CJC Pediatric and Congenital Heart Disease 3 (2024) 98–101

Editorial

The Weight of Trauma: Navigating Collider Stratification Bias in the Association Between Childhood Maltreatment and Adult Body Mass Index

Nicholas Grubic, MSc,[a] Jayati Khattar, MPH,[a] Vanessa De Rubeis, PhD,[b] Hailey R. Banack, PhD,[a] Julia Dabravolskaj, PhD,[c] and Katerina Maximova, PhD[a,c]

[a] Division of Epidemiology, Dalla Lana School of Public Health, University of Toronto, Toronto, Ontario, Canada

[b] Department of Psychiatry & Behavioural Neurosciences, Faculty of Health Sciences, McMaster University, Hamilton, Ontario, Canada

[c] MAP Centre for Urban Health Solutions, St. Michael's Hospital, Toronto, Ontario, Canada

In Canada, one-third of children do not enjoy a safe and healthy childhood.[1] This ranks Canada in the bottom 25% of affluent countries for child mental and physical well-being.[2] Childhood maltreatment, which encompasses all types of physical and emotional ill-treatment, sexual abuse, neglect, negligence, and exploitation, is a serious public health problem in Canada and globally.[1,3]

Experiencing childhood maltreatment can have enduring effects on health throughout the life course. These effects may include the adoption of risky health behaviours, poor mental and physical health, and chronic inflammation.[4,5] In turn, these factors can lead to increases in body weight,[5] which may have downstream consequences, including the risk of adult obesity and other chronic diseases (eg, type 2 diabetes, cancer, and cardiovascular disease).[6,7] Given the high prevalence of obesity in Canada, the identification of early-life contributing factors, such as childhood maltreatment, is needed to promote healthy development and reduce the burden of chronic disease.[6,8] Understanding the relationship between childhood maltreatment and health outcomes is important to inform the development of social policies and programmes that aim to ensure a safe and happy childhood for all children in Canada.

Key Findings

In this issue of the *Canadian Journal of Cardiology Pediatric & Congenital Heart Disease*, St-Arnaud et al.[9] conducted a secondary analysis of the BEL-AGE prospective cohort study to evaluate the association of childhood maltreatment with body mass index (BMI) among older adults with chronic illness. Childhood trauma (encompassing physical, sexual, and emotional subtypes) was assessed at enrolment, whereas BMI was measured at both baseline and 5 years after enrolment.

This study included 1232 older adults, with a mean age of 61 years. Nearly one-third (32.0%) of participants reported moderate to extremely severe scores on at least 1 subscale of the childhood maltreatment questionnaire, with 35.6% being classified as having obesity at the time of enrolment. Contrary to previous studies, childhood maltreatment was not significantly associated with BMI at baseline ($\beta = 0.004$, 95% confidence interval: −0.006 to 0.014) or at follow-up ($\beta = 0.001$, 95% confidence interval: −0.003 to 0.006) after adjusting for various sociodemographic, lifestyle, and clinical factors. No effect modification of this relationship by sex or coronary artery disease status was evident.

Strengths and Limitations

The authors leveraged data from a large Canadian cohort of older adults diagnosed with a chronic illness, thus capturing an under-represented population within the child maltreatment research field. Using a validated questionnaire to assess childhood trauma, alongside the objective measurement of anthropometric parameters by trained clinical staff, greatly reduced the potential for differential misclassification.[10]

To fully contextualize the findings of this study, it is essential to consider its limitations. Almost all included patients were White (98.5%), thus preventing the exploration of effect modification by race. This may also limit the generalizability of study findings to the racially diverse Canadian population. A review of child protective services reports has demonstrated ethnocultural variation in both reported and substantiated forms of maltreatment, which suggests that the association between childhood maltreatment and cardiometabolic health may vary across racialized groups.[11] Furthermore, the use of BMI to accurately reflect cardiometabolic health risks is an ongoing topic of debate.[12,13] This is largely due to its inability to comprehensively incorporate individual body composition, fat distribution, and

Received for publication April 23, 2024. Accepted May 2, 2024.

Corresponding author: Nicholas Grubic, Dalla Lana School of Public Health, University of Toronto, 155 College St, 6th Floor, Toronto, Ontario M5T 3M7, Canada.

