DIET QUALITY OF CANCER SURVIVORS AND NON-CANCER CONTROLS AND ITS ASSOCIATION WITH OBESITY AND NEIGHBOURHOOD ENVIRONMENT IN ATLANTIC CANADA

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Abstract

Background: Cancer survivors may be motivated to change their diet for weight management and improved survival. However, dietary behaviours and obesity are influenced by a range of individual-level and environmental factors rather than simply individual choices. This study aims to understand the diet quality of cancer survivors and its association with obesity and neighbourhood environment in comparison to non-cancer controls.

Methods: A cross-sectional study was conducted with 19,973 participants aged 35 to 69 years from Atlantic Canada. A healthy eating index (HEI) was used to evaluate diet quality using dietary intake collected from a food frequency questionnaire. Obesity was assessed using anthropometric and bio-impedance measures. Neighbourhood environment data were derived from the Canadian dissemination-area-level census data. Multivariable multi-level models were used to investigate HEI and its association with obesity in cancer survivors compared to non-cancer controls. The associations between neighbourhood deprivation, population density and HEI were also explored.

Results: Cancer survivors (n = 1930) had a higher mean HEI than non-cancer controls (mean difference: 0.45, 95% CI [0.07, 0.84]). Body mass index, waist circumference, waist-to-hip ratio, body fat percentage, and fat-free mass index were not associated with HEI, while trunk fat percentage had a weak positive association with HEI (0.45, 95% CI [0.08, 0.83]). The diet-obesity relationship did not significantly differ by cancer status. Mean HEI was lower in the most compared to the least socially deprived neighbourhoods (-0.56, 95% CI [-0.88, -0.25]), and in the most compared to the least dense neighbourhoods (-0.39, 95% CI [-0.77, -0.01]), but was not associated with material deprivation. Associations between diet quality, material deprivation and population density significantly differed by urbanicity. In rural areas, diet quality decreased with increasing material deprivation and decreasing population density, while the reverse was true for urban areas.

Conclusion: Cancer survivors had a slightly better diet quality than non-cancer controls, but both groups are in need of dietary improvement. Diet was not associated with obesity measures in the cancer and non-cancer groups but was associated with neighbourhood deprivation and population density with evidence of urban-rural differences, suggesting the complexity of dietary behaviour and the need for multi-level interventions.

Lay Summary

Cancer survivors are encouraged to eat healthy and have a healthy body weight. However, although cancer survivors may want to make healthy lifestyle changes after diagnosis, these changes may be helped or slowed by where they live, work and play. Moreover, their diet and body weight may also change due to cancer itself and treatments. Therefore, it is important to understand the diet quality of cancer survivors, how diet relates to obesity and how neighbourhood environment affects diet. We studied these three questions with approximately 20,000 people in Atlantic Canada, where there are high cancer rates. This study showed that cancer survivors have a slightly better diet than people without cancer. Poverty, social relationships and the number of people in neighbourhoods affect diet quality, indicating that many factors contribute to diet. This may help explain the null association between diet and obesity and suggest dietary interventions should consider multiple factors.

Preface

This study was reviewed and approved by the Behavioural Research Ethics Board at the University of British Columbia (Certificate #H15-02854). All the work presented in this thesis was conducted by Qianqian Gu under the supervision and guidance of the supervisory committee except for the construction of the healthy eating index. The healthy eating index was constructed by Dr. Zhijie Michael Yu from the Atlantic Partnership for Tomorrow's Health (PATH) project. Table 3.1 that presented the scoring scheme of the healthy eating index has been published as Supplementary Table 1 in Yu ZM, Parker L, Dummer TJB. Depressive symptoms, diet quality, physical activity, and body composition among populations in Nova Scotia, Canada: Report from the Atlantic Partnership for Tomorrow's Health. Preventive Medicine. 2014 Apr;61:106–13.

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List of Abbreviations

ACS - American Cancer Society

AHEI - Alternative healthy eating index

BF% - Body fat percentage

BIA - Bioelectrical impedance analysis

BMI - Body mass index

CCHS - Canadian Community Health Survey

DA – Dissemination area

DGA - Dietary Guidelines for Americans

DXA- Dual-energy X-ray Absorptiometry

EWCFG - Eating Well with Canada’s Food Guide

FFMI - Fat-free mass index

FSA - Forward Sortation Area

HEI - Healthy eating index

NHANES - National Health and Nutrition Examination Survey

NHL – Non-Hodgkin’s lymphoma

SES - Socioeconomic status

TF% - Trunk fat percentage

US - United States

WC - Waist circumference

WHR - Waist-to-hip ratio

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Chapter 1: Introduction

1.1 Cancer incidence, mortality and survival

Cancer is the leading cause of death in Canada (1). Almost half of Canadians are expected to develop cancer during their lifetime and approximately 1 in 4 Canadians will die of cancer (1). In 2017, 206,200 new cases and 80,800 cancer deaths were projected to occur (1). Due to early detection and advancements in treatment, cancer survival has improved over the past decades with an increasing five-year net survival rate[1] from 53% in 1992-1994 to 60% in 2006-2008 (1).

A cancer survivor is defined as anyone who has ever had cancer since the time of diagnosis to the end of his or her life (1,2). Currently, it is estimated that 55% of people with cancer are alive five years after their diagnosis (1). As the number of cancer survivors increases, the associated economic burden to the healthcare system is growing. The total net cost attributed to cancer increased sharply from $2.9 billion in 2005 to $7.5 billion in 2012 (3).

In addition, this estimated cost is likely conservative as cancer survivorship is accompanied by a higher risk of other chronic health conditions that may add financial, physical and mental burden to cancer survivors, their families and the healthcare system (4). Comorbidities increase the risk of all-cause mortality in cancer survivors, especially those with a better cancer prognosis, as these cancer survivors are less likely to die of cancer itself (5). According to the Surveillance, Epidemiology, and End Results (SEER) data, the prevalence of comorbidities among cancer survivors aged 65 years and older ranges from 31% for prostate cancer, 32% for breast cancer, 41% for colorectal cancer to 53% for lung cancer (6). Some comorbidities (e.g. diabetes, congestive heart failure) may develop due to the side effects of certain cancer treatments, or

[1] The five-year net survival is the relative survival ratio of cancer survivors compared to age-matched reference population. It is the probability of cancer survival in the absence of other diseases.

because of modifiable risk factors that are in common with cancer, such as unhealthy diet, physical inactivity, smoking, and obesity (5,7–10). The surge in the number of cancer survivors and increased risk of comorbidities necessitates research on lifestyle behaviours that may help them achieve healthier lives during survivorship.

1.2 Diet and cancer survival

Healthy eating is not only a recognized protective factor for the development of certain cancers and chronic conditions, but is also associated with survival after cancer diagnosis (11,12). One third of cancer deaths can be attributed to the combination of an unhealthy diet, physical inactivity, and overweight and obesity (12). The American Cancer Society (ACS) recommends cancer survivors to reduce the frequency of consumption and portion sizes of energy-dense foods to achieve or maintain a healthy body weight (14). Dietary recommendations also include emphasizing plant foods, eating at least 2.5 cups a day of fruits and vegetables, limiting consumption of red and processed meat, and replacing refined grains with whole grains (13). Health organizations in Canada have made similar recommendations for cancer survivors by encouraging adherence to *Eating Well with Canada's Food Guide* (14). Apart from recommendations about plant foods (e.g. fruits, vegetables, whole grains) and red and processed meat, the Canadian guideline also recommends consuming legumes, low-fat foods and healthy fats and limiting foods with too much sugar or salt, which are consistent with the ACS guidelines.

Dietary habits are closely linked to survival after cancer diagnosis. Systematic reviews and meta-analyses of observational studies have found a reduced risk of overall mortality among cancer survivors with high diet quality (15,16). Due to the role of diet in the etiology of some cancers, cardiovascular diseases and other chronic conditions, healthy eating may help prevent mortality from causes other than the primary cancer (17–19). Breast cancer survivors with high intake of fruits, vegetables, nuts, legumes, low-fat dairy products, and whole grains were found to have a 43% reduced risk of overall mortality and 65% reduced risk of non-cancer mortality (18).

Adherence to a healthy diet may also improve quality of life, which is an area gaining more attention with the increasing lifespan of cancer survivors. Evidence suggests that breast cancer survivors who adhere to recommendations regarding fruits, vegetables, grains, fats, sodium, protein and calcium after diagnosis have better mental health and physical functioning and less pain (20). Consuming 5 or more fruits and vegetables a day is also linked to better health-related quality of life among breast, colorectal, prostate and non-melanoma skin cancer survivors, according to an ACS study (21). Therefore, adopting a healthy diet should be one of the priorities to maximize quality of life, reduce the risk of second primary cancers and other chronic diseases, and improve overall survival.

1.3 Diet of cancer survivors

Cancer survivors are generally motivated to improve their diet after diagnosis (22,23). Many report being more conscious about their food choices (24). Approximately 45% of adults with breast, prostate or colorectal cancer self-reported consuming more fruits and vegetables after diagnosis, and 26-28% self-reported consuming less red meat and fat (24). Motives for diet improvement include preventing cancer recurrence, supporting treatment, managing body weight and achieving overall health (25). For many cancer survivors, a cancer diagnosis is a teachable moment when lifestyle modifications are more likely (26).

