The impact of the COVID-19 pandemic on childhood growth amongst children under 6 years old
A longitudinal cohort study in Ontario, Canada

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ABSTRACT

Objective

There is evidence that the COVID-19 pandemic has had an impact on childhood growth and obesity prevalence; however, the extent to which it has affected young children (<6 years old) living in Canada is unclear. Examining the impact of the COVID-19 pandemic on childhood growth among young children is important to understanding the potential enduring health and developmental repercussions. In this study, we sought to determine: 1) the association between the COVID-19 pandemic and the rate of change in the standardized body mass index (zBMI); 2) the association between the COVID-19 pandemic and the mean zBMI; and 3) whether the association between the COVID-19 pandemic and the rate of change in zBMI differed by zBMI quantiles.

Methods

This was a longitudinal cohort study that used Ontario electronic medical records data from the practiced-based research network UTOPIAN. The population was children <6 years old (N=22,307) who had had at least one primary care visit between March 10th, 2018 – March 11^{th,} 2022. The main exposure was the COVID-19 era (March 11, 2020-March 11, 2022). The outcome of interest was zBMI. Piecewise and linear mixed effects models with knots at the onset of COVID and 1 year into-COVID and quantile regression models were used to test the association between exposures and outcomes adjusted for rurality, racialized and newcomer index, income quintile and Material Resources Index.

Results

The cohort comprised of 83,269 visits from 22,307 unique children. The majority of visits (67.9%) occurred before COVID. Among the children, there was an even sex distribution, a high prevalence of urban residency, and a higher diversity in terms of racialized and newcomer populations. Overall, 17.6% of the children were classified as overweight or affected by obesity. The mean zBMI pre- and during COVID were -0.122 (SD: 1.300) and -0.394 (SD: 1.330), respectively. The piecewise linear mixed effects model revealed a pre-COVID annual increase in

zBMI (0.009 SD units per year on average (95% CI: 0.001, 0.017), which did not change during COVID (-0.004; 95% CI:-0.019, 0.011). The linear mixed effects model found evidence of a relationship between the COVID-19 era and an increase in mean zBMI (0.158 SD units, 95% CI: 0.256, 0.291). In all models, rural, more diverse, and more material resourced populations were associated with a decrease in the rate of change in zBMI. In the quantile regression analysis, zBMI quantiles did not show evidence of an association with the COVID-19 era.

Conclusion

Our analysis revealed that while the pre-COVID rate of change in zBMI was increasing, there was no evidence of an association between the COVID-19 era and the rate of change in zBMI. However, the COVID era was associated with an overall increase in mean zBMI. Further, there was no evidence of an association between the COVID-19 era and rate of change in zBMI differing by zBMI quantile. Our findings highlight an important ongoing public health emergency, overweight and obesity, that has persisted through the pandemic. This epidemic is far from seeing an end like the COVID pandemic. Effective primary care and public health interventions are required that would ideally address the multiple environmental and socio-cultural dimensions of childhood growth.

RESUME

Objectif

Il existe des preuves que la pandémie de COVID-19 a eu un impact sur la croissance des enfants et la prévalence de l'obésité; cependant, la mesure dans laquelle elle a affecté les jeunes enfants (<6 ans) vivant au Canada n'a pas été clairement établie. Il est important d'examiner l'impact de la pandémie de COVID-19 sur la croissance des jeunes enfants pour comprendre les répercussions potentielles durables sur la santé et le développement. Dans cette étude, nous avons cherché à 1) déterminer l'association entre l'ère COVID-19 et le taux de changement de l'indice de masse corporelle standardisé (IMCZ) 2) déterminer l'association entre l'ère COVID-19 et l'IMCZ moyen; et 3) si l'association entre l'ère COVID-19 et le taux de changement de l'IMCZ sont différait selon les quantiles de l'IMCZ.

Méthodes

Il s'agit d'une étude de cohorte longitudinale qui a utilisé les données des dossiers médicaux électroniques de l'Ontario provenant du réseau de recherche fondé sur la pratique, UTOPIAN et NORTHH. La population était constituée d'enfants âgés de 0 à moins de 6 ans (N=22,307) qui avaient eu au moins une visite portant entre 10 mars 2018 et le 11 mars 2022. L'exposition principale était l'ère COVID-19 (11 mars 2020 – 11 mars 2022). Le résultat d'intérêt était l'indice de masse corporelle standardisé. Des modèles linéaires à effets mixtes par morceaux avec des nœuds au début de l'ère COVID-19, ainsi que des modèles de régression quantile ont été utilisés pour tester l'association entre les expositions et les résultats ajustés en fonction de la ruralité, de l'indice racialisé et de l'indice des nouveaux arrivants, du quintile de revenue et de l'indice des ressources matérielles.

Résultats

La cohorte comprenait 86, 269 visites de 22,307 enfants uniques. La majorité des visites (67,9%) ont eu lieu avant le COVID. Parmi les enfants, il y avait une répartition égale des sexes, une forte prévalence de résidence urbaine et une plus grande diversité en termes de populations racialisées et de nouveaux arrivants. Dans l'ensemble, 17,6 % des enfants ont été classés comme étant en

surpoids ou affectés par l'obésité.L'IMCZ moyen avant et pendant la COVID était de -0,122 (écart-type: 1,300) et de -0,394 (écart-type:1,330), respectivement. Le modèle linéaire à effets mixtes par morceaux a révélé une augmentation annuelle constante de l'IMCZ avant la COVID (0,009 unités d'écart-type par an en moyenne (IC 95 % : 0,001, 0,017)), sans changement significatif après la pandémie, et l'âge, la ruralité, l'indice des personnes racialisées et des nouveaux arrivants, et l'indice des ressources matérielles comme principaux prédicteurs de la variance de l'IMCZ. Le modèle linéaire à effets mixtes a mis en évidence une relation significative entre l'ère COVID-19 et une augmentation de l'IMCZ moyen (0,158 unités de déviation standard/an, IC 95% : 0,256, 0,291), l'âge et l'indice des ressources matérielles présentant une association positive avec l'IMCZ et l'indice des personnes appartenant à un groupe racialisé et des nouveaux arrivants présentant une corrélation négative. Dans l'analyse de régression par quantile, les quantiles d'IMCZ n'ont pas montré d'association avec l'ère COVID-19.

Conclusion

Notre analyse a révélé que si le taux de variation de l'IMCZ avant l'introduction de la COVID était en augmentation, il n'y avait aucune preuve d'une association entre l'ère de la COVID-19 et le taux de variation de l'IMCZ. Cependant, l'ère COVID était associée à une augmentation globale du zBMI moyen. En outre, il n'y avait aucune preuve d'une association entre l'ère de la COVID-19 et le taux de variation de l'IMCZ différant selon le quantile de l'IMCZ. Nos résultats mettent en évidence une importante urgence de santé publique, le surpoids et l'obésité, qui a persisté tout au long de la pandémie. Cette épidémie est loin de connaitre la même fin que la pandémie de COVID. Des interventions efficaces en matière de soins primaires et de santé publique sont nécessaires et devraient idéalement porter sur les multiples dimensions environnementales et socioculturelles de la croissance de l'enfant.

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PREFACE AND CONTRIBUTION OF AUTHORS

This study was developed with the collaboration of my co-authors. The thesis manuscript resulting from this research study will be submitted to the Canadian Journal of Public Health. This journal serves as the ideal platform due to its alignment with the study's focus on the impact of COVID-19 on childhood growth, a subject of considerable public health significance. This journal's commitment to addressing public health issues in Canada makes it a pertinent choice for reaching an audience deeply invested in child health and pandemic-related research, thus ensuring that our study's insights can effectively contribute to shaping informed health policies and practices.

The development of this manuscript was a collaborative effort, with each author contributing a diverse set of skills and expertise in their respective roles. Isabella Mignacca spearheaded the project's study design, manuscript and was responsible for conducting all analyses. Dr. Patricia Li provided support and guidance throughout the project's entirely, particularly in data collection and interpretation. Dr. Imaan Bayoumi provided constructive feedback at every stage of the research process which contributed significantly to the development of ideas. In addition, Dr. Catherine Birken had a crucial role in offering feedback, insights, and review of multiple iterations of the manuscript. Sumeet Kalia and Tao Chen facilitated data collection and cleaning and provided insight on analysis with R programming. Dr. Keown-Stoneman provided expertise in the field of biostatistics which helped in the data analysis and interpretation stage of this project. The collaborative effort amongst all authors ensured the comprehensive development of this manuscript which is presented as the culmination of all efforts. All have provided their final approval for this thesis and the accompanying manuscript.

LIST OF FIGURES, TABLES AND GRAPHS

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CHAPTER 1: INTRODUCTION

The COVID-19 pandemic was an unprecedented global health crisis that left a mark on societies worldwide. In addition to its long-term effects on health, the pandemic has disrupted daily activities, interpersonal relationships, and economic stability (Manchia, et al. 2022). One domain impacted by these changes is childhood growth and obesity prevalence.

Research conducted internationally has provided minimal insight on the COVID-19 crisis' consequences on childhood growth throughout the course of the pandemic. The prevalence of overweight and obesity data for children under 5 years old has not been very well documented and is an area in need of exploration (Jones, et al. 2017). As the pandemic progressed, it became evident that a critical gap existed in our knowledge of this issue, particularly as it related to Canadian children. Limitations of current literature available are that they were conducted early on in the pandemic, were conducted outside of Canada and that studies relied on subjective rather than objective measures. The experiences and outcomes of young children during the pandemic remained unclear, requiring investigation. Understanding patterns of growth will aid in developing mitigation and recovery strategies.

The COVID-19 pandemic had a profound effect on the healthcare sector in Canada. The strain on hospitals and other healthcare facilities, particularly in pediatric services cannot be understated. Canada's healthcare system known for its universality was impacted by the reallocation of employees, resources and hospital capacity toward COVID-19 response operations (CIHI, 2022). It is important to consider how these adjustments may have affected children's health in the short and long term.

Childhood growth during the pandemic may have been affected by several factors that interrupted families' regular routines. Lockdowns and social distancing measures brought about

significant changes in food practices and levels of physical activity, which may have resulted in changes in BMI. In addition, predictions of many scholars speculate that weight in children will increase due to the cumulative effects of decreases in physical activity, increased sedentary behavior and high caloric diets among children during the pandemic (Knapp, et al. 2022b).

The overall objective of this thesis was to determine the association between the COVID-19 era (pre- vs. during pandemic) and childhood growth among children < 6 years old in Ontario, Canada. Specifically, we sought to:

1) Determine the association between the COVID-19 era and the rate of change in the age- and sex-standardized body mass index (zBMI) (primary outcome).
2) Determine the association between the COVID-19 era and the mean zBMI.
3) Determine whether the association between the COVID-19 era and rate of change in zBMI differed by zBMI quantile

By examining childhood growth and obesity prevalence in Canada during the COVID pandemic, this thesis addresses a gap in the current literature and may provide critical insights that can guide targeted interventions, policy development and healthcare strategies to address this urgent public health concern for the benefit of children's well-being and the broader healthcare system.

CHAPTER 2: BACKGROUND

2.1 Role of Primary Care in Childhood growth

Pediatric primary healthcare is the continuous, coordinated, and comprehensive care provided to children. It encompasses care from early infancy to young adulthood. Pediatric primary care entails health supervision with an emphasis on preventing physical and mental health conditions, proactive counselling and wellness promotion, and observation of physical, cognitive, and social growth and development (Boudreau, et al. 2022). In addition, it entails conducting age-appropriate screening for health promotion and disease prevention.

The primary care of children plays an essential role in fostering their growth and development. Well-child visits, which act as important checkpoints that are related to the immunization schedule but allow for regular growth monitoring, are essential to the delivery of pediatric preventive care. There are at least 11 that are recommended within the first five years of life (Li, et al. 2021a). In particular, various domains such as nutrition, behavior, injury prevention and others are assessed at each well-child visit. These visits give primary care providers, including family physicians, pediatricians, and nurse practitioners or nurses, the opportunity to intervene early and assess developmental milestones related to growth (Ray, et al. 2022).

The routine evaluation of a child's growth indicators is essential to the role of primary care. Healthcare professionals use the World Health Organization growth charts as useful tools for analyzing patterns and detecting potential concerns (Hale and Jackson 2021). These measures are rigorously recorded and analyzed throughout time. Primary care providers can intervene promptly and offer resources to address the problems when deviations from anticipated growth patterns are observed. (Kosowan, et al. 2020). In addition, there is evidence that childhood

obesity can track to adulthood leading to a variety of cardiometabolic diseases. A systematic review determined that childhood obesity was associated with diagnoses of type 2 diabetes, cancer and metabolic syndrome in early adulthood (Horesh, et.al, 2021).

Primary care providers offer a variety of strategies to combat childhood obesity. With their ability to provide preventative treatment, health monitoring, and advice on healthy lifestyles, primary care providers are vital first points of contact for children and their families. Primary care providers play a crucial role in the early detection of childhood obesity through standard health examinations that include growth pattern tracking, BMI calculations, and discussion of food and physical activity habits. In addition, they provide education, passing along vital information regarding healthy eating habits, weight management techniques, and age- and developmental-appropriate behaviours. Furthermore, family physicians and pediatricians serve as intermediaries, putting families in touch with counsellors, nutritionists, and community initiatives that promote healthy eating and physical exercise (Brown and Perrin 2018). Primary care providers offer a supportive environment for children and families by actively engaging in healthy living and advocating for it. They emphasize the significance of lifestyle modifications and preventative steps to reduce the risks associated with childhood obesity.

2.2 COVID-19 related factors' impact on childhood growth

In late 2019, the COVID-19 pandemic caused by the novel coronavirus SARS-CoV-2 emerged. It spread across the world, leading to a wide range of health and safety measures, such as lockdowns, social isolation, remote learning and mask regulations. These steps were crucial to limit the spread of the virus, safeguard vulnerable populations and diminish the strain on healthcare systems (Filip, et al. 2022).

The COVID-19 pandemic was an unparalleled global health emergency, which had a significant impact on a number of societal aspects, including child development and growth.

Understanding how the pandemic related to children's health, and how it might have affected childhood growth are crucial to understanding the significance of the pandemic's influence. Children contracted COVID-19 with varied degrees of severity; however, beyond the immediate effects on health, children's lifestyles were significantly altered by the pandemic (Zengin, et al. 2021). Lockdowns and school closures disturbed daily patterns, limiting possibilities for physical activity, and possibly encouraging sedentary behaviours (Knapp, et al. 2022b). For example, a systematic review and meta-analysis conducted by Runacres et.al, which looked at the impact of COVID-19 on sedentary time and behavior in children and adults, demonstrated that children were most affected by increased sedentary time (with a change of sedentary time compared to pre-COVID of 159.5 min/day, SD=142.6 min/day) (Runacres, et al. 2021). Similar findings were found by Li et al.'s study, which aimed to determine the association between COVID-19 restrictions and children's outdoor time and screen time. Their results showed that for a cohort with a mean age of 5.5 years, public health preventive measures were associated with longer screen time (11.3 min/day, 95% CI 3.88, 18.79) and shorter outdoor time (-17.2 min/day, 95% CI -22.07, -12.40) (Li, et al. 2021b). In addition, restricted outdoor activities, increased screen time and decreased access to organized sports contributed towards unhealthy movement behaviours (Kharel, et al. 2022). Moreover, the pandemic may have brought on factors that promote unhealthy weight gain and obesity, such as stress, anxiety and unhealthy eating habits (La Fauci, et al. 2022).

The pandemic's rapid spread and numerous effects has brought concerns about the implications for child health. Children have had to navigate interrupted routines, fewer opportunities for physical activity and lifestyles changes that could have a significant impact on their health and development. Understanding and addressing these consequences for childhood

growth and obesity remain crucial for maintaining child health, well-being, and developing recovery plans as the world continues to grapple with the difficulties brought upon by the COVID-19 pandemic.

2.3 Childhood obesity in Canada before and during COVID-19

Childhood obesity in Canada was a serious health concern prior to the COVID-19 pandemic. The prevalence of overweight and obesity among Canadian children and youth had been steadily increasing over the years (Rao, et al. 2016). In addition, obesity rates among children and youth in Canada have nearly tripled in the last 30 years (Government of Canada, 2023). In addition, however, the prevalence of overweight and obesity has been stabilizing but remains high and a public health concern (Olds, et al. 2011).