E-mail: nicholas.j.grubic@gmail.com

https://doi.org/10.1016/j.cjcpc.2024.05.001

metabolic profiles, which have been shown to differ according to age and race.[14-17] Additional research to uncover racial disparities in the relationship between childhood maltreatment and cardiometabolic health, specifically using alternative weight-related metrics, will inform the design of tailored public health interventions.

Exploring the Influence of Collider Stratification Bias

Although the authors found no statistically significant association between childhood maltreatment and adult BMI, this finding should be carefully interpreted in the context of sample selection. In particular, this result may be partially explained by *collider stratification bias,* which is a form of selection bias due to restricting a sample to one level of a specific variable known as a *collider*.[18] This under-recognized type of bias is commonly visualized through the use of directed acyclic graphs (DAGs). In brief, DAGs are graphical tools that are used to describe potential or known pathways between an exposure and outcome by connecting variables (known as nodes) with unidirectional arrows (known as edges). The use of DAGs to reduce bias through study design and analytical decisions is becoming increasingly popular across various scientific fields, including child maltreatment and cardiometabolic research.[19-22] We refer the reader to the seminal article by Greenland et al.[23] and other helpful pieces for an in-depth introduction to DAGs.[24-26]

Collider stratification bias refers to a mechanism in which a common effect of 2 unrelated variables collides at a third variable, referred to as the *collider*, creating a spurious statistical association between the 2 unrelated variables.[27] By conditioning on a collider, which is commonly achieved through adjustment, stratification, or restriction in observational studies, the causal effect of interest can be biased. Figure 1 provides the general and study-specific structure of collider stratification bias, delineating potential biasing pathways of the causal relationship of interest (X→Y). In the present study, the selection of older individuals with a chronic illness (including, but not limited to, cardiovascular disease, arthritis, diabetes, and asthma) into the study sample may have led to collider stratification bias, thus providing a potential explanation for the unexpected null finding between childhood maltreatment and adult BMI.

According to DAG theory, all noncausal pathways connecting X to Y must be blocked to provide an unbiased effect estimate between X and Y (ie, only the causal pathway X→Y should remain open and unblocked). Blocking a noncausal pathway can be achieved by conditioning on a variable along a noncausal pathway (which was performed using restriction in the present study). In our fictitious example (Fig. 1A), the noncausal pathway X←L→Y can be blocked by conditioning on L, a known and measured confounder (or a common cause of both X and Y). In comparison, the noncausal pathway connecting X to Y that includes a collider C (X→C←U→Y) is not blocked when the collider is conditioned on.[28] Instead, conditioning on a collider induces a spurious association between X and U, thus opening a noncausal pathway from X to Y (X–U→Y). In other words, a noncausal path that includes a collider is already blocked (and thus the collider should not be conditioned on); however, it can be opened by conditioning on that collider. Reblocking this noncausal pathway would require conditioning on all common causes of the collider and Y, which may include various unknown and/or unmeasured variables (U). Therefore, after conditioning on both L and C in Figure 1A, 2 pathways connecting X to Y remain open: (1) the causal pathway (X→Y) and (2) the noncausal collider-induced pathway (X–U→Y). For this reason, conditioning on a collider through restriction (ie, restricting a sample to a certain singular stratum of a collider) is expected to lead to