However, some cancer survivors are faced with challenges with respect to dietary changes. Bowel disturbances post radiation therapy has been reported by some patients, which may lead to avoidance of foods high in fibre (24). Other side effects of cancer treatments, including anorexia, vomiting, nausea, early satiety and changes in tastes and smells may also alter eating habits and pose a high risk of inadequate nutrient intake (13). As a consequence, despite motivation to improve diet, many survivors still fail to meet dietary guidelines. A study of 106 breast cancer patients reported that only 36-38% consumed more than 5 servings of fruits and vegetables, as recommended by the ACS guidelines (27). Similar results were observed in an Australian study (28), in which the mean dietary score of breast cancer patients was 33.2 out of 74, indicating poor adherence to the Australian dietary guidelines. When comparing people with and without a history of cancer, some studies suggest that cancer survivors have a better diet, while others found no difference or a poorer diet (28–35). Among cancer survivors, people with breast cancer were observed to have better diet quality, compared to those with colorectal, prostate or lung cancer (29,30). Some research indicate better diet quality in recently diagnosed cancer survivors, while others suggest no difference (30,32,36).

Most studies have assessed intake of fruits and vegetables or nutrients when comparing the diets of cancer survivors to non-cancer controls (30–35); few have compared overall diet quality (28,29). In addition, diet quality has been rarely characterized for cancer sites other than breast, colorectal, prostate and lung cancer. Studies that compared diet quality between major cancers have generally not explored whether differences are independent of sex, SES or other factors. To better understand the dietary needs of cancer survivors, more research is required to explore how diet quality varies by cancer site and years since diagnosis.

1.4 Diet and obesity in cancer survivors

Cancer survivorship guidelines advise cancer survivors to achieve and maintain a healthy body weight through diet and physical activity (13,14,37). According to the World Cancer Research Fund and American Institute for Cancer Research (WCRF/AICR), there is convincing evidence that excess body fatness is associated with cancers in breast (postmenopausal), colorectum, mouth, pharynx, larynx, esophagus (adenocarcinoma), stomach (cardia), pancreas, liver, gallbladder, kidney, prostate (advanced), ovary and endometrium (17). Abdominal fatness also increases the risk of pre- and post-menopausal breast, colorectal, pancreatic, endometrial, ovarian and high-grade and advanced prostate cancer (12,38–43). After the diagnosis of cancer, obesity is a potential risk factor for recurrence or second tumours, cancer mortality and all-cause mortality, particularly among breast and colorectal cancer survivors (44–49).

As with physical activity, healthy eating is a well-recognized protective factor for overall and abdominal obesity in the general population. Individuals who have a better diet quality, suggested by higher diet quality indices or healthy diet patterns (e.g. Mediterranean diet), are less likely to have a high BMI and WC (50,51). A high diet quality has also been shown to attenuate gains in abdominal fat (52).

However, the association between diet quality and obesity is more complex in cancer survivors than the general population due to changes in diet, weight and body composition after diagnosis. Cancer treatments and cancer itself may contribute to weight and body composition changes. Cancer used to be thought of as a disease accompanied by weight and muscle loss as patients were usually diagnosed at advanced stages (13). At present, weight loss and sarcopenia still affect a proportion of cancer survivors, especially those with advanced cancers or those with gastrointestinal and lung cancer (53). However, with earlier diagnosis and a high prevalence of obesity-related cancer, a larger number of cancer patients have excess body weight at diagnosis, which is carried through treatment to long-term survivorship (13). Among the 32,447 cancer survivors identified in the US National Health Interview Surveys, the prevalence of obesity was 32% in 2014, presenting an increase of over 9% from 1997 (54).

In addition, weight gain is prevalent among patients with cancer during or after treatment (55). For breast, colorectal and prostate cancer, studies demonstrate a higher percentage of patients experience weight gain than weight loss (56–59). Chemotherapy may also result in increased weight among breast cancer survivors (9,60), and hormone therapy has been associated with weight gain in prostate cancer survivors (10). However, loss of skeletal muscle is also common among cancer survivors, even those who are overweight or obese. A review article by Baracos and Arribas (61) suggested that on average, 34% of overweight and 25% of obese cancer patients had sarcopenia, known as sarcopenic obesity. This phenotype is mostly seen in locally advanced and metastatic cancer and pancreatic cancer, and is independently associated with cancer survival (61).

The alteration in weight and body composition after cancer diagnosis necessitates research to evaluate relationships between diet quality, obesity and body composition in cancer survivors. BMI and WC are two simple and practical anthropometric measures often used in large-scale observational studies to indicate overall and abdominal adiposity. However, there is additional value in using more direct measurements of body composition and fat distribution, although studies of this nature are lacking.

1.5 Diet and environmental factors

Diet quality and obesity are not influenced by a single factor. According to the social ecological framework, individual health behaviours are impacted by a complex interaction of intrapersonal, interpersonal and environmental factors (62). Studies of obesogenic environments have identified a few key aspects, including physical (built), social and economic characteristics of the environment (63).

Most of the research that has investigated physical characteristics and diet intake focuses on neighbourhood food environments (64–66). Other elements of the physical environment have yet to be explored. Neighbourhood characteristics, such as population density, land use mix and street connectivity manifest how walkable the neighbourhoods are and have suggested links to residents' physical activity and obesity (67–69). Neighbourhoods with higher population density are generally more compact areas, have a higher degree of street connectivity, and have greater mixed residential, commercial/retail, institutional, office uses (70). Therefore, high population density potentially facilitates greater and easier access to food retails within walking distances, which in turn may influence diet quality among residents. However, there has been limited research on the association between population density and diet quality directly. Exploring this association may help identify areas at risk of poor diet quality.

Previous research has suggested a probable association between the socioeconomic environment, food access and dietary habits. A high neighbourhood socioeconomic status (SES) or low deprivation was associated with greater access to supermarkets, less access to fast food restaurants, and a healthier diet in the US (71,72). On the other hand, Canadian research showed increased availability of both healthy and unhealthy food retails in more deprived areas or no association between neighbourhood deprivation and overall diet quality (73–75). More research is required in the Canadian context to assess the relationship between neighbourhood deprivation and overall diet quality.

As indicated by Townsend (76) and Pampalon et al.(77), there are two dimensions of deprivation: material and social. Material deprivation represents deprivation of goods and conveniences, such as housing and car, while social deprivation reflects deprivation of social networks, from family to community (77). Most studies of neighbourhood deprivation and diet only evaluated material deprivation (i.e. education, employment, and income), or assessed two dimensions altogether in a composite score. Limited research studied material and social deprivation individually in relation to overall diet quality. Understanding the association between population density, neighbourhood deprivation and overall diet quality may help target dietary interventions and educational programs to areas in need, which would benefit both cancer survivors and non-cancer individuals.

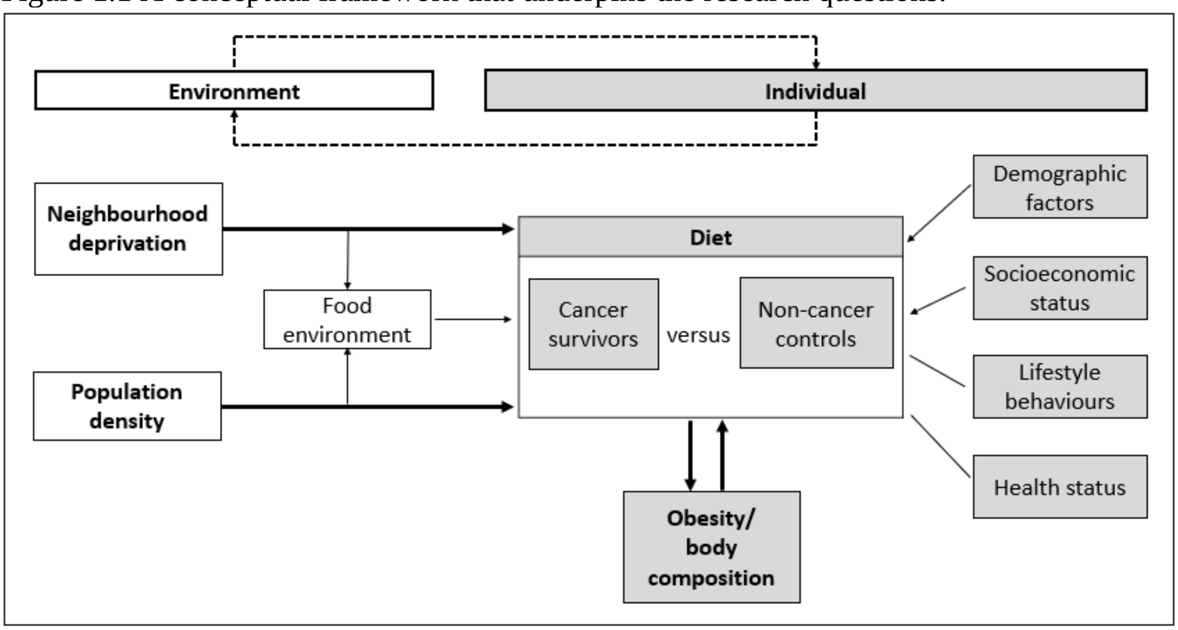
1.6 Research questions

Given the limited evidence on cancer survivors' overall diet quality, the present study investigated how well Canadian cancer survivors adhere to dietary guidelines using a Canadian diet quality index in comparison to non-cancer controls and how cancer survivors' diet quality varies by cancer site and years since diagnosis. Due to the potential changes in diet and weight after a cancer diagnosis, this study further assessed the association between diet quality, obesity and body composition with cancer status as a potential effect modifier. This study uniquely included anthropometric measures of obesity and bioelectrical impedance analysis (BIA) of fat mass (overall and regional) and fat-free mass to directly quantify body composition and fat distribution. In addition, with the aim of better informing diet interventions and policy making, this study explored factors influencing diet quality via obesogenic environments; neighbourhood material deprivation, social deprivation and population density.