Childhood obesity may have negative effects on social and emotional development in addition to physical health. Based on observed association, it has been demonstrated that children who were obese had a higher risk of contracting long-term illnesses such as type 2 diabetes, cardiovascular disorders and joint problems (Balasundaram and Krishna 2023). In addition, they frequently dealt with psychosocial difficulties such as stigmatization and lower quality of life (Nieman, et al. 2012; Sanyaolu, et al. 2019). However, public health measures and programs were put in places. For example, national campaigns such as ParticipACTION encouraged children to engage in physical activity (ParticipACTION, 2020).

The COVID-19 pandemic's development brought about new concerns and exacerbated existing ones. Similar to what was experienced internationally, the pandemic severely disrupted children and families' life in Canada, having a variety of negative impacts on growth in young children. Factors that affected Canadian children included: lockdowns, daycare facility and

school closures and limitations on recreational activities interrupted daily schedules (Moore, et al. 2020). These changes may have had detrimental effects on children's health and increased the risk of childhood obesity.

Other pandemic-related factors that affected children living in Canada were increased child stress and uncertainty. Physical barriers to social engagement reduced opportunities for interaction, which exacerbated feelings of loneliness and anxiety (Holmes, et al. 2020). The risk of pediatric obesity may increase as a result of changes in eating behaviours such as emotional eating (La Fauci, et al. 2022). Additionally, access to healthcare, particularly well-child visits and preventive care were hampered in the first year of the pandemic. In a population-bases cross-sectional study conducted in Ontario and Manitoba, Saunders et.al's found that in the first 9 months of the pandemic, primary care visits declined, and that children 1-12 years old had the greatest decrease in visits. The visits subsequently increased but did not reach pre-pandemic rates by November 2020. In Ontario, but not Manitoba, they observed disparities in the reduction of visits by immigrant and refugee families, and those from low socioeconomic neighbourhoods and urban areas (Saunders, et al. 2021).

The pandemic's associated economic difficulties also increased food insecurity in vulnerable groups. Job loss and income reductions made it difficult for families to access nutritious foods, which may have caused them to rely more on inexpensive and high-caloric foods (Gligoric, et al. 2022) (Kar, et al. 2021).

A literature review of childhood growth during the COVID-19 pandemic was included in this thesis to understand the current literature available on this topic. However, the pandemic presented challenges in Canada's battle against childhood obesity. In order to protect the health and wellbeing of Canadian children, it was vital that healthcare professionals, public health

organizations and communities collaborated to address this concern. As a result, determining the effects on children's growth patterns and rate of change throughout the pandemic is an important part of understanding and reducing the long-term repercussions on their health.

CHAPTER 3: LITERATURE REVIEW

3.1 Introduction

A systematic review of the literature was conducted to gain insights into what was previously known regarding the association of the COVID-19 pandemic on childhood growth and obesity prevalence for young children. In addition, the goal was to determine if previous studies have determined the association between the COVID-19 pandemic and changes in body weight for children under the age of 6 years old. The methodology and results of these studies were examined to inform the optimal methodological approach for this project.

3.2 Review Question

This literature review aimed to answer the following question:

What is the association between the COVID-19 pandemic and childhood growth in children <6 years old?

3.3 Methods

The literature was searched using PubMed to identify and collect research articles between March 11th, 2020 and October 24th, 2023.The search strategy was developed with the help of Genevieve Gore, a professional librarian. The search strategy involved 3 key concepts: COVID-19, obesity, and children. The final search strategy including MeSH terms and text words can be found in **Appendix A2.**

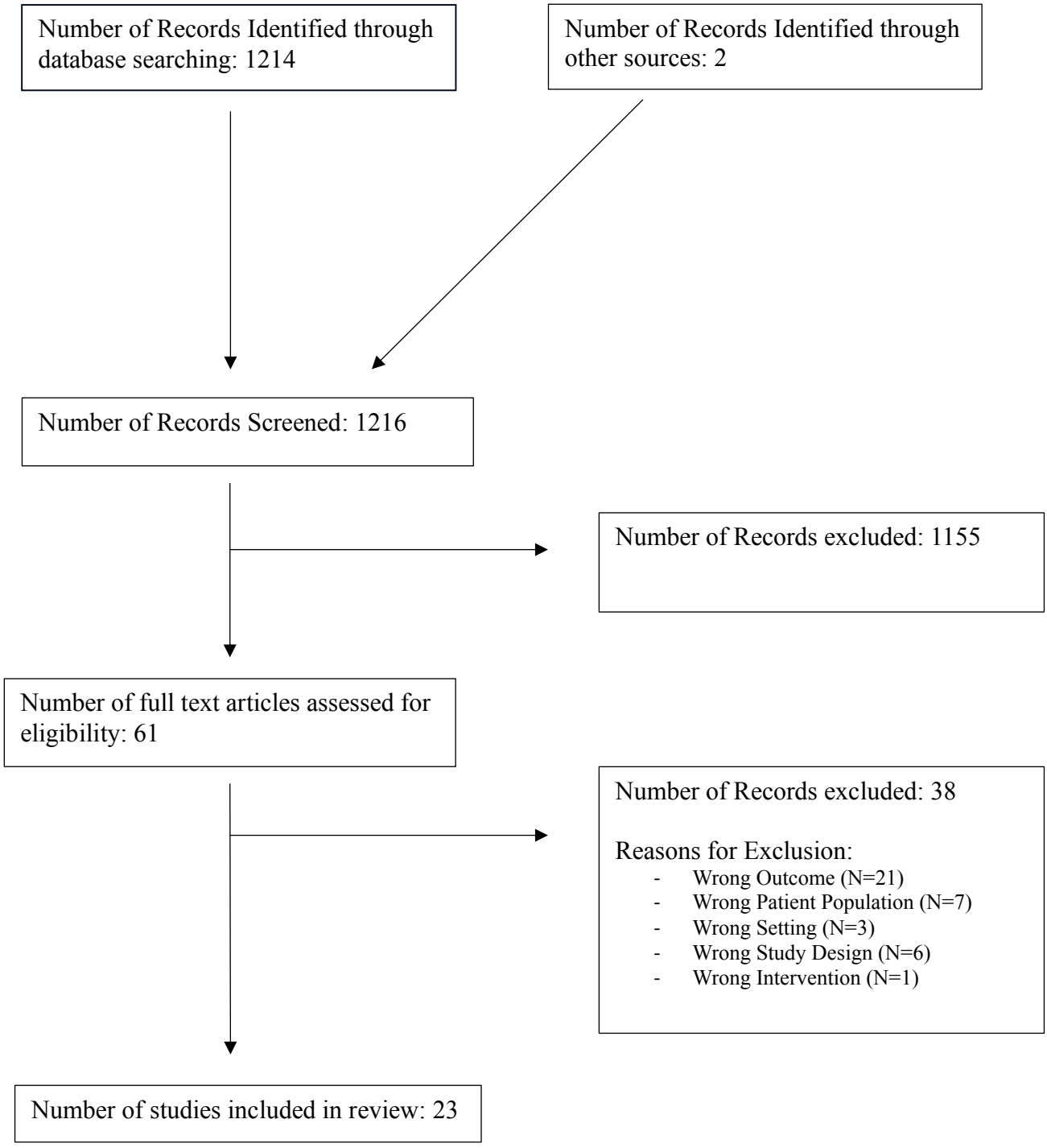
The inclusion and exclusion criteria for article selection can be found in **Appendix A1.** The search was limited to published literature from March 2020 to October 2023 in order to account for articles relevant during the pandemic period. The review included children between

the ages of 0-5 years old. The search was restricted to studies conducted in high-income countries, as defined by the World Bank , for the purpose of this thesis (Nada Hamamdeh 2022). In addition, only primary research papers focusing on childhood growth during the COVID-19 era and published in English were included. Protocols, briefs, commentaries, and case reports/series were excluded from the final analysis.

The results were imported into Covidence, a screening and data extraction program, to monitor selected articles and eliminate duplicates (Cleo, et al. 2019). The search strategy in PubMed determined a total of 1214 articles **(Figure 1)**. A total of 2 articles were found through reference lists of articles included. Titles and abstracts of the research articles were screened to determine the association between the COVID-19 pandemic and childhood growth. Research papers that met any of the exclusion criteria were removed, resulting in 61 articles**.** Full-text screening was conducted which resulted in the exclusion of 38 articles as they were not directly related to the topic of interest or the correct target population. A total of 23 articles were included in the data extraction and synthesis phase. The characteristics of the included studies were extracted using a data collection template and recorded using an Excel file.

The main findings from the articles were summarized using a narrative synthesis because of the heterogeneity in exposures and outcomes of articles included in this review. Narrative synthesis allowed for the findings from the numerous studies to be synthesized in a meaningful and coherent manner.

Figure 1: Flow Diagram of Article Selection for Literature Review



3.4 Results

Overall, there were 23 articles include in this literature review. The studies encompassed a range of geographical locations including Greece (N=1) (Androutsos et al., 2021), Italy (N=4) (Dondi et al., 2020) (Farello et al., 2022) (Pujia et al., 2021) (Valenzise et al., 2021) , Sweden (N=3) (Faldt et al., 2023) (Miregard et al., 2023) (Nowicka et al., 2022) , Turkey (N=1) (Ceylan et.al, 2021) , United States (N=5) (Jenssen et al., 2021) (Knapp et al., 2022) (Koebnick et al., 2023) (Natale et.al, 2023) (Woolford et al., 2021), Korea (N=1) (Kang et al., 2021), China (N=4) (Li et al., 2022) (Long et al., 2023) (Wen et al., 2021) (Yang et al., 2022), Germany (N=1) (Vogel et al., 2022), Singapore (N=1) (Sum et al., 2022) and Canada (N=2) (Anderson et al., 2023) (Anderson et al., 2022). The included studies had data from 2017 to 2023 to account for changes in pre-pandemic and pandemic associations of childhood growth. All studies assessed the association between COVID-19 and childhood growth for children < 6 years old. However, some also included adolescents and adults. The study designs included a wide range such as cross-sectional studies (N=13), cohort studies (N=7), qualitative studies (N=1), observational retrospective studies (N=1), and systematic reviews and meta-analyses (N=1). The number of participants in individual studies was between 40 and 656,396. See **Table 1** for detailed study characteristics.

Body weight and changes in BMI during the COVID-19 pandemic

In China, the study conducted by Li et. al, investigated the physical changes of preschool children during COVID-19 school closures. They determined that weight increased for all urban preschool children after the outbreak (age 3–4 $p= 0.009$; age 4–5 $p < 0.001$; age 5–6 $p = 0.002$). Specifically, in the 5-6 year old group, the rate of overweight children increased from 11.4% to

15.5% and the rate of obesity increased from 6% to 9.9% between October 2019 and October 2020 (Li, et al. 2022). In addition, overweight and obesity in boys had a greater prevalence than in girls before and after the outbreak. Furthermore, the weight and BMI of the 3-4 and 4-5 year old groups increased at a faster rate than before. Similarly, in a study looking at nationwide trends of pediatric obesity and BMI z-score from 2017-2021, Yang et.al determined through hospital-measured and parent reported data that the COVID-19 lockdown was associated with an increase of 1.86% in prevalence of obesity in 2020 compared to 2019 (Yang, et al. 2022). This was a change to the observed trend of prior years, where the prevalence of obesity had decreased by 0.26% between 2017 and 2019. These results were pertinent to primary and junior middle school aged children between the ages of 3 and 19 years of age.

In addition, Anderson et. al analyzed a cross-sectional online survey in Canada in 2022 for caregivers of children aged 0-17 years of age to determine child and parent weight change as reported by parents during the pandemic. Of the 11,778 children, 5.5% lost more weight than expected and 20.2% gained more weight than expected. In addition, they discovered an association between weight change and parent income precarity, which was conceptualized using seven measures such as job loss, difficulty paying bills, major disruption to household food supply. When both parents had experienced job loss, parents reported an association with a twofold increase in odds of child weight gain (OR=2.03, 95% CI 1.37 to 3.03) or a sevenfold decrease in odds of child weight loss (OR=7.81, 95% CI 5.16 to 11.83) (Anderson et. al, 2022).

In a study conducted by Natale et.al on 216 children aged 2-5 years old, the study looked at how pandemic-related problems affected preschool-aged children based on disability and obesity status. According to the study findings, the prevalence of normal weight was 61% higher for children with disabilities. Normal weight was also more likely in children from families who

did not face food insecurity or work challenges as a result of the COVID-19 pandemic, showing that economic stability and access to resources may be important factors in maintaining a healthy weight. Obesity rates were higher among Hispanic children, families who were not English proficient and those whose primary language was Spanish. These findings suggest that socioeconomic factors and access to resources may have an impact on weight changes in pre-school aged children, with a specific emphasis on disability status, economic stability and language proficiency on obesity status throughout the pandemic (Natale, et al. 2023).

Pre-COVID 19 vs. COVID-19 era related associations in body weight and BMI

In a retrospective cohort study conducted in children aged 4-14 years old, Kang et.al, looked at changes in body mass index standard deviation scores (z-scores). In a cohort of 226 children, they determined that BMI z-scores increased by 0.219 (95% confidence interval [CI], 0.167–0.271) in the COVID-19 period compared to the pre-COVID-19 period (Kang, et al. 2021). Within the 6-month period defined as the COVID-19 period they noted a significant increase in childhood obesity which was associated with school closures.

Anderson et al. conducted a systematic review and meta-analysis to evaluate the literature available on the impact of the first year of the COVID-19 pandemic on weight change in both children and adults. A total of 74 studies were included and they used random effects meta-analyses to obtain pooled estimates of mean difference in outcomes. They yielded the following results: the pooled mean difference between pre vs. during the pandemic was 1.65 kg (95% confidence interval [CI]: 0.40, 2.90; 9 studies) for weight and 0.13 (95% CI 0.10, 0.17; 20 studies) for BMI *z*-scores, and the prevalence of obesity increased by 2% (95% CI 1%, 3%; 12 studies) (Anderson, et al. 2023). The findings of this study may be useful to guide health policy post-pandemic and suggests investing in research that is targeted for obesity prevention

initiatives for children as the authors concluded that there was a greater increase in weight gain, BMI and prevalence of obesity during the pandemic, particularly for children.

In the United States, a study conducted by Knapp et.al, looked at whether the rate of change of BMI increased during the pandemic in comparison to pre-Covid years. In their study population of 1,996 children aged 2-19 years, they determined that BMI increased during the pandemic compared to previous years (0.24 increase in annual weight gain in BMI (95% CI 0.02, 0.45)). In addition, they determined that children who were previously in the obese category compared to those who were of normal weight were at a higher risk of excess BMI gain during the pandemic (Knapp, et al. 2022a). However, in a study by Wen et al. conducted in China, they evaluated the prevalence of overweight and obesity in pre-school aged children and compared changes in BMI pre-COVID and during COVID-19 restrictions. They determined that during COVID-19 related school closures, childhood obesity prevalence had increased from 10.47% to 12.28% but overweight prevalence had decreased by 3.36% (Wen, et al. 2021). In terms of BMI changes, there was a decrease over the COVID-19 period compared to the pre-COVID period. When assessing changes in weight, they determined that there was no significant difference between the study periods.

The cross-sectional study conducted in Sweden by Fäldt et.al, aimed to look at changes in BMI among preschool children in Sweden before and during COVID-19 pandemic. They observed that obesity rates increased from 2.8% to 3.9% in 3-year-old females, with a general increase in obesity and overweight in 4-year-olds, and a drop in underweight frequency in boys. There was no change in BMI in 5-year-olds. In the four-year-old group, the finding of increased obesity rates was more prominent in lower socioeconomic areas, implying that the pandemic influenced health behaviours and increased the chances of childhood obesity, emphasizing the

importance of prevention measures, particularly in socioeconomically disadvantaged groups. In addition, the cross-sectional study by Jenssen et al. found similar results in a cohort of 314,260 children. They determined that overall obesity prevalence rose from 13.7% in June to December 2019 to 15.4% in June to December 2020. Moreover, obesity rates increased across all age groups, from 1.0% for patients aged 13 to 17 years to 2.6% for those aged 5 to 9 years (Jenssen, et al. 2021).

