med 2009;169:1216–23.
15. Morris J, Clayton D, Everitt M, Semmence A, Burgess E. Exercise in leisure time: coronary attack and death rates. Brit Heart J 1990;63:325-34.
16. Hu G, Qiao Q, Silventoinen K, Eriksson JG, Jousilahti P, Lindstrom J, et al. Occupational, commuting, and leisure-time physical activity in relation to risk for type 2 diabetes in middle-aged Finnish men and women. Diabetologia 2003;46:322–9.
17. Hamer M, Chida Y. Active commuting and cardiovascular risk: a meta-analytic review. Prev Med 2008;46:9-13.
18. Andersen LB, Schnohr P, Schroll M, Hein HO. All-cause mortality associated with physical activity during leisure time, work, sports, and cycling to work. Arch Intern Med 2000;160:1621-1628.
19. Samitz G, Egger M, Zwahlen M. Domains of physical activity and all-cause mortality: systematic review and dose-response meta-analysis of cohort studies. Int J Epidemiol 2011;40:1382-400.
20. Daley A. Exercise and depression: a review of reviews. J Clin Psychol Med Settings 2008;15:140-147.
21. Sherrill D, Kotchou K, Quan S. Association of physical activity and human sleep disorders. Arch Intern Med 1998;158:1894-8.
22. Katzmarzyk P, Janssen I. The economic costs associated with physical inactivity and obesity in Canada: an update. Can J Appl Physiol 2004;29:90-115.
23. Chen H, Goldberg MS, Villeneuve PJ. A systematic review of the relation between long-term exposure to ambient air pollution and chronic diseases. Rev Environ Health 2008;23:243-97
24. Åström DO, Forsberg B, Rocklöv J. Heat wave impact on morbidity and mortality in the elderly population: a review of recent studies. Maturitas 2011;69:99-105
25. Walsh C, Jakernan P, Moles R, O'Regan B. A comparison of carbon dioxide emissions associated with motorised transport modes and cycling in Ireland. Transport Res Part D - Transport Environ 2008;13:392-399.
26. Boies A, Hankey S, Kittelson D, Marshall J, Nussbaum P, Watts W, Wilson E. Reducing motor vehicle greenhouse gas emissions in a non-California state: a case study of Minnesota. Environ Sci Technol 2009;4:8721-8729.
27. Grabow ML, Spak SN, Holloway T, Stone Jr. B, Mednick AC, Patz JA. Air quality and exercise-related health benefits from reduced car travel in the midwestern United States. Environ Health Perspect 2012;120:68-76
28. Woodcock J, Edwards P, Tonne C, Armstrong B, Ashiru O, Banister D, et al. Public health benefits of strategies to reduce greenhouse-gas emissions: urban land transport. Lancet 2009;374:1930-43.
29. Thomson H, Jepson R, Hurley F, Douglas M. Assessing the unintended health impacts of road transport policies and interventions: translating research evidence for use in policy and practice. BMC Public Health 2008;8:339.
30. Stansfeld S, Matheson M. Noise pollution: non-auditory effects on health. Brit Med Bull 2003;68:243-257.
31. Van Kempen E, Kruize H, Boschuizen H, Ameling C, Staatsen B, De Hollander A. The association between noise exposure and blood pressure and ischemic heart disease: a meta-analysis. Environ Health Perspect 2002;110:307-317.
32. Woodcock J, Banister D, Edwards SP, Prentice AM, Roberts I. Energy and health 3 - energy and transport. Lancet 2007;370:1078-1088.
33. Sallis JF, Frank LD, Saelens BE, Kraft MK. Active transportation and physical activity: opportunities for collaboration on transportation and public opportunities health research. Transport Res Part A - Policy Practice 2004;38:249-268.
34. Beck LF, Dellinger AM, O'Neil ME. Motor vehicle crash injury rates by mode of travel, United States: using exposure-based methods to quantify differences. Am J Epidemiol 2007;166:212-8
35. Canadian Motor Vehicle Traffic Collision Statistics: 2006. Transport Canada. 2008; [cited ]; TP 3322. Available from: http://www.tc.gc.ca/eng/roadsafety/tp-tp3322-2006-menu-586.htm
36. Commuting Patterns and Places of Work of Canadians, 2006 Census. Statistics Canada. 2008; [cited December 13, 2011]; Catalogue no. 97-561-X. Available from: http://www12.statcan.ca/census-recensement/2006/as-sa/97-561/tables-tableaux-notes-eng.cfm
37. Trends in Motor Vehicle Traffic Collision Statistics 1988 – 1997. Transport Canada. 2001; [cited December 13, 2011]; TP 13743 E. Available from: http://www.tc.gc.ca/media/documents/roadsafety/Trends_88-97.pdf
38. Canadian Motor Vehicle Traffic Collision Statistics: 1999. Transport Canada. 2001; [cited December 13, 2011]; TP 3322. Available from: http://dsp-psd.pwgsc.gc.ca/Collection/T45-3-1999E.pdf
39. Canadian Motor Vehicle Traffic Collision Statistics: 2004. Transport Canada. 2006; [cited December 13, 2011]; TP 3322. Available from: http://www.tc.gc.ca/eng/roadsafety/tp-tp3322-2004-menu-691.htm
40. Canadian Motor Vehicle Traffic Collision Statistics: 2009. Transport Canada. 2011; [cited December 13, 2011]; TP 3322. Available from: http://www.tc.gc.ca/eng/roadsafety/tp-tp3322-2009-1173.htm
41. Jacobsen PL. Safety in numbers: more walkers and bicyclists, safer walking and bicycling. Inj Prev 2003;9:205-209.
42. Robinson DL. Safety in numbers in Australia: more walkers and bicyclists, safer walking and bicycling. Health Promot J Austral 2005;16:47-51.
43. Elvik R. The non-linearity of risk and the promotion of environmentally sustainable transport. Accid Anal Prev 2009;41:849-855.
44. International Traffic Safety and Analysis Group. IRTAD Annual Report 2010. OECD and International Transport Forum. 2010.[cited December 13, 2011]: Available from: http://internationaltransportforum.org/irtadpublic/pdf/10IrtadReport.pdf
45. Boogaard H, Borgman F, Kamminga J, Hoek G. Exposure to ultrafine and fine particles and noise during cycling and driving in 11 Dutch cities. Atmospher Environ 2009;43:4234-4242.
46. Rank J, Folke J, Jespersen PH. Differences in cyclists and car drivers' exposure to air pollution from traffic in the city of Copenhagen. Sci Total Environ 2001;279:131-6.
47. Briggs DJ, De Hoogh K, Morris C, Gulliver J. Effects of travel mode on exposures to particulate air pollution. Environ Int 2008;34:12-22.
48. Int Panis L, de Geus B, Vandenbulcke G, Willems H, Degraeuwe B, Bleux N, et al. Exposure to particulate matter in traffic: a comparison of cyclists and car passengers. Atmospher Environ 2010;44:2263-70
49. Zuurbier M, Hoek G, Oldenwening M, Lenters V, Meliefste K, Van Den Hazel P, et al. Commuters' exposure to particulate matter air pollution is affected by mode of transport, fuel type and route. Environ Health Perspect 2010;118:783-9.