Considering the complex and multi-faceted nature of dietary behaviour (**Figure 1.1**)[2], this research draws on several factors known to contribute to and/or be influenced by diet including demographic characteristics, socioeconomic factors, lifestyle behaviours, obesity, body composition, health status and environmental factors to answer the three research questions:

1. What is the diet quality of cancer survivors?
   a. How does diet quality compare to that of non-cancer controls?
   b. Does diet quality of cancer survivors vary by cancer site?
   c. Does diet quality of cancer survivors vary by years since diagnosis?
2. What is the association between diet quality, obesity and body composition in cancer survivors, compared to non-cancer controls?
3. What is the association between neighbourhood deprivation, population density and diet quality?

Figure 1.1 A conceptual framework that underpins the research questions.



[2] The conceptual framework is simplified to highlight the relationships that are most pertinent to the research questions. In addition to the associations indicated in the framework, there are other associations between neighbourhood environment and individual-level factors (e.g. SES, lifestyle behaviours, health status, obesity), which are altogether represented in the dashed arrows between "Environment" and "Individual" in Figure 1.1.

1.6.1 Study setting

To answer the research questions, data from the Atlantic provinces was used. The Atlantic provinces are of particular interest due to their relatively high cancer incidence rates and poor diet quality in Canada. The crude cancer incidence rates across Canada were the highest in the Atlantic provinces, with Newfoundland and Labrador, Prince Edward Island, Nova Scotia and New Brunswick contributing to 650.5, 609.7, 636.7, and 608.1 cases per 100,000 population in 2015, respectively (78). Although the high incidence may partially reflect a higher proportion of older population in those provinces, the projected age- and sex-standardized cancer incidence rates in 2017 were also highest in Newfoundland and Labrador for all cancer combined and some common types of cancer (1,79). The proportion of the population consuming 5 or more fruit and vegetables per day was also the lowest in the Atlantic provinces compared to all other provinces (80). For instance, less than 20% of residents from Newfoundland and Labrador consumed 5 or more fruit and vegetables per day (81). Therefore, the Atlantic provinces may benefit from the research questions the most in Canada as there is a large number of cancer survivors and the population are vulnerable to poor diet quality.

Chapter 2: Literature Review

2.1 Diet quality

Diet quality encompasses a range of concepts that are constantly evolving and has varying meaning to different individuals (82). Although there is still a lack of consensus for the definition of diet quality, it is well accepted that a high-quality diet is a healthy, nutritious, and balanced diet of great diversity that helps promote health and lowers risk of disease (82). Due to the multi-faceted concept, it has always been a challenge to quantify diet quality in research.

Previously, nutrition studies had a “reductionist” approach that focused on the relationship between single nutrients, foods, and health outcomes (83). However, this approach has limitations, as illustrated by the lack of success of dietary interventions that promoted the reduction of less healthy nutrients but neglected the importance of the nutrients used for substitution (84). For example, replacing saturated fats with unsaturated fats and carbohydrates from whole grains may reduce the risk of coronary heart disease (CHD), but substitution with carbohydrates from refined grains or added sugar may increase the risk of CHD (84). People do not eat foods and nutrients in isolation. The synergistic and antagonistic interaction between nutrients and foods prompted a shift of emphasis to examining dietary patterns rather than specific nutrients or foods (83).

The dietary pattern approach measures “the quantities, proportions, variety or combinations of different foods and beverages in diets, and the frequency with which they are habitually consumed”(85). Several countries, such as the US and Australia, have focused on promoting healthy diet patterns in their most recent dietary guidelines for the population, and so does the next release of *Eating Well with Canada’s Food Guide* (EWCFG) anticipated in Fall 2018 (86,87).

The dietary pattern method allows researchers to assess diet quality in a more holistic manner. Dietary patterns can be measured using an *a priori* or *a posteriori* approach (88). As an *a posteriori* method, which is exploratory and data-driven, cluster analysis groups participants with similar food intakes and/or frequencies together, while factor analysis aggregates food groups in high correlations to explain the variations in food intakes across diet patterns (88). On the other hand, the *a priori* method assigns people scores based on the recommendations from a pre-defined diet pattern, such as national dietary guidelines, Mediterranean diet, or Dietary Approaches to Stop Hypertension (DASH) diet (88). The derived score reflects the adherence to the pre-determined healthy diet patterns, with a high score indicating a high diet quality.

2.1.1 Healthy eating index (HEI)

The healthy eating index (HEI) is an *a priori* method that measures adherence to dietary guidelines. It was originally developed to monitor how the US population met nutrition needs and recommendations from the US Department of Agriculture Food Guide Pyramid (89) and was later updated to HEI-2005, -2010 and -2015 to reflect the changes made in the Dietary Guidelines for Americans (DGA), such as updated recommendations about vegetables, whole grains, refined grains, specific types of fats, seafood and added sugar (90–92). A variant form of HEI, alternative HEI (AHEI) was developed aiming to specifically capture food patterns that reduce the risk for chronic disease (93). The content and construct validity of HEI have been illustrated by the following characteristics: the components of HEI successfully represent the various aspects of the DGA; HEI yields high scores for healthy menus designed by nutrition experts; HEI has a wide enough range to distinguish meaningful differences in diet quality, is able to distinguish groups with known differences in diet (males vs females, smokers vs non-smokers, the young vs the old), is independent of diet quantity and represents more than one dimension of diet (91,94). The internal reliability was supported by the relatively high Cronbach's alpha (>0.6) and moderate correlation between total and component HEI scores (94). The original, updated and alternative versions of HEI have been widely used in health research and shown to predict the incidence of major chronic diseases, including cardiovascular disease (CVD), type 2 diabetes and some cancers, as well as mortality risk (16,93,95–97). However, since most studies compared risk of health conditions across quantiles of HEI scores, reduction of disease was associated with different increments in HEI across studies, making it difficult to estimate a meaningful HEI difference.

In Canada, the HEI-2005 was first adapted to the Canadian HEI (HEI-C) to assess adherence to the 2007 EWCFG (98,99). The HEI-2010 was also recently adapted (100). The general recommendations were similar between the EWCFG and DGA, including increasing the consumption of the adequacy components (i.e. total fruit and vegetables, whole fruit, dark green and orange vegetables, total grain products, whole grains, milk and alternatives, meat and alternatives, and unsaturated fats) and limiting the consumption of the moderation components (i.e. saturated fats, sodium, and "other food"). As with the US HEI, the HEI-C also has a best score of 100, with 60 points assigned to the adequacy components and 40 points assigned to the moderation components (99,100). However, instead of evaluating food intakes per 1000 calories of total energy as in the US HEI, the HEI-C criteria were expressed as EWCFG servings based on the age- and sex-specific recommendations (99,100).

Compared to the US HEI, there is limited research on the HEI-C and even less on the HEI-C and health outcomes (101–104). On a population level, Jessri et al. recently reported that the mean total HEI-C-2010 score for the Canadian population is 50.8 out of 100, indicating an overall poor adherence to the EWCFG (100). As with the US HEI, HEI-C components reflect recommendations in the EWCFG, indicating content validity (99). HEI-C also provides high scores for healthy diet patterns like DASH, Healthy Eating Pyramid and the No-Fad Diet, suggesting its good construct validity (99). A higher HEI-C-2010 score is associated with healthy lifestyle behaviours (e.g. physical activity, non-smoking, vitamin use), suggesting face validity (100). Also, the HEI-C-2010 has a high Cronbach's alpha (0.78), demonstrating its high internal reliability (19). Unlike HEI-C, HEI-C-2010 is uncorrelated with energy intake although diet intake was not assessed in the unit of energy (99,100).

2.1.2 Factors associated with diet quality

Diet and food choices are complex behaviours influenced by sociodemographic, lifestyle, and health-related factors. The neighbourhood environment-the space in which people, live, work, and engage in recreation also influences eating behaviours. An understanding of these factors and their interactions with diet can help provide context to dietary patterns and why diet may or may not differ among populations with specific characteristics.

2.1.2.1 Sociodemographic factors

Age is one factor that is known to influence food intake and diet quality. Higher HEI scores were found in older age groups in several studies (99,102,105,106). In a study of adults aged 20 years and older from 187 countries, there was a higher adherence to healthier diet patterns among older age groups, regardless of sex and country of residence (107). A healthy diet was characterized by higher consumption of fruits, vegetables, whole grains, beans and legumes, nuts and seeds, milk, fish, polyunsaturated fats, plant omega-3s, and dietary fibre, and lower consumption of red and processed meat, sugar-sweetened beverages, saturated fats, trans fats, cholesterol, and sodium (107). The higher diet quality among older adults may be attributed to greater awareness of health behaviours to prevent or manage chronic diseases (106,108). However, older age may also be accompanied by changes in taste and smell, digestive ability, hormonal status and oral health (109). As well, older adults generally have lower food and energy intake (109), which may make it difficult to meet nutrient requirements.