Another study conducted in the United States by Koebnick et.al, evaluated whether changes in weight amongst school-aged youth in California varied by race and ethnicity, socioeconomic status and number of neighbourhood parks. In children aged 5-11 years, they found that the distance from the median BMI-for-age increased by 1.72 kg/m^2 (95% CI: 1.61-1.84) in Hispanic and 1.70 kg/m^2 (95% CI: 1.47-1.94) in Black youth during the lockdown compared with 1.16 kg/m^2 (95% CI: 1.02-1.29) in non-Hispanic White youth (Koebnick, et al. 2023). Therefore, there was evidence that race and ethnicity and other social factors were associated with excess body weight increase during COVID-19.

The study conducted by Vogel et.al also looked at weight gain patterns before and during the COVID-19 pandemic. They compared trends of 3-month change in zBMI in the period pre-pandemic (2005-2019) and peri-pandemic (September 2019-July 2020). There was a yearly increase in the 3-month change in zBMI from 2005 to 2019, and this rate was 30 times higher from 2019 to 2020 compared to 2005 to 2019 (Vogel, et al. 2022). Across the entire study, the trend revealed a progressive increase in obesity levels prior to the pandemic but the COVID-19 pandemic showed evidence of a greater acceleration in weight gain, especially in the children classified as obese. Furthermore, Woolford et. al, discovered similar findings in their retrospective cohort study using electronic health record data. Their results showed that an

increase in weight (mean gain of 2.3kg) occurred for children in the 5-11 year age group. In addition, the prevalence of overweight and obesity also increased during the pandemic from 36.2% to 45.7% compared to pre-pandemic (Woolford, et al. 2021). The results of these studies further solidify that weight gain was associated with COVID-19 era related changes.

In a study by Long et.al, looking at differences in rates of overweight and obesity from 2018 to 2021 in kindergarten children, they determined that rates of obesity and overweight increased (6.9% to 9.5% and 14.3% to 18.2%, respectively) (Long, et al. 2023). The results of this study were used to provide nutritional guidance to caregivers in developing a healthier lifestyle for children during public health emergencies. Similarly, the study in Sweden conducted by Miregård et al., compared national data on the prevalence of overweight and obesity among 4-year old children in 2018 versus 2020. In the COVID cohort of children (N=100,001), 13.3% were overweight or affected by obesity which when compared to the pre-COVID cohort of children (N=105,445) 11.4% were overweight or obese (Miregård, et al. 2023). These results further support the need for research on the prevalence of overweight and obesity among children, which can support prevention programs for young children.

Lifestyle and dietary habit changes during the COVID-19 pandemic and changes in body weight

Many studies included in this review focused on the effects of the COVID-19 restrictions on children's body weight and lifestyle habits. The cross-sectional study conducted by Androutsos et al. in Greece focused on reported changes in children's and adolescents' lifestyle habits during the first COVID-19 lockdown and explored associations between lifestyle behaviours and body weight (Androutsos, et al. 2021). Results demonstrated that body weight increased by 35% for children/adolescents between April-May 2020. In addition, they

determined that sleep duration and screen time increased during the first wave while physical activity decreased. Furthermore, their regression analysis showed that body weight increase was associated with increased consumption of snacks and dietary changes.

Similarly, Ceylan et al.'s descriptive study explored the effects of restrictions applied on children (N=464) during COVID-19. They determined that screen time increased while physical activity decreased. In addition, children's body weight increased by an average of 3.87 kg (SD: 2.2) and parents reported that their children seemed more tense and stressed (Ceylan, et al. 2021).

Additionally, the cross-sectional study conducted by Dondi et al. in Italy, demonstrated that there was an increase in BMI in children aged three and four (Dondi, et al. 2020). Prevalence of obesity in 3-year-old girls increased from 2.8% to 3.9%. During the COVID-19 pandemic, there was a statistically significant change in BMI in four-year olds ($p < 0.001$), with an increasing prevalence of obesity (both boys and girls) and overweight (in girls) from 11.1% to 12.8% (Dondi, et al. 2020) . There was no change in BMI observed in 5-year-olds. In addition, they determined that children in low socioeconomic regions had a higher risk of obesity.

A qualitative study conducted by Nowicka et al. used interviews to examine how pre-school parents perceived changes in their children's weight and lifestyle behaviours during the first two waves of the pandemic (Nowicka, et al. 2022). They discovered that changes in behaviours and weight were different across the cohort of participants. Furthermore, differences in children's obesity-related behaviours were associated with their parents' practices. Across all results, they determined that children's weight and lifestyle habits were embedded in household resilience. In resilient households, children were better suited to adapt to challenges posed by the pandemic.

The cross-sectional study by Farello et. al focused on changes in eating habits, physical activity and sleeping behaviours of Italian children. They determined that COVID-19 was associated with an increase in high caloric foods and that more parents reported obesity in their children after lockdown (+0.6% in the 5-11 age group) compared to before lockdown (Farello, et al. 2022). Furthermore, there was a decrease in physical activity and an increase in sedentary lifestyle habits. Similarly, another cross-sectional study conducted in Italy by Pujia et.al, determined that there was an increase in consumption of snacks and processed food products. In addition, 59.7% of study participants reported body weight gain due to an increase in height and consumption of dairy products and sweet packaged snacks (Pujia, et al. 2021).

Sum et al. conducted a survey to determine the impact of COVID-19 restrictions on lifestyle changes and potential link with child adiposity after 1 year of lockdown. Out of 229 school-aged children, 24.5% of pre-school aged children eliminated any form of outdoor play after lockdown. Elimination of outdoor play was defined as a parent report of any frequency (non-zero) of outdoor play before lockdown and no outdoor play after lockdown, excluding those cases where parents reported no outdoor play in either period. The elimination of outdoor play, as described by parent report, was associated with an increase in BMI of 0.48 and a z-score BMI of 0.18 units in school-aged children demonstrating that lifestyle habit changes lead to increase in weight and BMI (Sum, et al. 2022).

The study by Valenzise et al. determined how COVID-19 lockdowns affected a pediatric population affected by obesity between the ages of 2-19 years. The study showed that there was an increase in daily meals during the lockdown for all children. Furthermore, 97% of children were sedentary (i.e. spent time playing videogames, attending online school, watching television) during the lockdown period. There was no significant difference in BMI before vs. during

lockdown however, the mean value of BMI increased from 30.2 (SD = +/-4) to 32.0 (SD = +/-5.5) between the pre-COVID and COVID-periods (Valenzise, et al. 2021).

3.5 Conclusions

In conclusion, a thorough picture of the complex effects of the COVID-19 pandemic on childhood growth and body weight is painted by the wide range of studies included in this literature review. The studies revealed an association between pandemic-related parameters and modifications in food patterns, lifestyle habits, and ultimately body weight, spanning different geographic regions and populations. All studies showed an increase in BMI or weight during the first year of COVID, others highlighted the significance of socioeconomic disparities and household resilience in coping with obstacles imposed by the pandemic. Some studies included the utilization of population-based registry data for both cross-sectional and longitudinal analyses, which allowed for a large and real-world sample. Some studies tracked the same cohort of children pre- and post-COVID for prospective anthropometric profiling allowing for a more temporal and accurate understanding of how the pandemic impacted children's body weight. However, many studies used cross-sectional study designs which are unable to establish causality. In addition, some studies only reported growth trends and BMI during the pandemic period which does not allow for interpretation of whether changes during COVID-19 were different than pre-pandemic times. There may have been a lack of representativeness for general population extrapolation, biases from online surveys and questionnaires such as survey bias, and inherent observational study limitations preventing conclusive explanations for associations observed. This literature review also demonstrates that there is still a lack of research on body weight changes after the 1st year of the pandemic, specifically for young Canadian children. The

wealth of data provided by the studies in this literature review emphasize the pandemic's potential implications for the health landscape of young children. In addition, it highlights the importance of interventions geared to the issues experienced by children during the pandemic's course by shedding light on modifications to weight change. These findings not only elucidate the need for addressing the effects of COVID-19 but also echo the underlying goal of this study, which is to investigate how the COVID-19 pandemic has possibly affected the growth of children under the age of 6 years old in Canada.

Table 1: Characteristics of Included Studies in the Literature Review

Authors (Year)	Study Design	Setting	Study Period	Data Source	Patient Population	N	Statistical Analysis and associated outcome(s)	Change in body weight
Androutsos et.al (2021)	Cross-sectional	Greece	30/04/2020 – 24/05/2020	Online Survey	Children aged 2-18 years living in Greece	397	Multiple regression, changes in body weight and lifestyle behaviours	Increase
Ceylan et. al (2021)	Cross-sectional	Turkey	07/2020 – 11/2020	Social Media	Children aged 3-18 years old	464	Independent samples t-test & Mann-Whitney U test, lifestyle behaviours, mental health and weight gain	Increase
Dondi et. al (2020)	Cross-sectional	Italy	01/09/2020 – 15/09/2020	Online survey	Children aged 0-18 years old living in Italy	5,811	Multivariable logistic regression,	Increase
Fäldt et. al (2023)	Retrospective cross-sectional	Sweden	05/2015 – 02/2023	National quality register for childcare	Children aged 3-5 years old living in three Swedish regions	25,049	Multiple binary logistic regression, anthropometric data	Increase
Farello et. al (2022)	Cross-sectional	Italy	07/01/2021-18/01/2021	Online survey	Children aged 5-18 years old	402 children, 563 adolescents	Chi-squared test, lifestyle habits and weight status	Increase
Jenssen et. al (2021)	Cross-sectional	United States	01/2019-12/2020	Medical records from Children's hospital of	Children aged 2-17 years old	314,260	Comparison of obesity rates, obesity rates and associated factors	Increase

				Philadelphia Care Network				
Kang et. al (2021)	Cohort	Korea	02/03/2019 – 01/03/2020	Medical records from growth clinic of Seoul St.Mary's Hospital	Children aged 5-14 years old	226	Paired sample t-test & regression, anthropometricand laboratory parameters	Increase
Knapp et. al (2022)	Cohort	United States	03/2020 – 05/2021	Data from ECHO-wide Cohort Study	Children aged 2-19 years old	1,996	Linear mixed effects model, BMI	Increase
Koebnick et. al (2023)	Cohort	United States	03/2020 – 01/2021	Electronic health record data	Children aged 5-17 years	160,472	Linear mixed-effects model, change in adiposity	Increase
Li et. al (2022)	Cross-sectional	China	2018-2020	Survey	Children aged 3-6 years	1,688	Chi-squared test, changes in physical development and obesity rates	Increase
Long et. al (2023)	Cross-sectional	China	2018-2021	Data from children's growth and development in kindergarten's of Jiading district	Children aged 3-7 years	44,884	Generalized linear mixed modelling & Chi-squared test, overweight and obesity rates	Increase
Miregård et. al (2023)	Cross-sectional	Sweden	2018-2020	Medical record data from Swedish Child Health services	Children aged 4 years old	Pre-COVID: 52,941 COVID: 51,115	Chi-squared test, prevalence of overweight and obese children	Increase
Natale et. al (2023)	Cross-sectional	United States	11/2021 – 12/2021	Questionnaire sent to parents of children in early childcare centers	Children aged 2-5 years	216	Multivariable logistic regression, anthropometric measures	Increase

Nowicka et. al (2022)	Qualitative	Sweden, Romania & Spain	04/2020-05/2020	Interviews	Children aged 2-6 years	70	Thematic analysis, changes in eating, screen-time and physical activity behaviours	Increase and decrease
Pujia et. al (2021)	Cross-sectional	Italy	03/2020-06/2020	Online survey	Children aged 5-9 years	439	Chi-squared test & Pearson's correlation, Changes in BMI and dietary habits	Increase
Sum et. al (2022)	Cohort	Singapore	07/2020-09/2020	Online survey	Children aged 1-4.5 years	604	Paired t-test and paired Wilcoxon rank sum test, changes in child lifestyle habits and body mass indices	Increase
Valenzise et. al (2021)	Cohort	Italy	2020-2021	Medical records	Children aged 2-18 years	40	Descriptive statistics and Kolmogorow-Smirnov's test, anthropometric measures and biochemical parameters	Increase
Vogel et. al (2022)	Cohort	Germany	11/2019-07/2020	Medical records from CrescNet patient registry	Children aged 1-18 years	252,910	Generalized additive mixed models, change in BMI-SDS	Increase
Wen et. al (2021)	Observational retrospective study	China	11/2019-09/2020	Medical records from Children's health care network system in China	Children aged 3-5 years	124,603	Fisher's exact test, changes in BMI	Decrease

Woolford et. al (2021	Cohort	United States	03/2019-06/2020	Electronic health record data from KPSC	Children aged 5- 17 years	191,509	Mixed effect and Poisson regression, distance of BMI from median BMI for sex and age adjusted for height and overweight or obesity	Increase
Yang et. al (2022)	Cross-sectional	China	01/2017-04/2021	Medical records and parent-reported data	Children aged 3-19 years old	656,396	T-test and Chi-squared test, prevalence of obesity and overweight children and BMI z-score	Increase
Anderson et. al (2023)	Systematic review and meta-analysis	Canada	01/2020-11/2021	Individual studies included a variety of data sources*	Children and adults	74	Narrative synthesis, weight change in children and adults	Increase
Anderson et. al (2022)	Cross-sectional	Canada	05/2021-07/2021	Online survey	Children aged 0-17 years old	9,667	Multinomial logistic regression, Parent reported weight change for their children	Increase and decrease

***** Data sources included: self-reported measurements, electronic medical record data, laboratory measurements

CHAPTER 4: THESIS RATIONALE & OBJECTIVES

4.1 Rationale and Relevance of Study

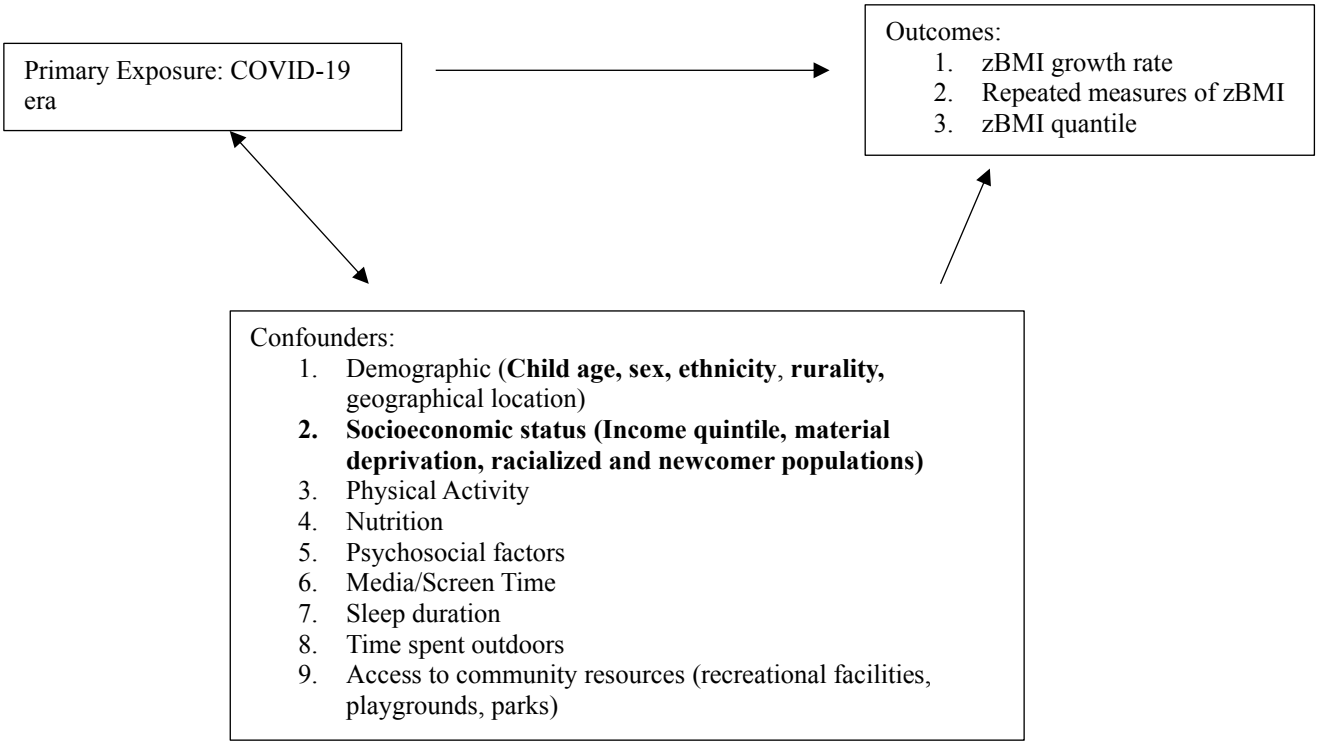
To the best of our knowledge, no study has thoroughly examined the effects of the COVID-19 pandemic on the growth of children aged 0 to 6 in Canada. This study therefore, is novel and may provide important data to the body of existing research. Numerous studies conducted globally have examined the pandemic's overall effects on children's growth, but this study may close this knowledge gap by offering a detailed investigation within a particular geographic and demographic setting. Focusing on the standardized body mass index (zBMI) rate of change and examining possible correlations across zBMI quantiles, the research aims to identify patterns and trends that might provide a nuanced exploration for Canada's children. For policies and interventions to be tailored in a way that is both contextually appropriate and community-responsive, this approach may be of importance. In addition, a review of the literature determined that there is a large range of global patterns in childhood growth during the pandemic which provided a better understanding of the broader environment and aims to ground the research in a global perspective. This approach enhances the study's novelty, thereby addressing the limited data available in Canada on young children. This study has the benefit of a large sample size of children with directly measured height and weight before and during the pandemic. This study may contribute to the scholarly discourse and guide targeted interventions for the population in Ontario.