50. McCreanor J, Cullinan P, Nieuwenhuijsen MJ, Stewart-Evans J, Malliarou E, Jarup L, et al. Respiratory effects of exposure to diesel traffic in persons with asthma. New Eng J Med 2007;357:2348-2358.
51. McNabola A, Broderick BM, Gill LW. Relative exposure to fine particulate matter and VOCs between transport microenvironments in Dublin: personal exposure and uptake. Atmospher Environ 2008;42:6496-6512.
52. Hertel O, Hvidberg M, Ketzel M, Storm L, Stausgaard L. A proper choice of route significantly reduces air pollution exposure - a study on bicycle and bus trips in urban streets. Sci Total Environ 2008;389:58-70.
53. Strak M, Boogaard H, Meliefste K, Oldenwening M, Zuurbier M, Brunekreef B, et al. Respiratory health effects of ultrafine and fine particle exposure in cyclists. Occup Environ Med 2010;67:118-24.
54. Thai A, McKendry I, Brauer M. Particulate matter exposure along designated bicycle routes in Vancouver, British Columbia. Sci Total Environ 2008;405:26-35.
55. British Medical Association. Cycling: Towards Health and Safety. Oxford: Oxford University Press; 1992.
56. Johan de Hartog J, Boogaard H, Nijland H, Hoek G. Do the health benefits of cycling outweigh the risks? Environ Health Perspect 2010;118:1109-16
57. Rabl A, Audrey de Nazelle A. Benefits of shift from car to active transport. Transport Policy 2012;19:121-131
58. Rojas-Rueda D, de Nazelle A, Tainio M, Nieuwenhuijsen MJ. The health risks and benefits of cycling in urban environments compared with car use: health impact assessment study. BMJ 2011;343:d4521. doi: 10.1136/bmj.d4521.
59. de Nazelle A, Nieuwenhuijsen MJ, Antó JM, Brauer M, Briggs D, Braun-Fahrlander C, et al. Improving health through policies that promote active travel: a review of evidence to support integrated health impact assessment. Environ Int 2011;37:766-77.
60. Elvik R. Publication bias and time-trend bias in meta-analysis of bicycle helmet efficacy: a re-analysis of Attewell, Glase and McFadden, 2001. Accid Anal Prev 2011;43:1245-51.
61. Lusk AC, Furth PG, Morency P, Miranda-Moreno LF, Willett WC, Dennerlein JT. Risk of injury for bicycling on cycle tracks versus in the street. Inj Prev 2011;17:131-5.
62. Reynolds CCO, Harris MA, Teschke K, Cripton PA, Winters M. The impact of transportation infrastructure on bicycling injuries and crashes: a review of the literature. Environ Health 2009;8:47.
63. Teschke K, Harris MA, Reynolds CCO, Winters M, Babul S, Chipman M, et al. Route infrastructure and the risk of injuries to bicyclists: a case-crossover study. Am J Public Health 2011; Accepted pending minor revisions.
64. Winters M, Teschke K. Route preferences among adults in the near market for cycling: findings of the cycling in cities study. Am J Health Promot 2010;25:40-47