Females generally consume a healthier diet than males. Females consistently have higher consumption of fruits and vegetables (81,110,111). In terms of overall diet quality, a US study reported that females had a higher mean HEI than males by 5 units (106). Similar results have been seen with HEI-C scores for the Canadian population as well (99,102). In addition, lower total energy intake, energy density and percent of energy from fat have also been observed in females (112).

Racial disparity in diet quality also exists. Studies in the US have reported that non-Hispanic blacks have poorer diet quality, compared to non-Hispanic whites and other ethnic groups. Based on NHANES data, non-Hispanic whites were observed to have higher diet quality scores than Non-Hispanic blacks, but lower scores than Mexican Americans (113,114). Overall diet quality improved among the Non-Hispanic whites from 1999 to 2012, whereas there was smaller or no improvement among the other two ethnic groups (114). The racial differences may be explained by the socioeconomic inequities, cultural factors, and biological differences (113,115). In Canada, compared to Asians and South Asians, Caucasians were more likely to follow a prudent diet pattern, characterized by fruits and vegetables, legumes, whole grains and water, as well as a western diet pattern with high intakes of processed meat, refined grains, and salty and sugary foods (116). Asians, on the other hand, consumed more rice, vegetables, seafood and organ meat on average (116). Diet quality of Aboriginal Canadians appeared to be poorer than non-Aboriginal Canadians (99). However, the difference did not remain significant after adjusting for several diet, socioeconomic, lifestyle and health characteristics (99).

Social relationships are known to influence the type and variety of foods that a person consume. Dietary patterns are similar among spouses (117). People who are widowed, divorced or separated have lower odds of high diet quality, compared to married counterparts (118). The influence of marital status on diet is dependent on gender; males benefit more from living with partners (119). In a study of 9,580 adults aged 50 years or older, Conklin et al. found that single or widowed individuals had a lower variety of vegetable intake than those with partners, and the difference was more evident in males (119). Compared to married men, widowed and divorced/separated men were less likely to consume fresh fruit and vegetables daily, respectively (120). However, post-menopausal women who became divorced or separated experienced greater improvement in AHEI score, compared to women who remained married (121).

The variation in dietary habits by socioeconomic status (SES) is well known. Higher education and income have been associated with a healthier diet, indicated by high HEI scores, Mediterranean diet scores and healthy diet patterns derived from factor analysis (122–124). A review of studies assessing education, income, occupation and diet suggested that those with a high SES had higher intakes of fruits and vegetables, whole grains, fish, lean meat, low-fat dairy products, and lower intakes of refined grains and added sugar (125). The association between SES and diet is true in developed countries, and low-to-middle-income countries (126,127). Food cost is a barrier to a high diet quality for low-SES people. Energy-dense foods such as refined grains, added sugar and added fats are less expensive, whereas nutrient-dense foods such as whole grains, fish, fruit and vegetables cost more (125,128). The lower diet quality in low-SES people may also be explained by limited nutrition knowledge, lack of time for grocery shopping and cooking and less access to healthy foods in their neighbourhood (125,129).

2.1.2.2 Lifestyle characteristics

Healthy eating tends to cluster with other healthy lifestyle behaviours, including physical activity, non-smoking and alcohol abstinence. The odds of a high HEI score was 1.32 times higher among people who met physical activity guidelines (i.e. engaging in at least 150 minutes of moderate-intensity or 75 minutes of vigorous-intensity physical activity or the combination of both per week) (130). Greater leisure-time physical activity was associated with a healthy diet pattern (131–133). In addition, leisure-time physical activity was inversely associated with consumption of meat and alcohol (132). Despite the clustering of leisure-time physical activity and healthy eating, research on the association between occupational physical activity and diet patterns revealed less consistent results (131,132).

Smoking is a strong correlate of an unhealthy diet. Exposure to smoke may lead to appetite suppression and changes in taste, contributing to a distinct diet pattern among smokers from non-smokers (134). According to a Canadian study on 5,214 individuals in Quebec, smokers were 50% more likely to have an HEI score in the lowest quartile (least healthy), compared to non-smokers (133). A meta-analysis of 51 studies from 15 countries showed that, compared to non-smokers, smokers had significantly higher intakes of total energy, fats, saturated fats, cholesterol and alcohol, and lower intakes of fibre, anti-oxidant vitamins, iron, calcium and polyunsaturated fats (134). Former smokers had a greater tendency to consume a healthier diet compared to current smokers including higher intakes of fruits and vegetables, eggs, cereals, and yogurt (135,136).

Excessive alcohol use is associated with increased risk of chronic conditions including cancer (137). The ACS guideline for cancer prevention recommends consuming no more than one drink a day for women and two drinks a day for men (138). Cancer survivors during active treatments are recommended to avoid or limit alcohol consumption (13). Like smoking, a higher level of alcohol consumption was associated with poorer diet, demonstrated by lower intake of fruits, grains, dairy products and vegetable oil, compared to abstaining from alcohol (139). The relationship between alcohol consumption and diet quality may depend on how alcohol is quantified; in either amount or frequency. An NHANES study of 3,729 people reported a lower mean HEI score by 6 units among those who consumed more than 3 drinks per day compared to 1 drink per day, but the mean HEI score was higher with greater frequency of alcohol use (i.e. the number of days people consumed alcohol per year) (140). Another study found a substantial reduction in the mean HEI score when the consumption of alcoholic drinks was 5 or more per day in men and 3 or more per day in women, compared to less than one drink per day (141). In addition, there was a significant interaction between smoking and alcohol use on the food intake. The reduction in fruit intake and increase in meat intake in heavy drinkers compared to never-drinkers were larger in never-smokers, compared to current smokers, suggesting a larger impact of alcohol consumption on diet intake among never-smokers (139).

2.1.2.3 Health status

Poor diet quality is linked to the onset of many chronic diseases, such as diabetes, CVD, and cancer, individuals may have a poor diet when they are diagnosed. However, following diagnosis, individuals may be motivated to make changes or may receive lifestyle counselling for disease management, leading to adoption of a healthier diet. According to a large national study of Canadians aged 12 years or older, people with a diagnosis of heart disease or diabetes were more likely to consider calcium, fibre, and fat contents when they selected foods than those without heart disease or diabetes (142). They also had a greater tendency to avoid foods high in fat, salt, cholesterol or calories (142). A separate study found that people diagnosed with diet-related chronic diseases (at least one of diabetes, CHD, hypercholesterolemia, hypertension or cancer) were 30% more likely to have a higher HEI, compared to people without any diet-related chronic diseases (143). Among this population, people with diabetes were most likely to have a high HEI (143). In terms of food intake, people with diabetes had a higher intake of vegetables, fish, meat, and a lower intake of sugar, sweetened foods and alcohol, compared to those without diabetes (144,145). Reduced intake of added sugar was also observed in people with CVD, although evidence is inconsistent on overall diet intake, as both healthier and less healthy diets have been observed among people with CVD in comparison to the CVD-free people (146,147).

2.2 Diet quality and cancer

2.2.1 Diet quality and cancer survival

Similar to people with diabetes and CVD, people are also advised to adopt a healthy diet following a cancer diagnosis for disease management. Health organizations such as WCRF/AICR, ACS, and the American Society of Clinical Oncology recommend cancer survivors consume a diet high in fruits and vegetables, legumes and whole grains, and low in red meat, processed meat, sugar and fat, especially saturated fat (13,17,148–151).

Recent systematic reviews and meta-analyses of prospective cohort studies provided evidence for the diet recommendations by indicating a protective effect of healthy diet on overall mortality among cancer survivors (15,16). According to one of the systematic review and meta-analyses, people with the highest diet quality as assessed by the HEI, AHEI, and DASH scores, had a significantly reduced odds of all-cause mortality by 0.78 times, as compared to people with the poorest diet quality (16). In another systematic review and meta-analysis, Schwedhelm et al. showed that a prudent diet after cancer diagnosis characterized by high intakes of fruits and vegetables, poultry, whole grains, and low-fat dairy products was associated with a lower risk of overall mortality (OR: 0.77, 95% CI: 0.60-0.99), while a Western diet including high intakes of red and processed meat, sweets and desserts, refined grains and high-fat dairy products was associated with a higher risk of overall mortality among cancer survivors (OR: 1.51, 95% CI: 1.24-1.85) (15). The limited research on cancer recurrence presents mixed results. While two large prospective cohort studies indicated that a western diet increased the risk of cancer recurrence, metastasis or mortality in colorectal cancer patients, Schwedhelm et al. suggested no association between diet quality and cancer recurrence in their meta-analysis (15,152,153). The non-significance may partly be attributed to the limited number of studies on cancer recurrence and high heterogeneity among studies with respect to age and sex distribution, diet quality measures, types of cancer, time since diagnosis, definitions of study outcomes and various other factors (15).