4.2 Objectives

The objective of this study was to determine if there was an association between the COVID-19 era and childhood growth in children <6 years old in Ontario, Canada. In particular,

we aim to determine the association between COVID-19 and the rate of change in standardized body mass index (zBMI) and mean zBMI. In addition, as a tertiary objective, we examined whether COVID-19 era and zBMI are associated with zBMI quantile.

4.3 Conceptual Model of the Current Study



Notes:

- Confounders that are **bolded** have been included as covariates in the current study.
- Ethnicity and socioeconomic status were included using an area-level proxy (to approximate these measures because individual-level data is unavailable)

The conceptual model depicted in the diagram is designed to investigate the impact of the COVID-19 pandemic on childhood growth, specifically analyzing the standardized body mass index (zBMI) among children under 6 years of age in Ontario, Canada. The primary exposure of interest is the COVID-19 era, which is anticipated to affect three key outcomes: the growth rate of zBMI, repeated measures of zBMI over time, and the distribution of zBMI across quantiles.

The model also acknowledges a comprehensive set of confounding variables, including demographic factors (such as child age, sex, ethnicity, rurality, and geographical location), socioeconomic status, physical activity, nutrition, psychosocial factors, media/screen time, sleep duration, time spent outdoors, and access to community resources like recreational facilities, playgrounds, and parks. These confounders are understood to possibly influence both the exposure and outcomes, suggesting a complex interaction of factors that must be considered when examining the direct and indirect effects of the COVID-19 era on child growth. However, our study only included the following confounders: age, gender, rurality, income quintile, material deprivation index and racialized and newcomer populations. The model acts as a framework for the current study, directing data gathering and analysis to reveal the links between the pandemic and childhood growth trends.

CHAPTER 5: MANUSCRIPT

The impact of the COVID-19 on childhood growth amongst children under 6 years old living in Ontario, Canada

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Abbreviations:

zBMI: Standardized Body Mass Index
EMR: Electronic Medical Records
POPLAR: Primary Care Ontario Practice-based Learning & Research Network
UTOPIAN: University of Toronto Practice-Based Research Network
NORTHH: Northern Ontario School of Medicine Research Towards Health Hub

SD: Standard Deviation

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Conflicts of Interest: All authors have no conflicts of interest to disclose.

What is Known on The Topic:
Results from previous studies demonstrated a relationship between the COVID-19 pandemic and growth for both adolescents and adults. However, little is known about the association between the pandemic and childhood weight changes for children under the age of 6 years old.

What this Study Adds:
This study addresses a notable gap in research on the effects of the COVID-19 pandemic in Canada, with a particular focus on children under the age of six. We found that there was an annual increase in zBMI prior to the pandemic, but the onset of the pandemic was not significantly associated with a change in this rate. However, the overall mean zBMI increased during the COVID era compared to the pre-COVID era, which may contribute to a concerning growing population of obesity in early childhood. Thus, effective primary care and public health interventions to address obesity in young children are needed the post-pandemic era and will likely need to remain a priority in future pandemics.

Ethics Approval:
This study has received research ethics board (REB) approval from Queen's and McGill University.

5.1 Introduction

The COVID-19 pandemic was declared as a global health crisis on March 11th, 2020, by the World Health Organization (Cucinotta, 2020). Across the globe, COVID-19 has created a variety of difficulties such as education disruptions, social restrictions, and changes in access to healthcare (Whitley, et al. 2021). It has left a lasting impact on the global population. Nations struggled to address the complex issues that this pandemic has presented, worries about its potential wide-ranging effects surfaced, especially for the most vulnerable populations, including children. Children are particularly vulnerable during their formative years to environmental effects, such as dietary and socioeconomic factors, which can have a substantial impact on their long-term health and growth. Anderson et al. conducted a systematic review and meta-analysis of the literature up to November 2021 to determine the impact of the pandemic on weight change amongst children and adults. Of the 74 included studies, 33 (43%) included children or adolescents. Among children and adolescents, the pooled evidence, rated as very low certainty using GRADE, showed an increase in weight, BMI, weight circumference and the prevalence of obesity during the first year of the pandemic compared to prior (Atkins, et al. 2004). The authors speculated that weight gain could be greater within the entirety of the COVID pandemic, which ended May 5, 2022 (Anderson, et al. 2023).

Given the dearth of literature on the impact of the COVID pandemic on preschool-aged children beyond the first year of the pandemic, and given the importance of weight gain in early life, which has been associated with obesity and morbidity later in life (Moschonis, et al. 2023) (Reilly and Kelly 2011; Simmonds, et al. 2016), the current study aimed to determine the association between the COVID-19 era (pre- vs. during pandemic) and childhood growth among children < 6 years old in Ontario, Canada. Specifically, we sought to:

1) A) Determine the association between the COVID-19 era and the rate of change in the age- and sex-standardized body mass index (zBMI) (primary outcome).

   B) Determine the association between the COVID-19 era (with a knot at 1 year into the COVID-19 pandemic) and the rate of change in the age- and sex-standardized body mass index (zBMI)

2) Determine the association between the COVID-19 era and mean zBMI.
3) Determine whether the association between the COVID-19 era and rate of change in zBMI differed by zBMI quantile

Our main hypothesis was that the COVID-19 pandemic was associated with an increase in zBMI for young children. In addition, we hypothesized that children in higher zBMI quantiles compared to children with the lowest would have a higher rate of change in zBMI during the pandemic.

This study will address a critical gap in knowledge in the literature and may be important for policymakers, medical professionals, and caregivers to inform prioritization of child health-related policies and practices for the era post-COVID pandemic and future pandemics.

5.2 Methods

5.2.1 Setting

With over 15 million inhabitants, Ontario is the most populous province in Canada. In a census conducted by Statistics Canada in 2021, there are over 900,000 children under the age of six currently living in this province. Ontario's diverse urban, suburban, and rural environments provide a complex context for our analysis. As with the rest of Canada, Ontario provides universal access to inpatient and outpatient healthcare services– including pediatric healthcare – to its population, administered through the Ontario Health Insurance Plan (OHIP).

5.2.2 Study Design and Data Sources

This study employed a longitudinal cohort design to investigate how the COVID-19 pandemic has affected childhood growth for children under the age of 6 years old. The study included data from March 10, 2018, to March 11th, 2022, which included data from two years of pre-pandemic and during the pandemic. We used data from POPLAR (Primary Care Ontario Practice-based Learning and Research Network), which includes six Practice-based Learning and Research Networks across university departments of family medicine in Ontario, and the Alliance for Healthier Communities (See Appendix B.1). The entire POPLAR network includes different healthcare setting such as Aboriginal Health Access Centers, Community Health Centers, nurse practitioner-led clinics, and family medicine clinics including over 1,000 family physicians and encompasses the health of over 1.5 million people. For the current study, data from electronic medical records (EMR) were available from two of the networks, UTOPIAN (University of Toronto Practice-Based Research Network) and NORTHH (Northern Ontario School of Medicine Research Toward Health Hub) research networks.

5.2.3 Study Population

The inclusion criteria were children who were between the ages of 0 and 6 years old with a primary care visit between March 10, 2018, and March 11, 2022; received primary care from clinics affiliated with the UTOPIAN (University of Toronto Practice-Based Research Network) and NORTHH (Northern Ontario School of Medicine Research Toward Health Hub) research networks. Primary care visits were defined as either visit for which a diagnosis code for well-child care was billed, a service code for an intermediate assessment with at least 1 service code for a vaccination that is usually administered between 0 to 6 years old, or a service code for an intermediate assessment and at least 1 Anatomical Therapeutic Chemical (ATC) code for vaccination that is expected between 0 to 6 years old. Details can be found in **Table 10.** Each child contributed ≥1 visit to the dataset (See **Appendix B.2** for additional information**)**. In terms of exclusion criteria, if a patient did not have a valid date of birth, age, and sex recorded they were excluded from the study. In addition, if the patient's primary care physician did not meet minimum data quality (over 20% of rostered patients had no lab, medication and billing data) they were also excluded. Subsequently, if the patient was not rostered or did not have a periodic health exam or any family practice visit at any point in time then they were also excluded. Lastly, patients who had a virtual visit were excluded as data for height, weight and zBMI will be clinically heterogeneous and less standardized due to home measurements.

5.2.4 Main Exposure: COVID-19

The study's main exposure variable was the COVID-19 pandemic. The World Health Organization (WHO) designated COVID-19 a global pandemic on March 11, 2020. A state of emergency and shutdowns were declared in Ontario on March 17, 2020. In the current study, we used the WHO declaration as the start of the COVID era (March 11, 2020–March 11th, 2022)

and defined the pre-COVID era as March 10, 2018–March 10, 2020). Two years in the pre-COVID era allowed for data to capture baseline trends in childhood growth prior to potential pandemic-related influences. The distinct time periods made it possible to compare the pre-pandemic and pandemic eras and examine trends in childhood growth over these particular time periods. The COVID-19 era encompassed a period characterized by unparalleled difficulties and societal transformations, whilst the pre-COVID era provided a crucial reference point for comprehending and contrasting growth trends preceding the pandemic's noteworthy impact (See **Appendix B.3**).

5.2.5 Outcomes: zBMI growth rate from 0 to <6 years old

The primary outcome of interest in this study was the rate of change in age- and sex-standardized body mass index (BMI) over time, represented as zBMI and derived from the WHO standards (2006). The zBMI data was cleaned according to the published methods, which involved an automated technique for detecting implausible numbers in pediatric EHR growth data (Daymont, et al. 2017). The R packages used included growthcleanr and zscorer. The current assessment encompassed individuals with at least one zBMI measurement pre- and during-COVID-19, enabling a comprehensive analysis of rate of change in zBMI over time and the mean zBMI. Employing piecewise linear mixed-effects models, facilitated the examination of zBMI variations across multiple time points, accommodating individuals contributing single observations, such as infants or recently enrolled participants. In addition, piecewise linear mixed effects models were employed to account for population growth prediction but also provide insight on individual growth trends via the random effects component.

The secondary outcomes of interest were repeated measurements of zBMI and zBMI quantile. For detailed information, see **Appendix B.5.**

5.2.6 Covariates

The study's baseline patient characteristics included a range of variables that are used to stratify health equity and comprehend the participants' demographic composition. These characteristics included the child's sex (male or female), age (continuous), rurality (rural/urban), the family's socioeconomic status (SES), which was determined by using the ON-Marg (Ontario Marginalization Index) material resources index (quintile), the ON-Marg racialized and newcomer populations index (quintile), and income quintile (See **Appendix B.4)**.

The socioeconomic status variables are ecological variables assigned based on the child's postal codes. Using the Statistics Canada Postal Code Conversion File, each postal code was assigned a dissemination area, which was then used to assign rurality and quintiles for income, material resources, and racialized and newcomer populations using Canadian census data (Canada 2024). The ON-Marg material resources index aims to represent access and acquiring basic material needs and includes the percentage of the population who are unemployed, without a high school degree, lone-parent families, are below low-income cut-off, have dwellings needing major repair, and the percentage of income from government transfer payments. The ON-Marg racialized and newcomer populations index is based on the percentage of the population who are recent immigrants and who self-identify as "visible minority" (as defined by Statistics Canada) (Ontario 2023).

In a study examining the effect of COVID-19 on childhood growth, it is critical to include these baseline characteristics to adjust for possible confounding variables. For example, as growth patterns change greatly between age and sex, child sex and age are crucial in understanding developmental variations and to accurately examine if there is an association between the COVID-19 pandemic and childhood growth rates (such as zBMI) (Costa, et al.

2021). Socioeconomic status will have an influence on dietary choices, access to healthy foods and opportunities for physical activity (Scaglioni, et al. 2018). Moreover, rurality provides insights into the particular issues faced by children in rural settings. In particular, limited access to healthcare services and recreational facilities which may affect body weight changes (Armstrong, et al. 2015). The racialized and newcomer populations index aids in evaluating the varied consequences of the pandemic on multiple ethnic groups (Williams and Mohammed 2009) (Hartley 2004). Understanding how these socioeconomic factors work together, is important in assessing the association between COVID-19 and childhood growth.

5.2.7 Statistical Analysis

To offer an overview of the study population, we reported descriptive baseline demographic data included in the pre-COVID an during COVID-eras. Categorical data such as child sex, rurality, income quintile, material resources and racialized and newcomer indices, were summarized using proportions. Age and zBMI were reported as means and standard deviations.

Piecewise linear mixed-effects models (PLMMs) and linear fixed effects models are used to manage data structures where there is non-independence of data (in the current case, due to repeated measures of zBMI across time from individuals) by accounting for both fixed effects, i.e. the covariates, and random effects, i.e. the individual differences not explained by these factors.

For the primary analysis, we used PLMMs with a knot at March 11, 2020 to analyze the association between the COVID era and the rate of annual change in zBMI adjusted for covariates (age, sex, rurality, income quintile, material resources index, and racialized and newcomer index). The knot placed at March 11, 2020 allowed for the zBMI slope to be compared in the pre-COVID and during COVID eras. In the first step of this analysis, we

investigated multicollinearity by assessing the variance inflation factors (VIFs) for all variables using the car package in R. VIF values under 5 demonstrate minimal collinearity between variables and values greater than 5 suggest multicollinearity (Kim 2019). This ensures that the regression models are statistically robust. We then verified model assumptions by plotting the residuals of the rate of annual change in zBMI against the year to check for linearity and heteroscedasticity of the residuals over time. Normality of the residuals (rate of annual change in zBMI) was also assessed using a quantile-quantile (Q-Q) plot. Given prior work where linear assumptions were not met with age and zBMI, we looked at residual plots with age. In addition, we imputed missing covariate data to reduce potential bias from the missing data using Multivariate Imputation by Chained Equations (MICE) in R, which assumes covariates were missing at random.

Given the decrease in lockdowns and school closures, and increase in COVID-19 immunization and vaccination status of the population in the second compared to the first year of the COVID era, we repeated the analysis with a piecewise linear mixed-effects model that included a knot at March 11, 2020 and a knot at March 11, 2021 to examine the association between COVID era and the rate of annual of change in zBMI adjusted for covariates.

In our second objective, we used linear mixed effects models to determine the association between the COVID-19 era and mean zBMI while adjusting for child age, sex, rurality, income quintile, material resources and racialized and newcomer indices. We followed the same steps as in the primary analysis (checking model assumptions, multicollinearity, and using MICE for missing covariate data).