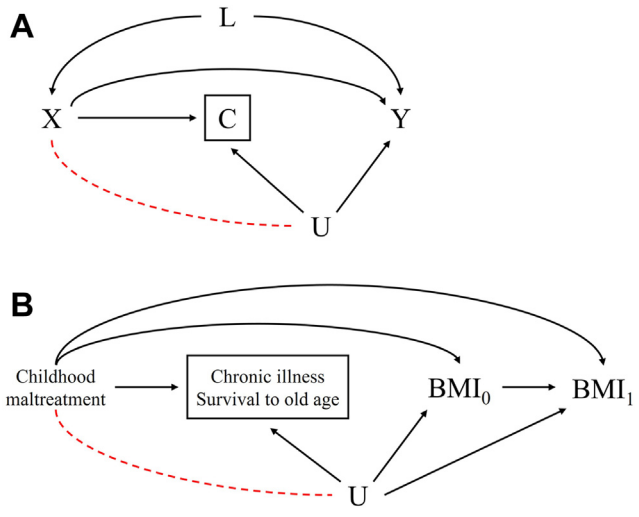

Figure 1. Directed acyclic graphs describing the structure of collider stratification bias. (**A**) By conditioning on the collider (C) and not conditioning on all unmeasured common causes of C and Y, a noncausal path between X and Y is opened via X–U→Y. (**B**) Collider stratification bias in the association between childhood maltreatment and adult BMI at 2 time points (0 = baseline, 1 = 5-year follow-up) among a sample of older adults with chronic illnesses. Additional covariates included in the final regression model were not included in the directed acyclic graph for simplicity. The **red dashed lines** indicate the spurious association created by conditioning on a collider. BMI, body mass index.

selection bias, which can distort the direct causal effect of interest (X→Y).[27,29]

St-Arnaud et al. recognized this potential selection bias in their study, which is common in research on older adults (Fig. 1B).[30] Individuals who experienced childhood maltreatment may have either died before study enrolment or reached an advanced stage of illness, rendering them unable to participate—*selection bias due to death or illness*. This is plausible given the well-known associations of childhood maltreatment with premature mortality and chronic diseases.[31,32] In the absence of conditioning on all common causes of chronic illness, survival to old age, and adult BMI (U in Fig. 1B), the causal effect estimate of childhood maltreatment on BMI will be biased. Although the authors controlled for various potential confounders (eg, sociodemographic characteristics, lifestyle behaviours, and clinical factors), adjusting for other unmeasured variables, such as childhood BMI and genetic factors (ie, potential variables for U in Fig. 1B), is necessary to obtain an unbiased measure of association according to this DAG. As with any study that evaluates life course epidemiologic relationships, obtaining accurate and repeated measurements of all unobserved variables poses a significant challenge. Nonetheless, restricting the study sample to individuals with a chronic illness who survived to old age may have biased (underestimated, in most cases) the true measure of association between childhood maltreatment and adult BMI due to collider stratification bias.[27,33]

Research in Context

In contrast to the results of this study, previous longitudinal investigations have reported on associations between experiences of childhood maltreatment and elevated risk of obesity during adulthood, even after controlling for confounders.[34,35] For example, in a study of 26,615 middle-aged and older adults participating in the Canadian Longitudinal Study on Aging, adversity during childhood exhibited a strong association with obesity measured using BMI and waist circumference.[36] This association has also been consistently documented in several systematic reviews.[5,17,37] The effects of gender and sex appear to vary across studies. One systematic review concluded that the association between childhood maltreatment and obesity was stronger in studies that included more women.[17] In comparison, another review found no effect modification by gender.[37] One recent study found no significant difference in the association between childhood maltreatment and BMI according to sex, as determined by genetic testing.[38]

Future Directions

Applying life course epidemiologic frameworks to consider sensitive or critical periods of development can help explain how childhood maltreatment may lead to adverse health effects, such as obesity later in life. Future work may consider evaluating trajectories of weight after exposure to childhood maltreatment, which may help to identify and better understand potential intervention windows for cardiometabolic health management. This is of importance as weight changes in older adults are recognized to be associated with frailty and an elevated risk of mortality.[39,40] In addition, studies should be designed in a manner that accounts for potential biases induced by collider stratification bias. At the study design level, the development of DAGs to describe causal associations is useful for detecting the presence of a collider, thereby reducing the possibility of erroneously conditioning on this variable.[19,20] Appropriate analytic strategies, such as marginal structural models, may also be employed to prevent collider stratification bias.[41] These models are instrumental in longitudinal studies with repeated measures of confounders, mediators, and colliders, which often leads to exposure-covariate feedback (ie, time-varying covariate affected by previous exposure).[42]

Conclusions

Continued research is needed to better understand the complex relationship of childhood maltreatment with obesity and other chronic conditions. Importantly, researchers should be aware of how biases, such as collider stratification bias, could inadvertently lead to complicated or inaccurate results.

Ethics Statement

The research reported in this article did not require ethics approval.

Patient Consent

The authors confirm that patient consent is not applicable to this article.

Funding Sources

NG is supported by the Canadian Institutes of Health Research (CIHR) Vanier Canada Graduate Scholarship.

Disclosures

The authors have no conflicts of interest to disclose.