2.2.2 Diet of cancer survivors

Cancer survivors are generally motivated to make lifestyle changes after diagnosis. According to a study of 7,903 cancer survivors, people made four positive health-related lifestyle changes on average after a cancer diagnosis, out of the 15 lifestyle behaviours assessed (e.g. health check-ups, eating healthy foods, exercise, using sunscreen, trying to lose weight, avoiding exposure to the sun) (154). The top three reported positive changes were getting regular health checkups, taking vitamins and/or supplements, and eating healthy foods (154). Two studies reported that approximately 40% of cancer survivors improved some aspects of their diet (23,154). For example, increased intakes of fruit, cruciferous vegetables, fish, legumes and nuts, and reduced consumption of meat and fat have been observed after a diagnosis (23,155). On the other hand, almost half or more cancer survivors maintained their pre-diagnosis diet (23,156). Furthermore, a prospective study of 696 incident cancer cases showed decreased intake of vegetables, dairy products, energy, micronutrients and fibre in the post-diagnosis diet compared to the pre-diagnosis diet (157). There may be individual variation in the factors affecting diet choices, including cancer treatments and the corresponding side effects, including gastrointestinal symptoms and altered taste and smell sensitivities (24,158).

There is mixed evidence about cancer survivor's diet in comparison to non-cancer controls with most research focusing on intakes of fruit and vegetables and selected nutrients (30–35). Approximately half of the research suggests a better diet among cancer survivors (30–33), and the other half reports no significant difference or poorer diet between the two populations (28,29,34–36). A large cross-sectional study that included 17,158 cancer survivors and 245,283 non-cancer controls from the Behavior Risk Factor Surveillance System Survey suggested that cancer survivors had 0.88 times the odds of not consuming 5 or more fruit and vegetables a day, independent of age, sex, ethnicity, education, BMI, and number of comorbidities (32). Similar findings were observed in a large study of prostate cancer survivors, who were 30% more likely to meet fruit and vegetable recommendations than non-cancer controls (31). In addition, cancer survivors had higher intakes of fibre, potassium, calcium, B vitamins, vitamin C, zinc, copper, manganese and a higher percentage of energy from protein in a smaller-scale Japanese cohort study (33). The same study also found a higher percentage of energy from total fats, saturated fats and monounsaturated fats in cancer survivors (33). In contrast, several other studies that compared cancer survivors, or breast cancer survivors only, with non-cancer controls did not find any significant difference in intakes of foods, such as fruit and vegetables, whole grains, processed meat, red meat, and intakes of nutrients, such as fats, fibre, macro- and micro-nutrients (29, 66–68).

Among the few studies that evaluated overall diet quality indices, a US study that compared 1,550 cancer survivors to 3,100 age-, sex, and race-matched controls from the National Health and

Nutrition Examination Survey (NHANES), reported a significantly lower HEI-2010 score in cancer survivors by 1.1 points out of a total score of 100, which may not be clinically relevant (29). More specifically, cancer survivors had less fibre intake and a higher percentage of energy from empty calories, reflecting calories from added sugar, solid fats and alcohol (29). In a separate study, breast cancer survivors had similar adherence to Australian dietary guidelines than non-cancer controls (28). The discrepancy in study findings above could be due in part to the different indicators of diet quality, heterogeneity in cancer survivors' characteristics, and unmeasured or residual confounding.

2.3 Obesity

A healthy body weight is another important aspect emphasized by cancer survivorship guidelines to reduce the risk of adverse health outcomes in cancer survivors (13,159). Emerging evidence shows that obesity increases the risk of all-cause and disease-specific survival in breast cancer survivors (47,160). Although evidence is inconsistent, some research also indicates that obesity has a negative impact on the risk of second-obesity related cancer, recurrence, disease-specific mortality or all-cause mortality for prostate, colon, stomach and bladder cancer (44,46,49,161–163).

Dietary factors play a role in the balance of energy intake and expenditure, the cumulative effect of which may lead to weight gain and obesity. Numerous epidemiological studies and clinical trials have been conducted to understand the links between foods, food groups, dietary patterns and obesity in the general population (101,164–167). However, there is comparably less evidence in cancer survivors. Some diet-based interventions have been carried out to promote healthy weight among cancer survivors, but the effect remains inconclusive (168–172). Many factors complicate the interpretation of results, including methodological issues, such as assessment of obesity.

2.3.1 Anthropometric measures of obesity

In large epidemiologic and clinical studies, anthropometric measures are commonly used as indicators of obesity for their simplicity and low cost. The most frequently used measure is body mass index (BMI), the ratio of body weight in kilograms to the square of height in metres. According to the World Health Organization (WHO), for adults, overweight and obesity are defined as a BMI between 25 to 29.9 kg/m^2 and greater than or equal to 30 kg/m^2, respectively, while a BMI between 18.5 and 24.9 kg/m^2 and below 18.5 kg/m^2 are considered as normal/healthy weight and underweight, respectively (173,174). The classification of BMI was developed based on the associated risk of mortality. Studies on various population have shown a U-shaped or J-shaped relationship between BMI and mortality (174–178). A recent meta-analysis of 239 studies from Asia, Australia and New Zealand, Europe, and North America showed that the lowest mortality risk was seen around a BMI of 20-25 kg/m^2, while there was an increased risk for a BMI greater than 25kg/m^2 (178).

Although BMI is used as an estimate of body fatness, it does not distinguish fat mass from lean body mass or reflect fat distribution. As a consequence, there are age-, sex- and ethnicity-related variations in body fat at equivalent BMIs (179). Aging is associated with loss of muscle mass and increase in fat mass. A Spanish study of 1,113 healthy participants found that percent body fat, as measured by dual-energy X-ray absorptiometry (DXA), increased in females from 35 to 55 years old and levelled off until the age of 70 when it declined again, while percent body fat constantly increased in males from 20 to 70 years old (180). On the other hand, percent lean mass declines throughout life with a significant drop around 65 to 79 years (180,181). Therefore, BMI may be a poorer indicator of obesity among older adults. BMI was shown to strongly correlate with total fat mass and percent body fat up to 65 years old in females and 55 years old in males (180).

There are also sex differences in body composition that may not be captured with BMI. Males tend to have lower proportions of fat mass than females (182,183). Jackson and colleagues reported the body fat of males was approximately 10.4% lower than that of females for the same BMI (182). The cutoffs for percent body fat that corresponded to a BMI of 25 kg/m^2 were 22.6% to 28.0% in males and 35.0% to 40.2% in females (183). This difference partly stems from the adolescent period, during which males gain more lean body mass during sexual maturation (184,185). The fat distribution of females also differs from that of males. Females are known to have a gynoid or "pear" shape with fat mostly accumulated on hips and thighs, whereas males have an android or "apple" shape, with fat stored predominantly around the abdomen, which strongly predicts all-cause mortality, cardiovascular mortality and cancer mortality independent of BMI (184,186). More specifically, males tend to accrue visceral fat, while women store more subcutaneous fat prior to menopause and more visceral fat after menopause (184). Furthermore, fat distribution also varies by ethnicity. It is reported that in comparison to White and Mexican Americans, African Americans tended to accumulate more fat mass on limbs but less on the trunk (187).

Due to lack of sensitivity and accuracy of BMI for capturing the variations in body composition and fat distribution, other adiposity measures have been adopted in epidemiological studies. In addition to percent body fat, waist circumference (WC) and waist to hip ratio (WHR) can shed light on abdominal or central obesity. Abdominal obesity is implicated in a range of metabolic conditions, including hyperglycemia, insulin resistance, inflammation, hypertension, and dyslipidemia, some of which mediates the relationship between obesity and chronic diseases, such as diabetes, cardiovascular diseases and some cancers (179,188). Compared to BMI, WC is a stronger independent predictor of visceral fat in both men and women (189). The combined use of WC and BMI also better predicted total abdominal fat than BMI alone (189). WC and WHR provide additional value to BMI in terms of predicting mortality. A meta-analysis of 18 prospective cohort studies involving 689,465 participants revealed that WC and WHR were associated with increased risk of mortality, independent of BMI (190). In another meta-analysis of nine cross-sectional studies, WC and WHR outperformed BMI in the prediction of CVD mortality (191).

2.3.2 Bioelectrical impedance analysis

Besides the anthropometric measures, many techniques can provide direct assessment of body fat and lean mass, such as DXA, computed tomography, magnetic resonance imaging and bioelectrical impedance analysis (BIA) (179). However, most techniques are cumbersome, expensive and technically demanding (179). BIA is a simple, portable and inexpensive technique to estimate overall body fat and regional fat mass (179). BIA assesses body composition by measuring the resistance of an electric current that travels through the body, based on the different conductance and impedance of body tissues. For example, the electric current passes through adipose tissue at a slower rate than through muscle, bone or water (192). Predictive equations were established to estimate fat-free mass and percent body fat from BIA-measured resistance (179). The 8-electrode BIA further allows assessment of segmental fat mass for trunk, arms and legs separately (193).

BIA has a small inter- and intra-observer variation and high reproducibility (192). Percent body fat measured by BIA correlated strongly with measurement from dual energy x-ray absorptiometry- a gold standard of body composition measurement (r=0.88) (194). However, there are limitations to BIA. A study of 591 healthy subjects found that BIA provided relatively accurate measures for people who had body fat within the normal range, whereas it overestimated body fat percentage in lean people and underestimated body fat percentage in obese people (194). In abdominally obese women aged 27 to 60 years, BIA underestimated body fat percentage by 5% and trunk fat percentage by 8.5% on average compared to DXA (195). BIA is also more likely to underestimate FM in people with low physical activity in comparison to physically active people (196).