The third objective involved determining whether the association between the COVID era and rate in change in zBMI differed by zBMI quantile. To address this objective, we

performed quantile regression at the 25th, 50th, and 75th zBMI quantiles. We applied the cluster function in R to take into account repeated measures of zBMI through bootstrapping (Bilias, et al. 2000). The models were adjusted for the same covariates as previous models (child age, sex, rurality, income quintile, material resources and racialized and newcomer indices). In addition, the 25th, 50th and 75th zBMI quantiles were plotted for visual comparison between the different quantiles. In our quantile regression analysis, we avoided following World Health Organization guidelines for different zBMI categories, as this traditional approach risked regression to the mean—a statistical phenomenon in which extreme values tend to return to the mean on subsequent measurements, potentially masking true effects. We avoided this problem by using quantile regression at the 25th, 50th, and 75th zBMI quantiles to account for our study population's particular zBMI distribution, resulting in a more accurate assessment of differential impacts.

The statistical software, R, was used for all statistical analyses, including linear mixed-effects models and quantile regression. The R packages used included mice (used for multiple imputation), lme4 (used for the piecewise and linear mixed effect model), quantreg (used for quantile regression analysis), rms (used the lsp function within this package to enable the comparison of non-linear age-related zBMI changes during the pre-COVID and COVID era), and emmeans (used to produce estimates from parameters).

5.3 Results

5.3.1 Descriptive Analyses

The flow diagram for the cohort selection process is displayed in Appendix B, Figure 4. The study sample included 83,269 visits made by 22,307 unique children. The assessment of baseline characteristics among patients prior to and during the COVID-19 time period can be

found in **Table 2**. In a total sample size of 22,307 people, 67.9% were recorded before COVID and 31.9% were captured during the pandemic. All other variables, including sex, age, rurality, racialized and newcomer index, income quintile, and material resources index had similar distributions pre- and during COVID. The zBMI increased during the COVID period, with higher mean values.

Table 2: Baseline characteristics of patients by pre-COVID and COVID time period

Variable	Time Period		Overall
	Pre-COVID	During COVID	
Total, N(%)	15,191 (67.9%)	7,116 (31.9%)	22,307 (100%)
Sex, N(%)			
Female	7,350 (48.4%)	3,510 (49.3%)	10,860(48.7%)
Male	7,841(51.6%)	3,606 (50.6%)	11,447 (51.3%)
Age (in years)			
Mean (SD)	1.43 (1.60)	0.83 (1.65)	1.24 (1.64)
Median [Min,Max]	0.77 [0, 5]	0.11 [0, 5]	023 [0, 5]
Rurality, N(%)			
Rural	1,771 (11.7%)	887 (12.5%)	2,658 (11.9%)
Urban	13,420 (88.3%)	6,229 (87.5%)	19,649 (88.1%)
Racialized and Newcomer Population Index, N(%)			
1 (least diverse)	1,520 (10.0%)	812 (11.4%)	2,332 (10.4%)
2	2,032 (13.4%)	955 (13.4%)	2,987 (13.4%)
3	2,738 (18.0%)	1,279 (18.0%)	4,017 (18.0%)
4	3,636 (23.9%)	1,701 (23.9%)	5,337 (23.9%)
5 (most diverse)	5,265 (34.7%)	2,369 (33.3%)	7,634 (34.2%)
Income quintile, N(%)			
1 (highest)	3,113 (20.5%)	1,393 (19.6%)	4,506 (20.2%)
2	2,571 (16.9%)	1,317 (18.5%)	3,888 (17.4%)
3	2,659 (17.5%)	1,332 (18.7%)	3,991 (17.9%)
4	3,241 (21.3%)	1,537 (21.6%)	4,778 (21.4%)
5 (lowest)	3,607 (23.7%)	1,537 (21.6%)	5,144 (23.1%)
Material Resources Index, N(%)			
1 (least deprived)	3,377 (22.2%)	1,591 (22.4%)	4,968 (22.3%)
2	3,602 (23.7%)	1,670 (23.5%)	5,272 (23.6%)
3	2,980 (19.6%)	1,420 (20.0%)	4,400 (19.7%)
4	2,469 (16.3%)	1,214 (17.1%)	3,683 (16.5%)
5 (most deprived)	2,763 (18.2%)	1,221 (17.2%)	3,984 (17.9%)
zBMI			
Mean (SD)	-0.122 (1.300)	-0.394 (1.330)	-0.209 (1.320)
Median [Min,Max]	-0.10 [-4.980, 4.870]	-0.414 [-4.950, 4.880]	-0.205 [-4.980, 4.880]
zBMI category			
Underweight (zBMI <-2)	1,103 (7.30%)	725 (10.20%)	1,828 (8.20%)
Normal (-2 ≤ zBMI ≤ 1)	11,160 (73.50%)	5,386 (75.70%)	16,546 (74.20%)
Overweight (zBMI > 1)	2,221 (14.60%)	743 (10.40%)	2,964 (13.30%)
Children affected by obesity (zBMI > 2)	707 (4.70%)	262 (3.70%)	969 (4.30%)

5.3.2 Association between COVID-19 era and rate of change in zBMI

To assess the rate of change in zBMI trends over various time points related to the COVID-19 pandemic, a piecewise linear mixed effects model was used, with a knot on March 11, 2020, to examine the zBMI slopes pre-COVID and during COVID. First, we investigated multicollinearity by assessing the variance inflation factors (VIFs) for all variables, which were all less than 4, showing that the covariates were not highly correlated. In addition, a diagnostic residual plot was conducted for zBMI slopes to check if residuals were normally distributed (**Figure 2)**. However, linear assumptions were not met with age (determined using a diagnostic residual plot, **Figure 3**). Therefore, we adjusted for age with a non-linear term using restricted cubic splines with 5 knots, as this number of knots is sufficient to capture non-linear patterns and more accurately reflects the rapid growth changes that occur in early years of development (Frank E. Harrell 2001). Once the assumptions were met, we continued with the analysis. The results of the model are displayed in **Table 3.** The pre-COVID era was associated with an increase in zBMI by 0.009 SD units per year (95% CI: 0.001, 0.017). The rate of change (slope) in zBMI during COVID-19 was not different than pre-COVID in our analysis.

Next, we conducted a piecewise linear mixed effects model with an additional knot at one year into the COVID-19 pandemic (**Table 4).** A diagnostic residual plot can be found in Appendix B, Figure 5. Similarly, there was a positive zBMI slope pre-COVID which did not show evidence of a difference compared to the slope of zBMI in the 1st and 2nd year of COVID.

5.3.3 Association between COVID-19 era and mean zBMI

The linear mixed effects model used to investigate the relationship between the COVID-19 era and mean standardized body mass index (zBMI) yielded the following results **(Table 5).** A diagnostic residual plot can be found in Appendix B, Figure 6. The COVID-19 era was related with an increase in mean zBMI (0.158 SD units, 95% CI: 0.160, 0.209).

5.3.4 Association between COVID-19 era and zBMI with zBMI quantile

Next, a quantile regression was conducted to determine whether COVID-19 era and rate of change in zBMI was associated with zBMI quantile. The plot of residuals can be found in Appendix B, Figure 7. Diagnostic plots of the quantile regression analysis at the various percentiles can be found in Appendix B, Figures 8-10**.** In the 25th, 50th, and 75th percentile models (**Table 6, 7, and 8, respectively**), there were no evidence of a change in zBMI prior to the pandemic nor for the slope change in zBMI after the onset of the COVID era.

5.4.5 Estimates of covariates in all regression models

In all models, rural, more diverse, and more material resourced populations were associated with a decrease in the rate of change in zBMI.

Figure 2: Diagnostic plot for residuals of slopes pre-COVID and during-COVID zBMI piecewise-linear mixed effects model

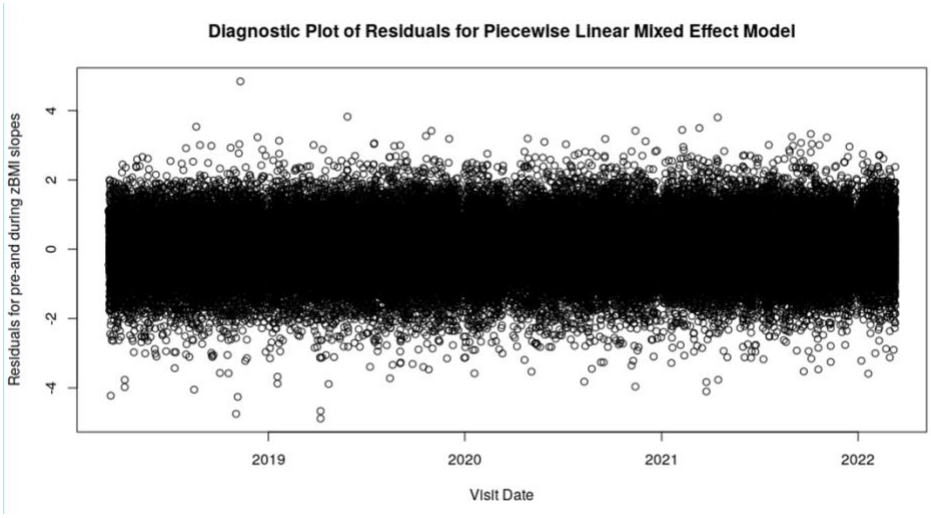


Figure 3: Diagnostic plot for residuals against age (in days)

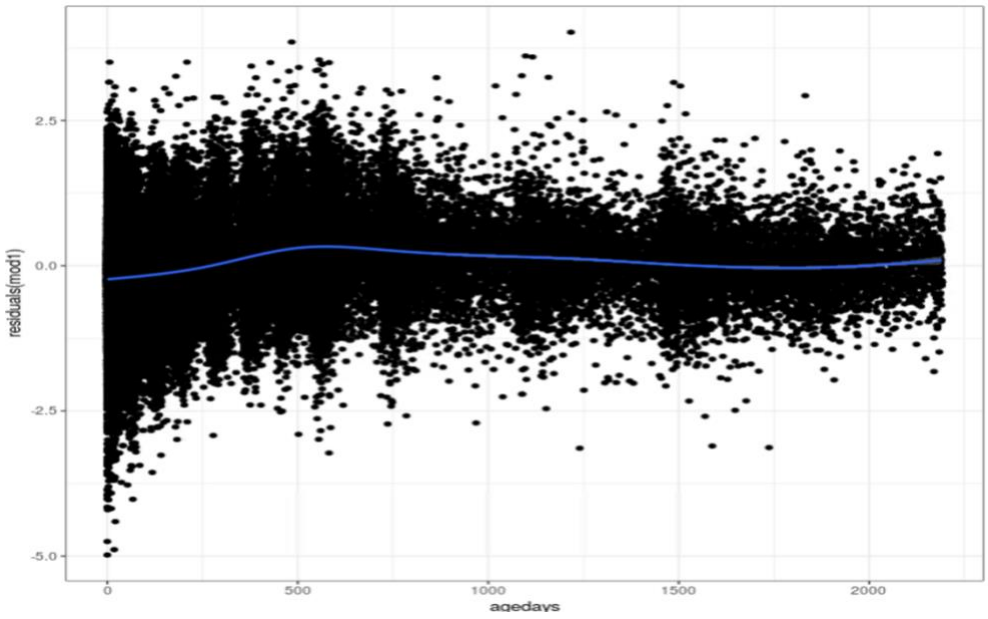


Table 3: Piecewise linear mixed effects model demonstrating association between COVID era and rate of change in zBMI

Parameter	Estimate	Standard Error	95% Confidence Interval
Fixed Effects			
Intercept	-0.326	0.050	(-0.424, -0.228)
Slope pre-COVID	0.009	0.008	(0.001, 0.017)
Slope change during COVID	-0.004	0.007	(-0.019,0.011)
Random Effects			
Variance	0.838	N/A	N/A
SD (Intercept)	0.915	N/A	N/A
Residual	0.648	N/A	N/A
SD (Residual)	0.803	N/A	N/A

Models adjusted for rurality, income quintiles, racialized and newcomer population index and material deprivation index.
Model also adjusted for age with restricted cubic splines and 5 knots.

Table 4: Piecewise linear mixed effects demonstrating association between COVID-19 era and rate of change in zBMI with knot at 1 year into COVID (2021-03-10)

Parameter	Estimate	Standard Error	95% Confidence Interval
Fixed Effects			
Intercept	-0.333	0.050	(-0.431, -0.235)
Slope pre-COVID	0.019	0.007	(0.004,0.034)
Slope change after COVID onset	-0.017	0.014	(-0.038,0.034)
Slope change after 1 year into COVID	0.036	0.018	(-0.109, 0.003)
Random Effects			
Variance	0.836	N/A	
SD (Intercept)	0.915	N/A	
Residual	0.648	N/A	
SD (Residual)	0.805	N/A	

Models adjusted for rurality, income quintiles, racialized and newcomer population index and material deprivation index.

Model also adjusted for age with restricted cubic splines and 5 knots.

Table 5: Results of association between COVID-19 era and mean zBMI using linear mixed effects modeling

Parameter	Estimate	Standard Error	95% Confidence interval
Fixed Effects			
Intercept	-0.059	0.051	(-0.161, 0.041)
COVID-era	0.158	0.009	(0.160, 0.209)
Random Effects			
Variance	0.927	N/A	
SD (Intercept)	0.964	N/A	
Residual	0.721	N/A	
SD (Residual)	0.849	N/A	

Models adjusted for rurality, income quintiles, racialized and newcomer population index and material deprivation index.
Model also adjusted for age with restricted cubic splines and 5 knots.

Table 6: Results of association of COVID-19 era and rate of change in zBMI with 25th zBMI quantile.

Parameter	Estimate	Standard Error	95% Confidence Interval
Intercept	-1.147	0.069	(-1.282, -1.012)
Slope pre-COVID era	0.012	0.015	(-0.017, 0.040)
Slope change after COVID onset	-0.026	0.025	(-0.075, 0.027)

Models adjusted for rurality, income quintiles, racialized and newcomer population index and material deprivation index.
Model also adjusted for age with restricted cubic splines and 5 knots.

Table 7: Results of association of COVID-19 era and rate of change in zBMI is associated with 50th zBMI quantile.

Parameter	Estimate	Standard Error	95% Confidence Interval
Intercept	-0.377	0.069	(-0.514, -0.246)
Slope pre-COVID era	0.008	0.013	(-0.017, 0.034)
Slope change after COVID onset	-0.003	0.022	(-0.048, 0.041)

Models adjusted for rurality, income quintiles, racialized and newcomer population index and material deprivation index.
Model also adjusted for age with restricted cubic splines and 5 knots.

Table 8: Results of association of COVID-19 era and rate of change in zBMI is associated with 75th zBMI quantile.

Parameter	Estimate	Standard Error	95% Confidence Interval
Intercept	0.506	0.068	(0.372, 0.639)
Slope pre-COVID era	0.017	0.015	(-0.011, 0.047)
Slope change after COVID onset	-0.023	0.025	(-0.072, 0.027)

Models adjusted for rurality, income quintiles, racialized and newcomer population index and material deprivation index.
Model also adjusted for age with restricted cubic splines and 5 knots.

5.4 Discussion

Main Findings

To our knowledge, this is the largest study of children <6 years old in the published literature in Canada, examining the relationship between the COVID pandemic and childhood growth. The cohort included 22,307 unique participants and 83,269 visits with most children living in urban areas and living amongst a higher diversity of racialized and newcomer populations. We demonstrated that there was an annual increase in zBMI prior to the pandemic, and this slope (rate) did not change with the onset of the COVID-19 pandemic. However, we observed an overall increase in mean zBMI during the COVID-19 era compared to pre-COVID. In the quantile regression models at the 25^{th}, 50^{th}, and 75^{th} percentiles, the rate of change in the zBMI did not change prior to COVID and this slope did not change after COVID either.