References

1. Raising Canada. Top 10 threads to childhood in Canada and the impact of COVID-19. Available at: https://childrenfirstcanada.org/wp-content/uploads/2021/03/RaisingCanadaReport_Final_Sept.pdf; 2020. Accessed April 16, 2024.

2. UNICEF Canada. Worlds apart: Canadian summary of UNICEF report card 16. Available at: https://www.unicef.ca/sites/default/files/2020-08/UNICEFReportCard16CanadianSummary.pdf; 2020. Accessed April 16, 2024.

3. World Health Organization. Child maltreatment; 2022. https://www.who.int/news-room/fact-sheets/detail/child-maltreatment#:~:text=It includes all types of,of responsibility%2Ctrustorpower. Accessed April 16, 2024.

4. Hughes K, Bellis MA, Hardcastle KA, et al. The effect of multiple adverse childhood experiences on health: a systematic review and meta-analysis. *Lancet Public Heal*. 2017;2:e356–e366.

5. Wiss DA, Brewerton TD. Adverse childhood experiences and adult obesity: a systematic review of plausible mechanisms and meta-analysis of cross-sectional studies. *Physiol Behav*. 2020;223, 112964.

6. Valenzuela PL, Carrera-Bastos P, Castillo-García A, et al. Obesity and the risk of cardiometabolic diseases. *Nat Rev Cardiol*. 2023;20:475–494.

7. Hruby A, Manson JE, Qi L, et al. Determinants and consequences of obesity. *Am J Public Health*. 2016;106:1656–1662.

8. Twells LK, Gregory DM, Reddigan J, Midodzi WK. Current and predicted prevalence of obesity in Canada: a trend analysis. *CMAJ Open*. 2014;2:E18–E26.

9. St-Arnaud V, Chicoine AX, Tardif JC, Busseuil D, D'Antono B. Childhood maltreatment and body mass index in older adults with chronic illness. *Can J Cardiol Pediatr Congenit Hear Dis*. 2024;3:87–97.

10. Delgado-Rodriguez M, Llorca J. Bias. *J Epidemiol Community Heal*. 2004;58:635–641.

11. Lavergne C, Dufour S, Trocmé N, Larrivée MC. Visible minority, Aboriginal, and Caucasian children investigated by Canadian protective services. *Child Welfare*. 2008;87:59–76.

12. Maximova K, Chiolero A, O'Loughliin J, Tremblay A, Lambert M, Paradis G. Ability of different adiposity indicators to identify children with elevated blood pressure. *J Hypertens*. 2011;29:2075–2083.

13. Chiolero A, Paradis G, Maximova K, Burnier M, Bovet P. No use for waist-for-height ratio in addition to body mass index to identify children with elevated blood pressure. *Blood Press*. 2013;22:17–20.

14. Caleyachetty R, Barber TM, Mohammed NI, et al. Ethnicity-specific BMI cutoffs for obesity based on type 2 diabetes risk in England: a population-based cohort study. *Lancet Diabetes Endocrinol*. 2021;9:419–426.

15. Heymsfield SB, Peterson CM, Thomas DM, Heo M, Schuna JM. Why are there race/ethnic differences in adult body mass index–adiposity relationships? A quantitative critical review. *Obes Rev*. 2016;17:262–275.

16. Harris TB. Weight and body mass index in old age: do they still matter? *J Am Geriatr Soc*. 2017;65:1898–1899.

17. Danese A, Tan M. Childhood maltreatment and obesity: systematic review and meta-analysis. *Mol Psychiatry*. 2014;19:544–554.

18. Lu H, Cole SR, Howe CJ, Westreich D. Toward a clearer definition of selection bias when estimating causal effects. *Epidemiology*. 2022;33:699–706.

19. Jaen J, Lovett SM, Lajous M, Keyes KM, Stern D. Adverse childhood experiences and adult outcomes using a causal framework perspective: challenges and opportunities. *Child Abuse Negl*. 2023;143, 106328.

20. Austin AE, Desrosiers TA, Shanahan ME. Directed acyclic graphs: an under-utilized tool for child maltreatment research. *Child Abuse Negl*. 2019;91:78–87.

21. Li H, Zheng C, Zhang Y, Yang H, Li J. The directed acyclic graph helped identify confounders in the association between coronary heart disease and pesticide exposure among greenhouse vegetable farmers. *Medicine (Baltimore)*. 2023;102, e35073.