2.3.3 Obesity and diet quality

The link between obesity and diet is widely recognized. Since dietary patterns emerged as a complementary approach to single-nutrient and single-food analysis, many studies have investigated how overall diet quality is associated with obesity (50). Asghari et al. (50) conducted a systematic review of cross-sectional and prospective studies on diet quality indices and obesity, of which most studies showed an inverse association between various HEI's (e.g. original HEI, HEI-2005, HEI-2010, AHEI) and BMI, with a stronger association seen in males. In some studies included in the systematic review, higher diet quality was correlated with a lower BMI only in men, but not in women (50). Guo et al. (164) showed that compared to a high- quality diet (HEI > 80), a poor-quality diet (HEI <50) was associated with 50% and 90% higher odds of overweight and obesity in men, while in women, it was associated with 70% higher odds of obesity but was not associated with overweight BMI. A limitation of approximately half of the studies included in the systematic review is lack of statistical adjustment for potential confounders such as energy intake, lifestyle behaviours and socioeconomic status, as BMI was not the main study outcome (93,197–200). In a recent study of the CCHS data, Sundararajan et al. adjusted for a more comprehensive list of factors including demographic characteristics, socioeconomic status, lifestyle behaviours, energy intake, self-perceived stress, urbanicity and province of residence in a finite mixture model analysis of HEI and BMI (101). The study observed two latent distributions of BMI and categorized people into high (mean 33 kg/m2) and low BMI groups (mean 22 kg/m2). A 0.1 kg/m^2 reduction in BMI with every one-unit increase in HEI was found, but only in participants with high BMI (101).

A similar inverse relationship was found for abdominal obesity in multiple studies of diet quality, measured by HEI, Diet Quality Index and other scores reflecting adherence to dietary guidelines (51,52,201–203). Adults aged 19 and older who were in the highest HEI quartile had 35% lower odds of an elevated waist circumference, compared to those in the lowest quartile (51). This was supported by another study showing a weak but significant inverse association between HEI and abdominal obesity (201). In addition, in the Women's Health Initiative Observational Study (WHI) of post-menopausal women, an improvement in diet quality score (i.e. HEI-2010, AHEI-2010 and DASH) by 10% was associated with a smaller increase in waist circumference and trunk fat mass over 3 years compared to women who consistently had a low diet quality. The results suggest that high diet quality or a positive change in diet may help attenuate the accumulation of abdominal fat in post-menopausal women (52).

Fewer studies have examined diet quality indices and lean body mass. While percent lean mass had no significant association with HEI (197,204), higher lean mass was positively associated with adherence to the Mediterranean diet pattern and diet diversity (205,206). Females in the highest quartile of the Mediterranean diet score had a higher fat-free mass percentage than those in the lowest quartile by 1.7%, after adjusting for age, physical activity, smoking status, energy intake, dietary misreporting and fat mass (205). Fat-free mass index was also higher by 1.3% in the highest quartile of the Mediterranean diet score compared to the lowest, but only in women younger than 50 years old (205). A diet high in total fats, monounsaturated fats, saturated fats, and trans fats was associated with a lower FFMI, while a diet high in polyunsaturated fats was associated with a higher FFMI (207).

2.4 Neighbourhood environment, obesity and diet

As with physical activity, diet and obesity were traditionally believed to be driven by individual-level determinants, such as income, education, nutrition knowledge and motivation (208). Two decades ago, the contribution of the neighbourhood environment to the obesity epidemic through diet and physical activity was identified, elucidating the complex interplay of individual and contextual factors on diet behaviours (209,210). Dietary intake can be influenced by the surrounding food environment, which encompasses the availability, accessibility, affordability, acceptability and accommodation of foods in the built environment (64). For example, residents who have easier access to supermarkets tend to consume more fruit and vegetables than residents with little access, as supermarkets generally offer a variety of high-quality foods at a low cost (211,212). The availability, proximity and prices of fast food outlets have also been found to influence diet behaviours and patterns (66,213,214).

2.4.1 Neighbourhood SES

2.4.1.1 Neighbourhood SES and Food Environment

The concept of "food deserts" draws a link between neighbourhood SES and the food environment. When the term food desert was coined in the 1990s, it was used to describe "those areas of inner cities where cheap, nutritious food is virtually unobtainable. Car-less residents, unable to reach out-of-town supermarkets, depend on the corner shop where prices are high, products are processed and vegetables are poor or non-existent" (215). The phenomenon of food deserts was later examined in different countries by comparing food accessibility in socioeconomically advantaged and disadvantaged areas (216,217). Evidence showed that food deserts existed in the US, where there were fewer numbers of supermarkets or further distance to nearest supermarkets in more disadvantaged areas, such as areas with a high proportion of low-income residents or African American residents (218–220). However, evidence from other countries was inconsistent. In the United Kingdom (UK), some studies found a higher number of fast food outlets in more deprived areas (221,222), whereas others found no significant association (223,224). One study reported the greatest number of total food retailers in the most deprived areas in Glasgow, UK (225). In Australia, despite less access to grocery stores, supermarkets and fast food restaurants in terms of proximity and density of stores, the prices of fruit and vegetables were lower in more deprived areas (226).

Research from Canada showed that there were a greater number of supermarkets and fresh food stores or fast food restaurants in more deprived areas in Québec, Alberta and British Columbia (73,227–229). This was supported by a study conducted in urban areas of three cities in Ontario, where the most deprived areas had better access to both healthy and unhealthy food retail outlets within walking distance (74). On the other hand, in urban and suburban areas of London, Ontario, a study found decreased access to supermarkets within walking distance with increasing deprivation, suggesting the existence of food deserts (230). The authors believed this discrepancy was due to the lower population density in London, where supermarkets and food retail stores had lower density overall (230). Most studies used a single index, either focusing on the material dimension of deprivation (e.g. income, employment, education) or a combination of material and social deprivation indicators (73,227–230). Few studies explored social deprivation independently in Canada, using information about the proportion of lone-parent families, residents living alone and residents divorced, separated or widowed (231,232). The limited evidence shows a distinct pattern of social deprivation compared to material deprivation in relation to the food environment (231,232). A study in Nova Scotia, Canada revealed that the number of fast food outlets per 1,000 residents increased with increasing social deprivation, but decreased with increasing material deprivation (232). This further suggests that material and social deprivation should be evaluated separately. At present, there are mixed results regarding access to supermarkets and fast food outlets in socially deprived areas (231,232).

2.4.2 Neighbourhood SES and diet quality

Despite the inconsistent findings of neighbourhood SES and food environment, residents in neighbourhoods with a higher SES generally have a more healthful diet. However, most studies have focused on single food groups or dietary components rather than overall diet quality. In a US study, a one-unit standard deviation increase in neighbourhood SES was positively associated with approximately two servings of fruit and vegetables per week (72). A secondary analysis of seven existing studies showed that living in socioeconomically advantaged areas was associated with an increased odds of ≥ 2 servings of fruit and/or ≥ 3 servings of vegetables in most countries including Canada, Scotland, Australia, New Zealand, and Portugal (233). Furthermore, fast food purchasing tended to be higher in the most socioeconomically disadvantaged areas, independent of individual SES, although the association only reached marginal significance (234). When indicators of area-level SES were analyzed separately, there was a 28% higher odds of consuming high-sugar and high-fat snacks in areas where >35% residents had lower than a high school education compared to areas where <22% residents had lower than a high school education (235). However, unemployment rate or average employment income was not associated with unhealthy eating (235).

Several studies in Australia showed poorer overall diet quality with increasing deprivation (105,236,237). The Diet Guideline Index was lower by 3 units in the most deprived areas compared to the least deprived areas, indicating poorer adherence to the Australian diet guidelines (236). There is a paucity of research assessing the relationship between area-level deprivation and overall diet quality in Canada. A study conducted in Calgary found no association between the HEI-C and socioeconomic deprivation index within 400m walking distance from home(75). The deprivation index was calculated using 7 indicators including single parenthood, education, marital status, unemployment rate, rented private dwellings and average value of dwellings (75). The conflicting results could arise from real regional variation or heterogeneity in the evaluation of diet quality and area-level SES.

2.4.3 Population density, food environment and diet quality

Population density, as defined by the number of residents divided by the land area, was found to be inversely associated with obesity (68,69). Increasing obesity has been witnessed with urban sprawl, manifested by an expansion of metropolitan areas that results in low population density and more reliance on vehicles (238). Population density reflects the urban form in terms of land use mix and street network patterns (69,239). Higher population density is positively correlated with a higher land use mix, street connectivity and use of public transit, which all contributes to a more pedestrian-friendly environment (69,239). As a result, residents living in highly dense areas are more likely to have access to food stores within walking distance (239). In contrast, residents in less densely populated areas may have to rely more on cars to access food.

Such environments most likely pose challenges to people without ownership of a car, including low-income people, elderly, children and adolescents (239).