# A Low Carbohydrate, High Protein Diet May Extend Your Life and Reduce Your Chances of Getting Cancer

Victor W. Ho, BSc[a], Gerald Krystal, PhD[b,c,d,e]

[a]Department of Experimental Medicine, Faculty of Medicine, University of British Columbia, Vancouver, BC
[b]Terry Fox Cancer Research Scientist of the NCI
[c]Professor, Pathology & Laboratory Medicine, University of British Columbia, Vancouver, BC
[d]Member, Experimental Medicine, University of British Columbia, Vancouver, BC
[e]Member, Genetics, University of British Columbia, Vancouver, BC

When glucose in our blood enters our cells, it is broken down via glycolysis to pyruvate. Pyruvate can then be converted into lactic acid and secreted, ending glycolysis, or into acetyl–CoA and broken down, with the help of oxygen ($O_2$), within mitochondria to carbon dioxide ($CO_2$) and water via oxidative phosphorylation (OXPHOS, i.e., the Kreb's, Citric acid, or tricarboxylic acid cycle).[1] In 1857, Louis Pasteur discovered that in the absence of $O_2$, normal cells survive by switching from OXPHOS, which generates 36 ATPs/glucose, to glycolysis, which only generates 2 ATPs/glucose. In the 1920s, Otto Warburg found that cancer (CA) cells, unlike normal cells, use glycolysis instead of OXPHOS even when $O_2$ is present, and this type of metabolism is called aerobic glycolysis or the Warburg effect.[1] Because most tumours use this less efficient energy generating system, they have to take up more blood glucose (BG) than normal cells to survive. This characteristic is the basis for identifying human CAs using PET scans with 18-fluorodeoxyglucose, a glucose analog.[2]

Importantly, every normal cell in our body is within 0.1 mm from a capillary, corresponding to the diffusion limit of $O_2$.[1] Thus, normal cells are no more than a few cell layers away from $O_2$ and nutrients.[3] However, glucose can diffuse slightly further than $O_2$, so when tumours grow beyond 0.1 mm, they can still acquire glucose and switch from OXPHOS to glycolysis by activating the transcription factor hypoxia inducible factor 1 (HIF1), which regulates over 70 different genes.[3] Amongst the genes turned on are cell surface glucose transporters (to increase glucose uptake), angiogenic factors (to induce the formation of new blood vessels), and enzymes (to enhance glycolysis and inhibit OXPHOS).[4,5] But why do CA cells still use glycolysis when $O_2$ is present? The answer is that many oncogenes, as well as inactivated tumour suppressors, activate HIF1.[4,6-8]

Correspondence
Gerald Krystal, gkrystal@bccrc.ca