Interpretation

In the current study, the rate of increase in zBMI was not different for the two time periods. Although some authors had raised concerns that the COVID-19 pandemic could aggravate the childhood obesity epidemic (Anderson et.al, 2022), the evidence of our study does not support this. This may be due to the fact that the mean age of children in our study is much younger than in previous studies, which included a wider range of older ages (preschool, school-aged, and teenage years) and excluded children <2 years old. In addition, it is possible that younger children were more likely to attend in-person primary care visits during COVID-19 compared to older children. Our finding that the COVID pandemic was overall not associated with an increase in the rate of change in zBMI was similar to a US EMR-based study examining monthly rate of change in BMI from January 2018 to November 2021 in children 2-19 years of

age (Pierce, et al. 2023). In the Pierce et al. study, the monthly rates of BMI change were 0.056 (95% CI: 0.056, 0.057) in the pre-pandemic period (January 2018 to February 2020), 0.104 (95% CI: 0.102, 0.106) in the early pandemic (March to December 2020), and 0.035 (95% CI: 0.033, 0.036) in the later pandemic (January to November 2021). Therefore, although there was evidence of an increased rate of change in zBMI in the early pandemic period, this was tempered by the later pandemic period where the rate of change was lower than the pre-pandemic times.

In addition, our study found evidence of an increased mean zBMI during the pandemic compared to pre-pandemic amongst young children, likely reflecting the ongoing trend that was occurring irrespective of the pandemic since the rate of change in zBMI did not differ between periods. There is currently no literature available focusing on mean zBMI for our study population (children aged 0-5 years old). However, Ge et al. looked at the impact of pandemic-related BMI change on Chinese children aged 8-12 years old. They determined that the mean annual change in BMI z-score before and during the pandemic was 0.039 (95% CI=0.037, 0.042) and 0.131 (95% CI=0.125, 0.138), respectively (Ge, et al. 2022). Similar results were drawn from another study conducted in China on children aged 6-17 years old, where they discovered that mean zBMI significantly rose from 0.29 in 2019 to 0.45 in 2020, resulting in a jump of 0.16 (95% CI: 0.14-0.18) (Hu, et al. 2021). These results are similar to our study where the COVID-19 era was related with an increase in mean zBMI (0.158 SD units, 95% CI: 0.259, 0.291). Ge et al. found a rise of 0.092 (95%CI: 0.087, 0.096) in the annual rate of change of zBMI during the pandemic compared to the pre-pandemic period, whereas our study did not find a difference. If overweight and obese children were more likely have a higher rate of change in zBMI compared to normal weight children, then the discrepancy between our findings and those of Ge et al. could

be explained in part by the different age groups because the rates of overweight and obesity in younger children may not be as pronounced as in older age groups (Biro, et al. 2016).

The quantile analysis provided detailed insights, demonstrating that the pandemic's impact on childhood zBMI is consistent across the population. To our knowledge, this is the first study to use quantile regression in order to determine whether rate of change in zBMI and COVID-19 differs by zBMI quantile. There was no evidence in the rate of change in zBMI during the pandemic for children at all quantiles. The quantile results stem from their real-world application. They emphasize that the mean zBMI provides an overview but does not account for population variability.

Although not the focus of this study, we found an association that children living in rural settings, in areas with more diversity in terms of racialized and newcomer populations, and in areas with more material resources had a decreased rate of change in zBMI and lower mean zBMI, whereas there was no evidence of an association between income quintile and zBMI. There is little known about the association between zBMI and rurality for infants and preschool children living in Ontario. However, a study by Wijesendura et al. conducted on Canadian children, determined that there was no statistically significant difference between urban/rural residency and child weight status risk (Wijesundera, et al. 2023). The literature available focuses mainly on children from the United States. For example, these results of a randomized control trial by Contreras et al., that found children living in rural environments were more likely to engage in emotional eating behaviors that may be associated with weight changes (Contreras, et al. 2021).

In contrast, the inverse connection with racialized and newcomer index may indicate cultural dietary choices or lifestyle habits that are protective against zBMI increase (Singh, et al.

2009). Similar to rurality, there is currently no literature focused on the association between zBMI and racialized and newcomer populations for children <6 years old in Canada. However, a study conducted by Wahi et al., which examined differences in BMI in immigrant vs. non-immigrant youth aged 12-19 years old, found that immigrant youth had a lower zBMI by 0.44 compared to non-immigrant youth ($p<0.001$), and zBMI increased by 0.02 with each year of residency in Canada (Wijesundera, et al. 2023). The results from this study are similar in that racialized and newcomer populations had a negative association with zBMI. A cross-sectional analysis by Murphy et al. which aimed to understand local racial and ethnic inequalities in childhood BMI for children aged 4-11 in the United Kingdom, discovered that Black African children had a consistently higher zBMI than other racial and ethnic groups. The mean zBMI for this group increased by 0.11 (95% CI = 0.04, 0.17; P = 0.001) in females and 0.17 (95% CI = 0.1, 0.24; P < 0.001) in boys. Children in the Mixed, Indian, Pakistani, Bangladeshi, other Asian, and Chinese groups had lower zBMI than the White British reference group (Murphy, et al. 2019). It can be therefore concluded that the relationship between zBMI and race and ethnicity or immigration status in children is complex and diverse. While some research imply that some race and ethnicity and immigrant lifestyle practices may result in lower zBMI, this is not consistent across the literature and amongst different racialized and newcomer population groups.

There was no evidence of an association with income quintiles and the increased zBMI with decreased material resources suggest that financial resources alone are insufficient to explain changes in childhood growth patterns. In the study conducted by Wijesundera et al. on children aged 4-6 years old, they also looked at how social determinants of health influenced children's weight status. In terms of income quintile, they observed a statistically significant association between household income and weight status. Children were less likely to be

overweight (relative risk ratios [RRR]=0.95, 95% CI: 0.94-0.95) and affected by obesity (RRR=0.88, 0.86-0.90) with every CAD 10,000 rise in income ($p<0.001$) (Wijesundera, et al. 2023). These results are not in line with the results found in the current study where there was no evidence of an association. Furthermore, they explored the association between material deprivation and weight status. They determined that children in the most deprived quintile (vs. the least deprived quintile) were more likely to have underweight (RRR=1.36, 95% CI: 1.13–1.62), overweight (RRR=1.52, 1.46–1.58) and obesity (RRR=2.83, 2.54–3.15; all $p<0.001$) (Wijesundera, et al. 2023). These results are similar to the results found in the current study in terms of the positive association with zBMI however, the relationship between material deprivation and zBMI are nuanced, revealing that, while material deprivation is associated with a higher risk of underweight in children, it also has an association with an increased risk of overweight and obesity.

To successfully address the relationships between socioeconomic status and zBMI, it is critical to focus on understanding the complexities of zBMI changes, such as the rate of change or mean, across different socioeconomic situations. More research is needed to uncover and understand the intricacies in these correlations across different groups. Understanding how these characteristics influence zBMI allows treatments to be better customized to the individual needs of varied populations, assisting in the effective management and mitigation of zBMI changes. The particular socioeconomic conditions that developed during the pandemic, such as job loss and financial hardship, may have caused changes in food security and availability, potentially influencing children's zBMI. However, we did not observe an association with income quintiles and zBMI.

Several factors could explain the current study findings of a higher mean zBMI during COVID. The pandemic-induced lockdowns resulted in the closure of schools and extracurricular activities, drastically disrupting children's daily routines. Sedentary behaviours such as decreased outdoor play and increased screen time may have contributed to zBMI changes in children during the pandemic. A study conducted by Li et. al on children from Ontario, aimed to determine the association between public health measures and children's outdoor play, sleep, and screen time during COVID-19. They determined that there was shorter outdoor play and increased screen time during the pandemic (Li, et al. 2021c). In addition, a study by Neville et.al, looked at how physical activity levels were affected during COVID-19 for children between the ages of 3-18, they discovered that physical activity decreased by 20% (90% CI, −34% to −4%) compared to the pre-pandemic period.

At the same time, increasing family time at home may have resulted in more scheduled meal times and potentially healthier eating habits (Bennett, et al. 2021) (Adams, et al. 2020). An exploratory survey conducted on Saudi, British and Turkish children (aged 4-7 years old), found that most parents (96.1%) were concerned about their children's nutrition and prepared food at home during the lockdown. Sixty-three percent of parents said that their children had not gained weight (Bahatheg 2021). The stress and worry associated with the pandemic, while significant, may have been mitigated within family units, resulting in a balance that did not manifest in dramatic changes in zBMI (Cohodes, et al. 2021). Furthermore, the study by Karim et.al on the impact of lockdown during COVID-19 on nutrition and food insecurity, found that severely food insecure households had a higher prevalence of stunting and underweight children (Rezaul Karim and Tasnim 2022). This may have resulted in malnutrition and thus lower weight children. Contrastingly, however, in Cipolla et al.'s cross-sectional study conducted on Italian children

showed that 67.2% of respondents increased their consumption of carbohydrates and a worse diet was detected in 61.3% of patients with BMI gain (p=0.000) (Cipolla, et al. 2021). Therefore, there is nuance in the association between eating habits and child weight as evidenced from the literature available.

The role of technology cannot be overlooked. Increased screen time, a prevalent fear during the lockdown, could have had a double impact. On the one hand, it may have resulted in more sedentary behaviour, but it also created opportunities for virtual physical activity through interactive games that encourage movement (Nagata, et al. 2020).

The issue of sedentary behaviors and dietary habits and its association with zBMI is nuanced. Some studies have demonstrated that children were eating healthier meals while others have shown more food insecurity and eating unhealthier foods. Additionally, many studies have reported on physical activity/sedentary habits early on in the pandemic; however, it is not clear how these have evolved over time. Therefore, many factors, that were not included in this analysis, may have contributed in various positive and negative ways, which may explain the current study's findings.

In a real-world context, our findings indicate that public health interventions should be multidimensional and culturally appropriate. The robustness of zBMI trends at the pandemic's immediate beginning requires further investigation, particularly to comprehend the pandemic's long-term effects on children's growth trajectories. The findings from this broad study can be used to construct interventions that target the individual needs of children at various positions along the zBMI distribution, with a focus on the socio-cultural variables identified in our analysis.

Limitations

This study, while giving useful insights into the health profiles of young children receiving primary care in Ontario, has several limitations that should be considered. To begin, the generalizability of our findings is limited to a specific demographic: children in Ontario who have a family physician and use primary care. In addition, the results are not generalizable to all of Ontario as the data sources focus on populations living in the Greater Toronto Area and regions of Northern Ontario. Moreover, the affiliated clinics of UTOPIAN and NORTHH use patient enrollment models. It has been shown that healthier and wealthier patients were more likely to be enrolled in patient enrolment models versus fee for services practices which also demonstrates that our study results may not be generalizable to all of Ontario (Laberge, et al. 2017). This restriction is noteworthy because it implies that our findings may not be reflective of children without access to primary care, who live outside of the Greater Toronto Area and regions outside of Northern Ontario. Further, the majority of the children were normal weight, and 17.6% were overweight or affected by obesity, which is lower than the reported prevalence among 3 to 19 years olds in 2013 in Canada of 27.0% (95% CI: 25.3% to 28.7%) (Rodd and Sharma 2016). As a result, caution must be given when extrapolating these findings to the general Canadian population.

In addition, this investigation stemmed from measurements related to weight and height which were accessed through electronic medical records. This limitation is considerable in light of recent adjustments in medical guidelines for diagnosing obesity. Notably, the American Medical Association (AMA) published a policy in June 2023 endorsing the removal of BMI as a standardized measure in medicine (Flegal 2023). This was driven by the argument that BMI is insufficient to accurately represent a person's health status as it cannot differentiate between muscle and fat mass. Similarly, the Canadian Obesity Guidelines suggest that diagnosing obesity

should take into account additional factors in conjunction with BMI (Wharton, et al. 2020). However, the study's ability to comply with these modifications was constrained by the breadth of our data collection which was restricted to height and weight data from electronic medical records.

Moreover, our study showed that 67.9% of patients were included in the pre-COVID era and 10.2% of patients in the during COVID cohort were underweight which was higher in comparison to pre-COVID. It is unclear if selection bias may have occurred if children who were underweight may have been seen more often for follow-up visits with their family physician to monitor their growth status.

The absence of data on chronic diseases and obesity-related comorbidities limits our ability to comprehend the full range of health consequences linked with weight changes in children. It also hinders our understanding of the interactions between obesity and other chronic illnesses, which is a critical subject for future research.

Our study was unable to account for all potential factors that could influence the pandemic's effect on BMI, such as sleep duration, sedentary behaviours (including increased screen time and decreased outdoor play), nutrition and food insecurity, preterm birth, or chronic illnesses. Furthermore, a potential limitation could be the induction of virtual visits, specifically during the 1st year of COVID-19. Additionally, covariates were included at the area level rather than individual patient level. In particular, the material deprivation index being based on postal code, may not be responsive to their current financial situation. Finally, our study design limited our ability to infer causality in our findings.

5.5 Conclusions

In conclusion, this study is the largest Canadian study which focuses on understanding the impact of the COVID-19 pandemic on childhood growth, with an emphasis on zBMI in Canadian children under the age of six. We discovered that the pandemic did not disrupt the previous trend of annual zBMI increases, and that the COVID era compared to pre-COVID was associated with an increase in the mean zBMI. Our findings highlight an important ongoing public health emergency, overweight and obesity, that has persisted through the pandemic. This epidemic is far from seeing an end like the COVID pandemic. Effective primary care and public health interventions are required that would ideally address the multiple environmental and socio-cultural dimensions of the problem.

Future research should focus on longitudinal studies to track the long-term impacts of the pandemic on childhood growth, widen the geographic reach to improve representativeness, and incorporate qualitative approaches to gain deeper insights into environmental and lifestyle factors. Furthermore, a more in-depth analysis of the nuances of socioeconomic status, beyond income and deprivation indices, might be beneficial in understanding their involvement in childhood obesity and growth patterns. Moreover, applying this methodology in a different cohort where data on eating behaviours, sleep, physical activity and screen is available may be beneficial. Investigating the impact of public health measures, as well as behavioural and psychological aspects, during the pandemic will be vital in developing a comprehensive picture of childhood growth dynamics during the pandemic and post-pandemic era. This study, therefore, not only sheds light on the immediate impacts of the COVID-19 pandemic on the growth of infants and young children, but also lays the groundwork for more broad, diversified, and detailed future research in this critical field of primary care and public health.

CHAPTER 6: DISCUSSION & CONCLUSIONS

6.1 Summary of Findings

This thesis was a quantitative analysis of the impact of COVID-19 on childhood growth for children aged 0-5 living in Ontario.

The introduction, background, and literature review (Chapter 1-3) encompassed the current knowledge available in terms of the pandemic's impact on childhood growth and obesity prevalence along with discussing the context in which this thesis was made. The importance of conducting this literature review was to highlight a gap in the current knowledge which led to the rationale of the study presented in Chapters 4 and 5. Limited studies have examined the impact of COVID-19 on childhood growth for children living in Ontario. To date, there are a few studies that looked at lifestyle and dietary habit changes during the pandemic. Results from the current study highlighted key findings that require more long-term follow up to understand the potential lasting health outcomes on this population of children.

Results (Chapter 5) showed that the study, which included 22,307 patients, that 68% of visits happened before the COVID-19 pandemic and 32.0% occurred during the pandemic. Sex distribution was similar, with females accounting for around 48% and males accounting for 51% in both times. Most patients (almost 88%) lived in urban areas and lived in areas with higher diversity in the racialized and newcomer index. Various methods were employed in the study to assess zBMI trends in relation to the COVID-19 pandemic. The piecewise linear effects model demonstrated a shift from an increasing trend (slope = 0.019, 95% CI: 0.004,0.034) prior to the pandemic to a falling trend (slope = -0.017, 95% CI: -0.038,0.034). The linear mixed effects model revealed small an overall increase in mean zBMI which were associated with socio-demographic characteristics such as rurality, less diversity in the racialized and newcomer index,

and populations with access to less material resources. Importantly, the quantile regression analysis gave precise insights on zBMI across different quantiles, revealing that the rate of change in zBMI before and during the pandemic were not associated with the zBMI quantile.

6.2 Significance to the Family Medicine Field

This research study on the impact of the COVID-19 pandemic on childhood growth exemplifies the College of Family Physicians of Canada's (CFPC) fundamental principles and their application in family medicine. It holds implications for understanding the important role of childhood growth monitoring within the primary care sector, particularly in future crisis situations. According to CFPC Principle 2, family medicine is a community-based discipline. The importance of knowing community-specific health concerns is shown by this study's analysis of the consequences of the pandemic on children aged 0 to 5 in Canada while keeping in mind the patients' socio-economic disparities and rurality. The research connects with the essence of family medicine by focusing on a specific geographic and demographic context, underlining the necessity for family physicians to address and change practices in response to local health needs and dynamics (Kelly 1997).