A study of the local food environment in the high population density city of Madrid, Spain and the less dense city of Baltimore, USA revealed that 77% of residents in Madrid had access to healthy food stores within 200m and 100% had access within 400m (239). On the contrary, only 4% of people had access to healthy food stores within 400m in Baltimore (239). Similarly, in less densely populated British Columbia, population density was positively associated with the availability and proximity of large supermarkets and fresh food stores (228). Shorter distance to food stores was also seen with increasing population density in a large rural area of Texas (240). Apart from the limited access to food stores, many less dense areas are remote geographically, where food costs are higher without a better food quality (241). However, evidence directly linking population density to diet quality is lacking.

Chapter 3: Method

3.1 Study design

The current study investigated the diet quality among cancer survivors and cancer-free individuals and the association between diet quality with obesity and neighbourhood environment. A cross-sectional research design was used. Ethics approval was obtained from regional and provincial ethics boards.

3.2 Data source

Individual-level data were self-reported or directly measured in the Atlantic Partnership for Tomorrow's Health (PATH) study, part of the Canadian Partnership for Tomorrow Project (CPTP). Information about the neighbourhood environment was at aggregated levels from the Census and the National Household Survey (NHS) collected by Statistics Canada.

3.2.1 CPTP and Atlantic PATH

The CPTP is the largest population-based, longitudinal cohort study in Canada, launched to investigate how environment, genetics and lifestyle factors interact to affect the development and progression of cancer and other chronic diseases (242). More than 300,000 Canadians have enrolled in CPTP since 2008 and will be followed for up to 30 years. The CPTP brings together five regional cohorts including the BC Generations Project, the Alberta Tomorrow Project, the Ontario Health Study, the Quebec CARTaGENE project, and the Atlantic PATH study in Nova Scotia, New Brunswick, Prince Edward Island and Newfoundland and Labrador.

Participants for the present study were drawn from the Atlantic PATH. The Atlantic PATH study recruited 35,935 residents of Atlantic Canada between 2009 and 2015 (243). Participants were included if they were 30 to 74 years old and lived in one of the Atlantic provinces. Outreach activities were used for recruitment, including media coverage, advertising, community and workplace events, invitations from the Provincial Health Insurance provider (Nova Scotia only), incentive programs (e.g. Airmiles program) and community champions who encouraged participation among friends and families (243). Participants provided responses to questionnaires in person at assessment centres, online or by mail. All participants completed a core questionnaire that was common among CPTP regional cohorts, while 68% of participants completed a questionnaire that was unique to the Atlantic PATH study, including questions on dietary intake (243). Physical measurements (e.g. height, weight, waist circumference and body composition) and biological samples (e.g. blood, urine and toenails) were assessed in a subset of participants.

Data in the CPTP regional cohorts underwent a rigorous harmonization process led by Maelstrom, to facilitate pan-Canadian comparisons. The harmonized dataset in the Atlantic PATH contains 31,173 participants aged 35 to 69 years, among whom 53% were from Nova Scotia, 28% from New Brunswick, 15% from Newfoundland and Labrador and 4% from Prince Edward Island (243).

3.2.2 Census of Population and National Household Survey (NHS)

Each participant in the Atlantic PATH was linked to neighbourhood environment information obtained from the census and NHS. The census is the largest and primary data source of the entire population in Canada, including 34.2 million people, consisting of citizens, landed immigrants and non-permanent residents and their families living with them (244). People living on the Indian reserves and in other Indian settlements were also included. The census information supports decision making for planning services for the neighbourhood, community, province and the country (245). Statistics Canada conducts a census on a five-year basis (244). As the baseline data from Atlantic PATH were collected between 2009 and 2015, the census data that most closely aligned was from 2011 and was therefore used. The 2011 census comprised ten questions that collected the demographic and linguistic information from respondents, such as age, sex, marital status, family characteristics in the households. A total of 60% of dwellings were invited to complete the questionnaires online, while approximately 40% of dwellings received paper questionnaires (244). A small proportion of people (e.g. residents in remote areas or Indian reserves or transient residents in large urban downtown areas) were interviewed by enumerators. The overall response rate in Canada for 2011 census was 97.1%, with a specific response rate of 97.6% in Newfoundland and Labrador, 97.7% in Prince Edward Island, 97.3% in Nova Scotia, and 97.0% in New Brunswick (246). The census data are disseminated by different levels of geographical areas, in which dissemination areas (DAs) are the smallest standard geographic unit.

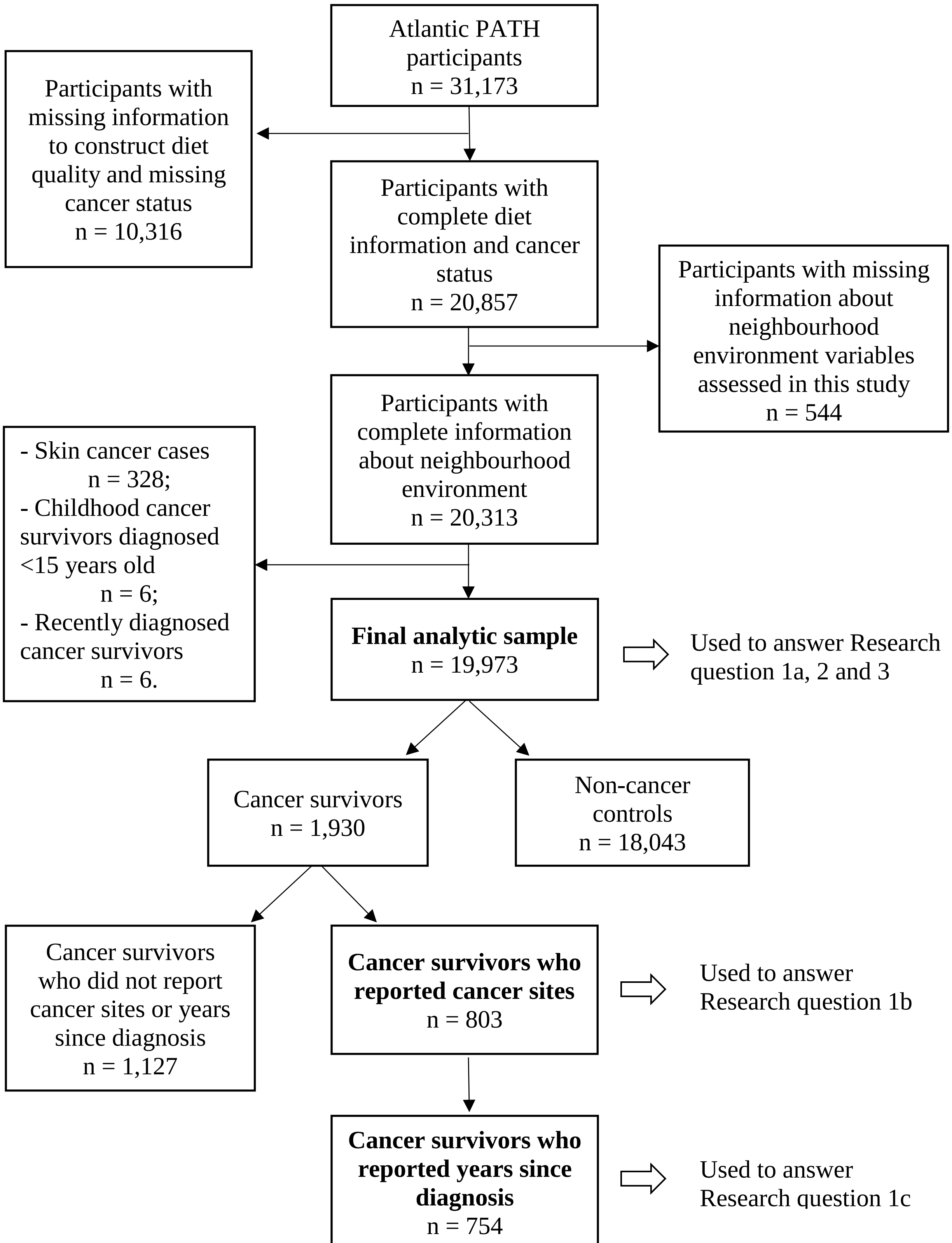
In 2011, the NHS was administered as a voluntary survey in complementary to the 2011 census to replace the long form census questionnaire. The survey randomly sampled 4.5 million dwellings, which comprised one-third of all dwellings in Canada. Similar to the census, it aimed to represent all residents in the provinces and territories of Canada. However, the NHS did not cover foreign residents, people living in institutional and non-institutional collective dwellings (e.g. hospitals, nursing homes, work camps, student residences), Canadians citizens and Armed Forces residing outside Canada (247). The survey responses were collected through self-administered questionnaires in all regions except for remote areas and Indian reserves where interviews were conducted. The NHS was used to collect information about demographic and socioeconomic characteristics of the residents and the dwellings in which they live. The survey included questions about basic demographics, families and households, ethnic diversity and immigration, education, labour, and income (247). The NHS received responses from 68.3% of occupied private households.