22. Tennant PWG, Murray EJ, Arnold KF, et al. Use of directed acyclic graphs (DAGs) to identify confounders in applied health research: review and recommendations. *Int J Epidemiol*. 2021;50:620–632.

23. Greenland S, Pearl J, Robins JM. Causal diagrams for epidemiologic research. *Epidemiology*. 1999;10:37–48.

24. Glymour M. Using causal diagrams to understand common problems in social epidemiology. In: Oakes MJ, Kaufman JS, eds. *Methods in Social Epidemiology*. 2nd ed. Jossey-Bass; 2006:393–428.

25. Digitale JC, Martin JN, Glymour MM. Tutorial on directed acyclic graphs. *J Clin Epidemiol*. 2022;142:264–267.

26. Shrier I, Platt RW. Reducing bias through directed acyclic graphs. *BMC Med Res Methodol*. 2008;8:70.

27. Banack HR, Mayeda ER, Naimi AI, Fox MP, Whitcomb BW. Collider stratification bias I: principles and structure. *Am J Epidemiol*. 2024;193:238–240.

28. Hernán MA, Monge S. Selection bias due to conditioning on a collider. *BMJ*. 2023;381:1135.

29. Hernán MA, Hernández-Díaz S, Robins JM. A structural approach to selection bias. *Epidemiology*. 2004;15:615–625.

30. Banack HR, Kaufman JS, Wactawski-Wende J, Troen BR, Stovitz SD. Investigating and remediating selection bias in geriatrics research: the selection bias toolkit. *J Am Geriatr Soc*. 2019;67:1970–1976.

31. Power C, Li L, Pinto Pereira SM. Child maltreatment (neglect and abuse) in the 1958 birth cohort: an overview of associations with developmental trajectories and long-term outcomes. *Longit Life Course Stud*. 2020;11:431–458.

32. Norman RE, Byambaa M, De R, et al. The long-term health consequences of child physical abuse, emotional abuse, and neglect: a systematic review and meta-analysis. *PLoS Med*. 2012;9:e1001349.

33. Weuve J, Tchetgen Tchetgen EJ, Glymour MM, et al. Accounting for bias due to selective attrition: the example of smoking and cognitive decline. *Epidemiology*. 2012;23:119–128.

34. Power C, Pinto Pereira SM, Li L. Childhood maltreatment and BMI trajectories to mid-adult life: follow-up to age 50y in a British Birth Cohort. *PLoS One*. 2015;10, e0119985.

35. Rehkopf DH, Headen I, Hubbard A, et al. Adverse childhood experiences and later life adult obesity and smoking in the United States. *Ann Epidemiol*. 2016;26:488–492.e5.

36. De Rubeis V, Gonzalez A, Tarride JÉ, Griffith LE, Anderson LN. A longitudinal study evaluating adverse childhood experiences and obesity in adulthood using the Canadian Longitudinal Study on Aging (CLSA). *Int J Epidemiol*. 2023;52:1100–1111.

37. Hemmingsson E, Johansson K, Reynisdottir S. Effects of childhood abuse on adult obesity: a systematic review and meta-analysis. *Obes Rev*. 2014;15:882–893.

38. Urquijo H, Soares AG, Fraser A, Howe LD, Carter AR. Investigating effect modification between childhood maltreatment and genetic risk for cardiovascular disease in the UK Biobank. *PLoS One*. 2023;18, e0285258.

39. Crow RS, Petersen CL, Cook SB, et al. Reported weight change in older adults and presence of frailty. *J Frailty Aging*. 2020;9:74–81.

40. Alharbi TA, Paudel S, Gasevic D, et al. The association of weight change and all-cause mortality in older adults: a systematic review and meta-analysis. *Age Ageing*. 2021;50:697–704.

41. Nandi A, Glymour MM, Kawachi I, VanderWeele TJ. Using marginal structural models to estimate the direct effect of adverse childhood social conditions on onset of heart disease, diabetes, and stroke. *Epidemiology*. 2012;23:223–232.

42. Williamson T, Ravani P. Marginal structural models in clinical research: when and how to use them? *Nephrol Dial Transplant*. 2017;32(suppl 2):ii84–ii90.