Furthermore, the primary goal of this study, which is to investigate the relationship between the COVID-19 era and childhood growth metrics, specifically the standardized body mass index (zBMI) rate of change and mean zBMI, is consistent with CFPC Principle 3, which states that the family physician is a resource to a defined practice population. The importance of monitoring zBMI in primary care settings cannot be emphasized. It is an important tool for family physicians to use in detecting early symptoms of potential health concerns in children, especially during crisis situations (Thein and Goh 1995). This proactive strategy allows for early intervention and allows for comprehensive patient care, which aligns with the primary principle

of family medicine, which is to provide holistic care to patients within a specific practice group (Nowak, et al. 2021).

Furthermore, the secondary goal of the study, which was to investigate associations between the COVID-19 period and rate of change in zBMI in terms of zBMI quantile, coincides with CFPC Principle 4, which emphasizes the patient-physician interaction as important to the function of the family physician. This study adds to the establishment of closer patient-physician connections by investigating complex changes in childhood growth during the pandemic. This strategy builds trust, allows for a better knowledge of patients' health situations, and allows family physicians to provide tailored interventions and personalized care to children in their practice groups. This patient-centered approach emphasizes the need of developing strong and long-lasting connections between family physicians and their patients, which serves as the foundation of effective primary care (2009).

Furthermore, the findings of this study on the necessity of childhood growth monitoring during crises highlight the multifaceted nature of family medicine. Understanding how external variables, such as a global health crisis, affect childhood growth allows family physicians to better modify their treatment plans and solutions to address emerging health concerns. This proactive approach creates resilience within primary care systems, ensuring quick and effective responses to protect children's health and well-being in the face of unforeseen circumstances (Ohta and Sano 2022). In summary, this study not only aligns with CFPC principles, but it also emphasizes the critical importance of childhood growth monitoring in primary care, particularly in the context of crisis situations.

6.3 Recommendations

1. The results of this project demonstrated that among young children, the rate of change in zBMI pre-COVID was increasing and that the mean zBMI continued to increase from pre-COVID to during COVID. This evidence points to an ongoing problem with overweight and obesity in childhood, which require effective primary care and public health prevention and treatment. For example, comprehensive nutritional programs should be implemented to teach families about healthy eating while addressing the pandemic's problems, such as greater reliance on processed foods and decreased physical activity. These programs should be adjusted to different age groups, taking into account the individual dietary demands of children at distinct developmental stages. According to a study conducted by Headey et al., the COVID-19 pandemic has significantly impacted childhood malnutrition and nutrition-related mortality, highlighting the importance of addressing these issues (Headey, D. et al., 2020). Proper nutrition is crucial for children's physical growth, cognitive development, and overall health.
2. Children who came from urban areas demonstrated a positive association with zBMI indicating challenges in healthcare in urban settings. This indicates a need for the implementation of opportunities for increased physical activity by developing safe and accessible parks and recreational facilities. In addition, it is important to promote access to healthy foods and nutrition programs to encourage and educate children about healthy food and the benefit of physical activity. Moreover, limiting the availability and marketing of unhealthy food options near educational facilities could also help these efforts. According to a study conducted in the United States, children living in newer neighbourhoods that tend to have an urban design and that have a higher density of

convenience stores which tend to sell high-calorie foods, are more likely to be overweight (Grafova 2008). This highlights the importance of targeted nutrition, physical activity, and urban planning initiatives in these areas.

3. The results of this project demonstrated that more diverse populations had a lower zBMI rate of change and mean zBMI suggesting that cultural influences can affect health behaviours. Implementing culturally responsive health initiatives that respect and accommodate other ethnic groups' values, beliefs, and customs. Multilingual resources, culturally customized food and physical activity guidelines, and collaboration with community leaders are all part of the effort to establish trust and improve health outcomes (Smitherman, et al. 2021).
4. Material resources index and zBMI were positively correlated indicating that patients who experienced higher material deprivation levels correlated with higher zBMI. Based off the narrative review by Lopez-Bueno, the COVID-19 pandemic heightened health risks for children from low-income families. These risks included nutritional problems and decreased physical activity. Implementing community-based interventions and support programs that meet the unique needs of children in low-income communities can be beneficial to increasing access to nutritional foods, encouraging physical exercise, and implementing educational materials regarding healthy lifestyle options. Addressing these discrepancies is critical for mitigating the acute and long-term health effects of social isolation and hardship on children who have lived through the pandemic (López-Bueno, et al. 2021).

6.4 Conclusion

In conclusion, in this study on the influence of the COVID-19 pandemic on childhood growth for Ontario children aged 0 to 5, we discovered valuable insights on the stability of zBMI patterns during this global health emergency. Our findings demonstrated that the previous trend of annual rises in zBMI remained mostly stable, with no evidence of variations across quantiles during the pandemic. Socio-demographic parameters such as urban residency, the racialized and newcomer index, and material deprivation index correlated with zBMI, indicating the importance of social, environmental, cultural, and lifestyle factors in childhood growth.

As we enter the post-pandemic period, these findings highlight the importance of continuous and extensive study to better understand the long-term effects of COVID-19 on child health. Future research should explore more into the subtle effects of socio-demographic parameters, particularly during recovery and normalcy following the pandemic. This thesis makes substantial contributions to the current research on childhood growth during crises, emphasizing the need of family medicine in monitoring, comprehending, and responding to these complex dynamics. The findings of this study are essential in influencing future health policies and practices to ensure that children's growth and well-being remain a primary focus of family medicine and public health efforts in the face of continuing and anticipated problems. By elucidating the stability of childhood growth patterns in the face of a global health crisis, this study not only reassesses the expected effects of such events on childhood obesity and growth, but it also emphasizes the importance of socio-demographic considerations in public health and clinical practice. Future research directions should aim to determine evidence-based primary care and public health interventions that would ideally address the multiple environmental and socio-cultural dimensions of childhood growth.

APPENDIX A: LITERATURE REVIEW

A.1 ELIGIBILITY CRITERIA

Inclusion Criteria:

1. Children aged 0-5 years old
2. Studies published during the COVID-19 era (between March 2020 – October 2023)
3. Research completed in high-income countries (HIC) as defined by the World Bank.
4. Related to childhood growth and obesity

Exclusion Criteria:

1. Children above the age of 5
2. Studies published before the COVID-19 era (Before March 2020)
3. Work completed in low-income or middle-income countries
4. Study design: Opinion pieces, commentaries, editorials, case series, case reports, protocols, briefs and studies not in English nor French

Limits:

- Studies available in English or French

A.2 SEARCH STRATEGY

Table 9: Search Strategy used in Literature Review

1. **"**Covid 19" [MeSH Terms] OR covid19 [Text Word] OR SARS-CoV-2 [Text Word] OR covid 19 [Text Word] OR corona* [Text Word]
2. "child,preschool" [MeSH Terms] or "Infant "[MeSH Terms] OR infan* [Text Word] OR toddler* [Text Word] OR pre school* [Text Word] OR preschool* [Text Word] OR neonate* [Text Word] OR newborn* [Text Word]
3. "Pediatric obesity" [MeSH Terms] OR "Weight Gain" [MeSH Terms] OR overweight [Text Word] OR obese [Text Word] OR obes* [ti] OR childhood obesity [Text Word] OR child obesity [Text Word] OR weight [Text Word] OR body mass index [Text Word] OR growth [Text Word] OR pediatric obesity [Text Word] OR paediatric obesity [Text Word]
Search strategy completed by combining: 1 AND 2 AND 3

APPENDIX B: METHODS

B.1 Data Sources

This project used electronic medical record data available from the Primary Care Ontario Practice-based Learning and Research Network (POPLAR). POPLAR is the collaboration of six approved Practice Based Research and Learning Networks that securely collect and de-identify electronic medical record (EMR) data in order to create a centralized provincial database that provide information on the vital work that primary care does, as well as support practices in providing optimal care across Ontario. In this study, data from two of POPLAR's practice-based research networks were used: UTOPIAN (University of Toronto Practice-Based Research Network) and NORTHH (Northern Ontario School of Medicine Research Towards Health Hub).

1. UTOPIAN

UTOPIAN is an important component of the POPLAR effort, focused on the organizational aspects of primary healthcare in Ontario. It entails a network of family physicians and primary care professionals in the province giving essential data on healthcare organization, patient outcomes, and practice trends. In addition, it contains all electronic medical records for primary care services provided by their affiliated clinics.

2. NORTHH

The Northern Ontario School of Medicine Research Towards Health Hub (NORTHH) is an important source of health data, especially for studies concentrating on medical needs and difficulties in Northern Ontario. Among its many tools, NORTHH has a large collection of electronic medical records for young children examined in clinics throughout the region. These records contain a wide range of information, including full patient histories and growth charts.

This information is critical for understanding children's health trajectories in these areas, especially given the unique environmental and socioeconomic elements that exist in Northern Ontario. The NORTHH database is an invaluable tool for researchers and healthcare providers because it contains comprehensive and region-specific health data. The NORTHH database, which contains extensive and region-specific health data, is a resource for researchers and healthcare professionals seeking to assess and improve pediatric health care policies and results in this disadvantaged area. Its richness and breadth provide a unique perspective on the health patterns of young children in Northern Ontario.

B.2 Study Population

Study participants were the population of children under the age of 6 years old who received primary preventive care from UTOPIAN or NORTHH research networks' affiliated hospitals. This population must have had at least 1 primary care visit within the pre-COVID and/or during-COVID period; defined as March 10, 2018-March 10, 2020 and March 11, 2020-March 11, 2022, respectively. In addition, the patient had a valid date of birth and age, valid sex (male/female/other) recorded, and patient's primary care physician must have met minimum data quality criteria (over 20% of rostered patients have lab, medication, and billing data), and patient was rostered or had a primary care visit between March 10, 2018-March 11, 2022.

B.3 Primary Exposure

The COVID-19 pandemic was the primary exposure studied in this project. The primary focus of the analysis was children's exposure to the COVID-19 pandemic and its associated factors, specifically its impact on changes in standardized body mass index (zBMI). The study periods prior and during the COVID-19 pandemic, beginning with the implementation of

pandemic-related restrictions and lockdowns. Changes in zBMI were analyzed by comparing pre-pandemic and pandemic data (weight and height), allowing for a detailed investigation of the relationship between the COVID-19 era's unique circumstances and zBMI.

B.4 Covariates

All covariates for each patient in the study were determined between March 10, 2018 and March 11, 2022, encompassing both pre-pandemic and pandemic periods. Age and sex were determined using the electronic medical records from the UTOPIAN and NORTHH databases. Socioeconomic status was determined using OnMarg Material Resources Index and Racialized and newcomer populations Index as quintiles. The Material Resources Index uses indicators that reflect access to and fulfillment of fundamental material necessities, such as % unemployed and % without a high school diploma. The racialized and newcomer population index includes indicators to reflect the percentage of recent immigrants and the percentage of people who identify as a 'visible minority' (as defined by Statistics Canada). This variable is divided into quintiles **Q1 = least deprived, Q5 = most deprived.** Each patient's SES quintile was determined using postal codes. Rurality was determined using the second digit of each child's postal code. This defined each child as either living in an urban or rural setting. Virtual and in-person well-child visits were identified using billing codes available through UTOPIAN and NORTHH.

B.5 Outcomes

The main outcome variable was created for this study; zBMI. zBMI was calculated using weight and height data and adjusting for age and sex by comparing to the World Health Organization growth standards. This variable were measured during the pre-COVID and COVID period. Well-child visit codes were used to define the visit dates in which height and weight were

recorded and were relevant for the pre-COVID or during COVID period. **Table 10** provides a description of these well-child visit codes (includes vaccine billing and ATC codes) (Practice 2022). The secondary outcome variable of interest was mean zBMI which was derived for the same study period. The tertiary outcome of interest was zBMI quantile which split the cohort of patients into the 25th, 50th and 75th percentile. The categorization of patients and their associated zBMI was then compared to the WHO growth standards.

Table 10: Well-child visit codes

Visit Type	**Billing Codes**
Well-baby care	916 (well-baby care) or 917 (annual health examination adolescent/adult)
Intermediate assessment AND well-baby care and immunization service code on the same day	A007 AND one immunization service code: tetanus-diphtheria-pertussis-containing (G840, G841, G847), varicella (G848), measles, mumps, rubella (G845), pneumococcal (G846), or meningococcal (G844).
Intermediate assessment AND well-baby care and at least 1 ATC code	**ATC codes:** J07BH|J07BH01|J07BH02|J07CA06|J07AM01|J07AM51|J07BF|J07BF02|J07BF03| J07CA01|J07CA02|J07CA08|J07CA09|J07CA12|J07AJ|J07AJ52|J07AF01|J07AG01| J07AG52|J07AL02|J07AL|J07AL01|J07AL52| J07AH07|J07AH|J07AH01|J07AH03| J07AH08|J07AH09|J07BD52|J07BD01|J07BD51|J07BD53|J07BD54|J07BE| J07BE01|J07BJ01|J07BK01|J07BD54|J07BK| J07BK02|J07BK03|J07BJ51|J07AG53| J07AG54|J07AH02|J07AH04|J07AH05|J07AH06|J07AH10|J07AJ01|J07AJ02|J07AJ51|J07CA03|J07CA04|J07CA05|J07CA07|J07CA11| J07CA13

Figure 4: Flow Diagram of Patient Selection Process

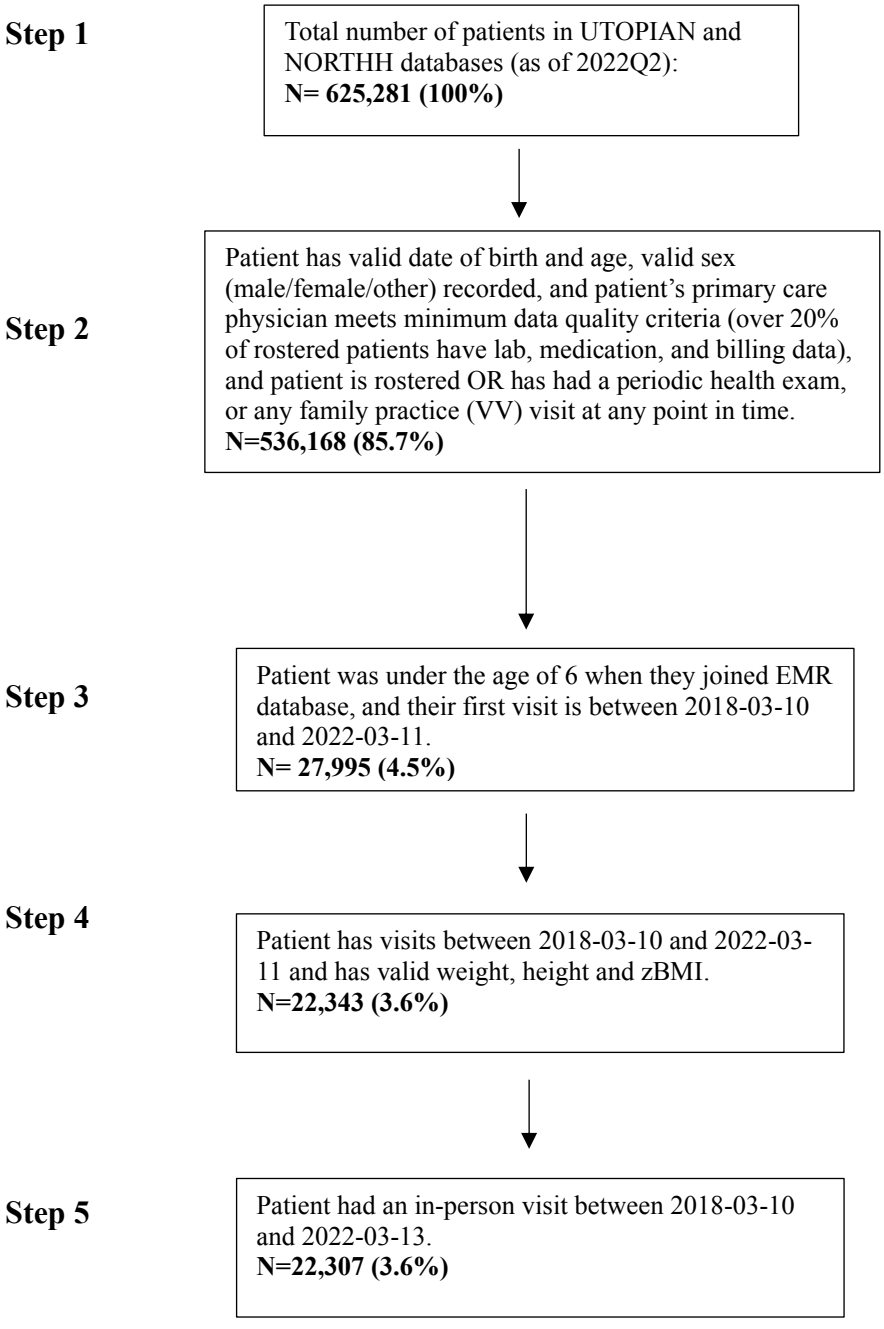


Table 11: Comparison between unadjusted mean zBMI and adjusted zBMI

	Unadjusted Average zBMI	Adjusted Average zBMI
Pre-COVID	-0.122 (SD: 1.3)	-0.117
During COVID	-0. 394 (SD: 1.33)	0.158

Figure 5: Q-Q plot for residuals of Piecewise linear Mixed Effects Model

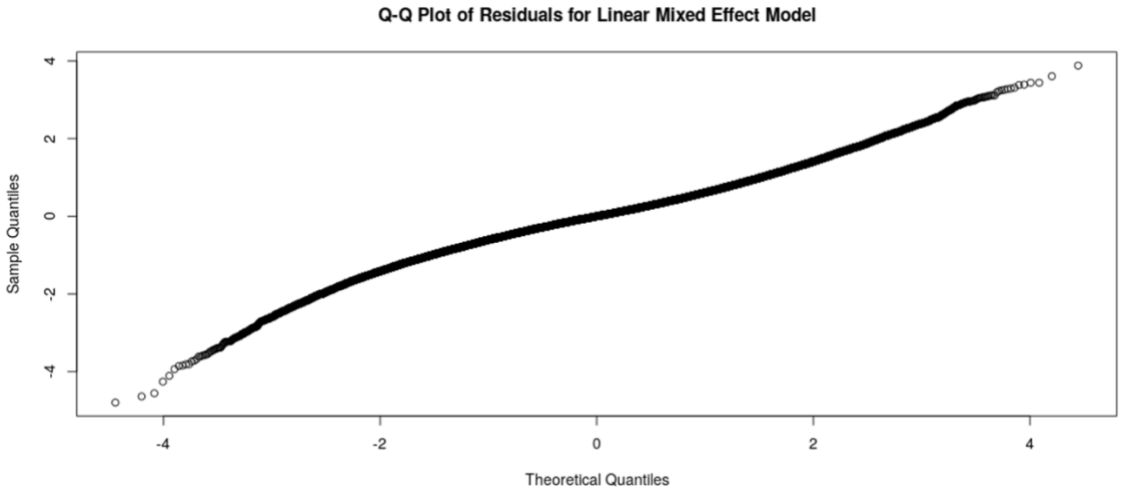


Figure 6: Diagnostic plot for residuals of mean zBMI analysis

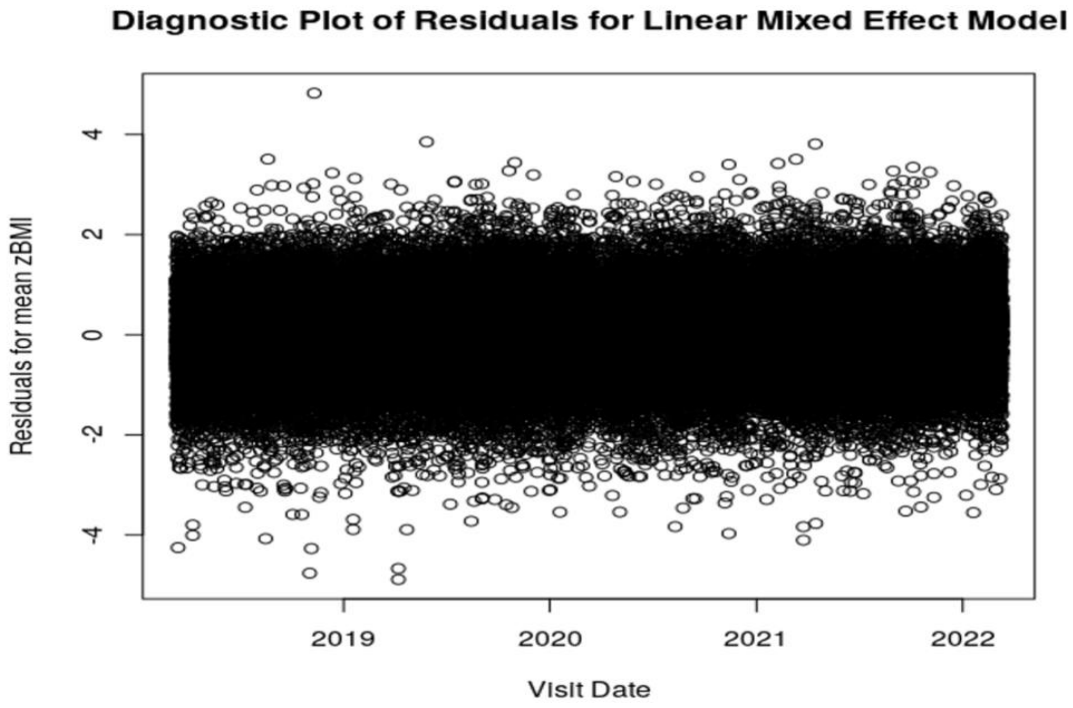


Figure 7: Q-Q Plot of Residuals for Linear Mixed Effect Model

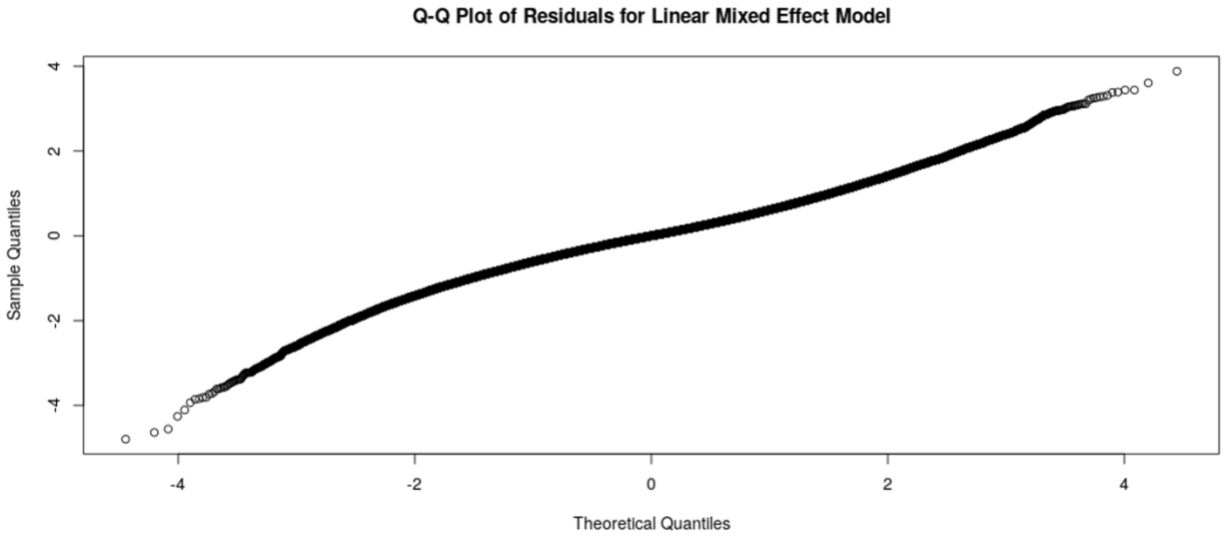


Figure 8: Diagnostic plot of quantile regression analysis at the 25th zBMI quantile

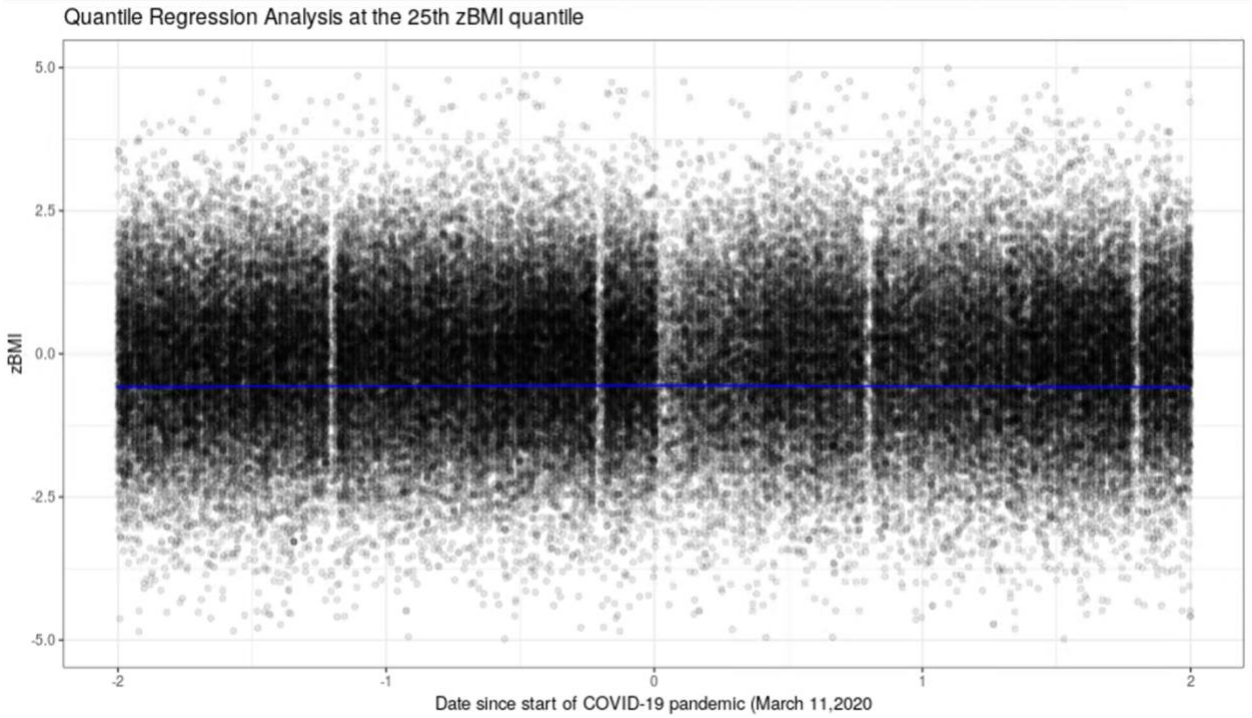


Figure 9: Diagnostic plot of quantile regression analysis at the 50th zBMI quantile

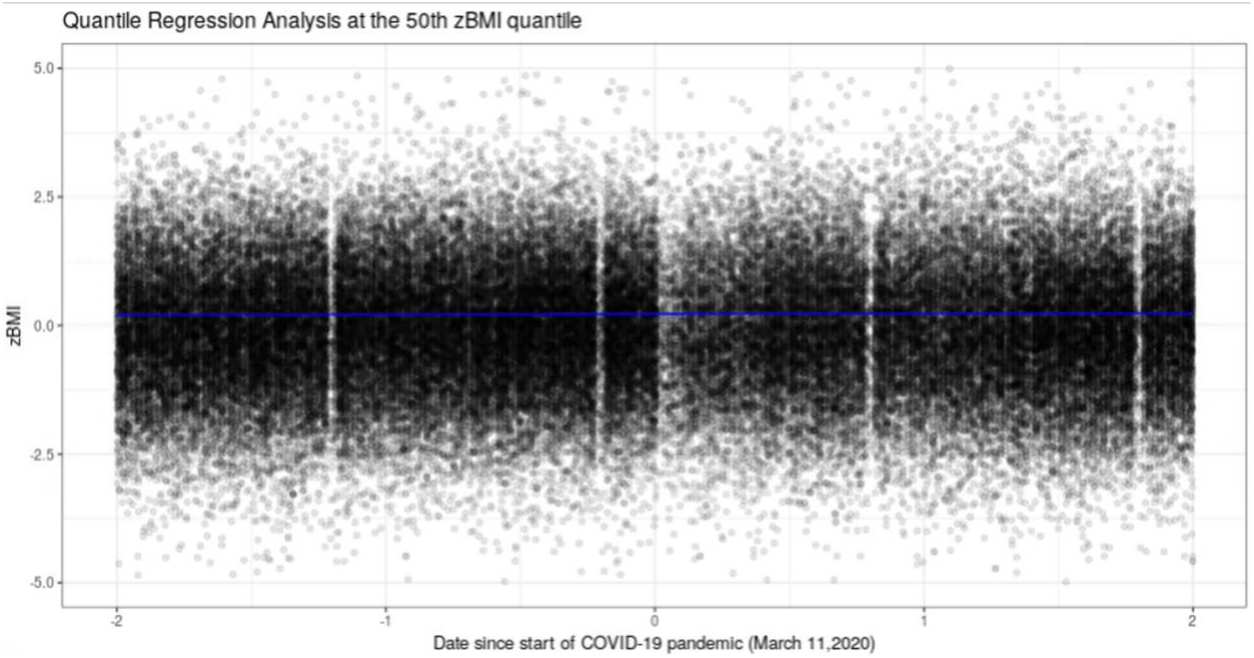
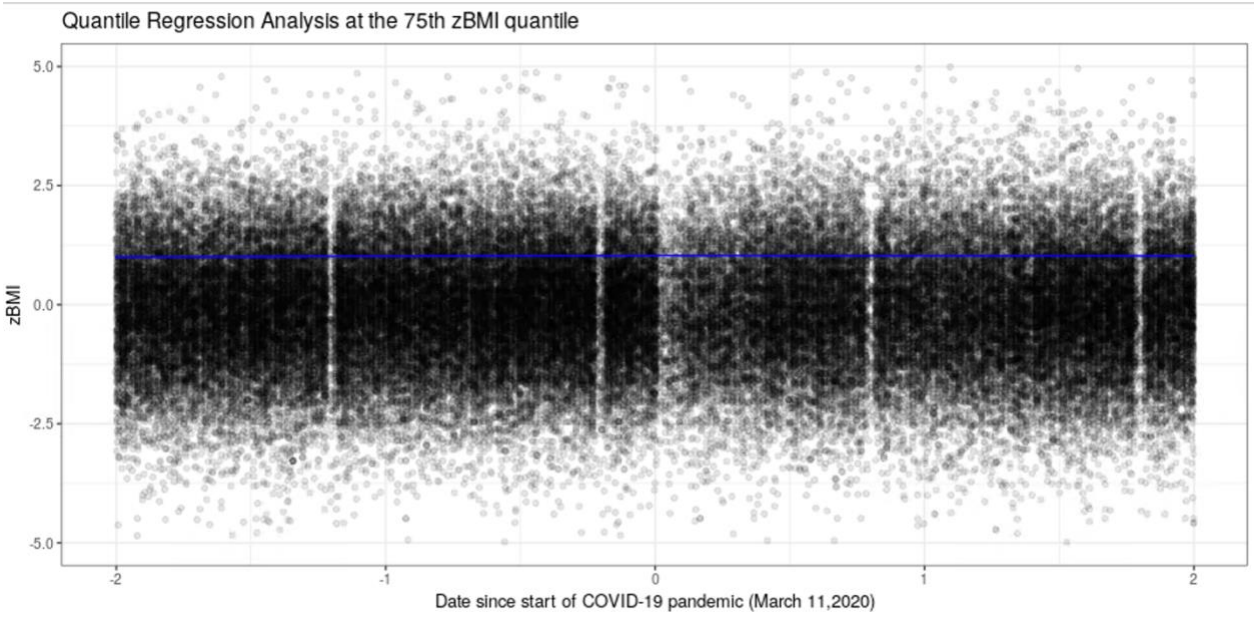


Figure 10: Diagnostic plot of quantile regression analysis at the 75th zBMI quantile



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