3.3 Study sample

Of the 31,173 participants from the Atlantic PATH, 19,973 were eligible for final analysis (**Figure 3.1**). Participants were excluded if there was incomplete information to construct the primary variable of interest, diet quality or if they had missing cancer status (n=10,316). Participants were also excluded if they had missing data for neighbourhood environment (n = 544). The missingness of neighbourhood data was either because of participants' incomplete address information, or incomplete census data for certain DAs due to data suppression or missing income information from the voluntary NHS. Additional exclusion criteria were applied to cancer survivors based on information about cancer sites and years since diagnosis, which were only reported in 50.4% of total cancer survivors. The study intended to exclude the non-melanoma cancer cases as they are non-fatal and treatment is relatively minor compared to other cancers. However, all skin cancer cases were excluded as there was lack of information to distinguish cases of non-melanoma from melanoma (n = 328). Exclusions were also made for cancer diagnosis before the age of 15 (childhood cancer survivor, n = 6) and cancer diagnosis within the past six months of study enrollment (n = 6) (**Figure 3.1**).

As a result, 19,973 participants including 1,930 cancer survivors and 18,043 non-cancer controls were included in the analytical sample to assess the diet quality of cancer survivors and non-cancer controls (research question 1a), and its association with obesity and body composition (research question 2), as well as its association with neighbourhood environment (research question 3, **Figure 3.1**). Of the 1,930 cancer survivors, 803 reported cancer sites and 754 reported years since diagnosis, **Figure 3.1**). To maximize the use of available data given the small number of cases with complete cancer-related information, the analysis for diet quality by cancer site (research question 1b) and years since diagnosis (research question 1c) was conducted on all cases with needed information.

Figure 3.1 A flow chart for the selection of the final analytic sample.



3.4 Study variables

3.4.1 Dependent variables

The dependent variable in this study was dietary quality. Participants reported their usual daily dietary intake using a food frequency questionnaire (FFQ) that was unique to the Atlantic PATH cohort. A total of 24 questions were used to assess the daily intake of fruit and vegetables, grains, dairy products, meat and alternatives, snacks, desserts, non-diet soft drinks, fats, sauces and salt in the prior 12 months. Participants were asked to indicate the number of servings they consumed in a typical day for the four main food groups: fruit and vegetables, grain products, dairy products and meat and alternatives. For other foods, participants were asked to indicate the usual frequency of consumption using times per day, times per week, times per month or rarely/never.

A Healthy Eating Index (HEI) was specifically developed for the PATH cohort using criteria adapted from the US and Canadian HEI (103,90,93,98) (**Table 3.1**). It was previously calculated by the PATH researchers and provided for use in this study (103). The scoring schemes reflect the recommendations from the EWCFG and several population-based studies for disease prevention (90,93,98,248). However, the HEI used in the Atlantic PATH is a modified version of the HEI-C, as not all the information was available to construct the originally developed HEI-C. There are five major criteria assessing participants' intake of foods from the four adequacy food groups (i.e. fruit and vegetables, grains, dairy products, meat and alternatives) and a moderation group (i.e. snack, dessert and non-diet drink) on a scale of 0 to 10. For the adequacy components, a score of 0 was assigned to participants for zero intake and the score increased proportionately with participants' intake up to the recommended level (**Table 3.1**). For the moderation component, a score of 10 was assigned to the recommended level and the score decreased with increasing intake. Ten additional criteria were used to evaluate participants' dietary behaviours regarding foods indicative of health-promoting or poor diets: dark green vegetables, whole fruit and vegetables, whole grains, oils, low-fat dairy products, fish, meat alternatives, saturated fat, sauces and salts. A score of one was assigned to each of these criteria met, otherwise a zero was provided (**Table 3.1**). The 15 component scores were summed to construct the overall HEI score ranging from 0 to 60, with a higher score indicating better diet quality. The HEI was then categorized into quartiles, from which the highest quartile was considered as high diet quality whereas the lower three quartiles were considered as low-to- intermediate diet quality. Both the continuous and binary forms of the HEI were used in the statistical analysis.

The FFQ and the HEI used in this study have not been assessed for validity and reliability. However, previous research from the Atlantic PATH that used both the FFQ and HEI have presented associations between the HEI and other variables in the anticipated directions. For example, male participants as well as participants with depressive symptoms were more likely to have poor diet quality (103,249). In a separate study, people with a higher HEI score were less likely to have obesity in the unadjusted and age- and sex-adjusted models, although the association was non-significant after adjusting for additional socioeconomic and lifestyle factors (104).

Table 3.1 A scoring scheme of the healthy eating index (© Elsevier 2014, by permission).[3]

Component	Score	Criteria for optimal score	Criteria for minimal score
Vegetables and fruit (serving/d)	0 to 10[a]	Age ≤ 50 yr: females ≥ 7 servings; males ≥ 8 servings Age > 50 yr: females ≥ 7 servings; males ≥ 7 servings	0 serving
Grain products (serving/d)	0 to 10[a]	Age ≤ 50 yr: females ≥ 6 servings; males ≥ 8 servings Age > 50 yr: females ≥ 6 servings; males ≥ 7 servings	0 serving
Milk and dairy products (serving/d)	0 to 10[a]	Age ≤ 50 yr: females ≥ 2 servings; males ≥ 2 servings Age > 50 yr: females ≥ 3 servings; males ≥ 3 servings	0 serving
Meat and alternatives (serving/d)	0 to 10[a]	Age ≤ 50 yr: females ≥ 2 servings; males ≥ 3 servings Age > 50 yr: females ≥ 2 servings; males ≥ 3 servings	0 serving
Snack, dessert, and non-diet soft drink (serving/d)	0 to 10[a]	< 0.5 serving/d	≥ 2 servings/d
Eat at least one serving of dark green vegetables each day	0 or 1	At least 1 servings of dark green vegetables per day	0 serving
Have vegetables and fruit servings more than juice	0 or 1	Vegetables and fruit servings greater than juice servings	Vegetables and fruit servings less than or equal to juice servings
Make at least half of grain products whole grain each day	0 or 1	Ratio of whole grain products to total grain intake ≥ 0.5	Ratio of whole grain products to total grain intakes < 0.5
Do not eat bread with oil products	0 or 1	Do not eat bread with butter, margarine, oil, or oil spray	Eat bread with any oil products
Drink lower fat milk or milk alternatives	0 or 1	Drink skim, 1%, or 2% milk or milk alternatives	Drink whole milk
Have meat alternatives such as beans, lentils, and tofu	0 or 1	Eat at least 1 serving/d of tofu, bean curd, beans, or other legumes	0 serving
Eat fish	0 or 1	Eat at least 1 serving of fish per day	0 serving
Do not eat saturated fat or its products	0 or 1	Do not eat any saturated fat or its products	Eat butter, lard or bacon fat, or Ghee
Season food with soy sauce or fish sauce at the table	0 or 1	Never or rarely	Sometimes or always
Add salt to food at the table	0 or 1	Never or rarely	Sometimes or always
Total score (range)	**0 to 60**		

[a] Intermediate intakes were scored proportionately between 0 and 10.

[3] Reprinted from Preventive Medicine, Vol 61, Zhijie M. Yu, Louise Parker, Trevor J.B. Dummer, Depressive symptoms, diet quality, physical activity, and body composition among populations in Nova Scotia, Canada: Report from the Atlantic Partnership for Tomorrow's Health, Pages 106-113, Copyright (2014), with permission from Elsevier.

3.4.2 Independent variables

3.4.2.1 Cancer status

Participants were asked "has a doctor ever told you that you had cancer or a malignancy of any kind?" and were dichotomized into cancer survivors or non-cancer controls based on the binary responses (yes/no). Cancer survivors were asked to indicate the cancer site(s) and age(s) at diagnosis(ses). When a person had multiple cancer diagnoses, information for the primary cancer was used in the present study. Years after diagnosis was calculated as the difference between age at Atlantic PATH baseline and age at diagnosis.

3.4.2.2 Obesity and body composition measures

Weight, height, waist and hip circumferences, and body composition were measured at assessment centres. Tanita bioelectrical impedance device was used to measure body weight, fat mass, fat-free mass and trunk fat mass. Height was assessed using a Seca stadiometer, while waist and hip circumferences were assessed using tape measures. Based on these measurements, body mass index (BMI) and body fat percentage (BF%) were calculated to reflect overall obesity and body fatness. Waist circumference (WC), waist-to-hip ratio (WHR), and trunk fat percentage (TF%) were used to indicate abdominal obesity, while fat-free mass index (FFMI) was used to reflect lean body mass. They were calculated using the formula below,

$$\text{BMI (kg/m}^2\text{)} = \text{weight/height}^2$$

$$\text{BF\%} = \text{fat mass/weight} * 100$$

$$\text{WHR} = \text{waist circumference/hip circumference}$$

$$\text{TF\%} = \text{trunk fat mass/fat mass} * 100$$

$$\text{FFMI (kg/m}^2\text{)} = \text{fat-free mass/height}^2$$

Self-reported height and weight were also collected. BMI was categorized as underweight (<18.5 kg/m^2), normal weight (18.5-24.9 kg/m^2), overweight (25.0-29.9 kg/m^2) and obese (≥30.0 kg/m^2) (174). Obesity was defined as having a WC of >102cm in males and >88cm in females (250), a WHR of ≥ 0.90 in males and ≥ 0.85 in females (250), or a BF% of >25% in males and >35% in females (174,251). As there are no standard cutpoints for FFMI and TF%, they were dichotomized using the 75th percentile value for each sex (FFMI: 22.49 in males and 18.28 in females; TF%: 64.0 in males and 52.6 in females).

3.4.2.3 Neighbourhood environment

Both population density and area-level deprivation were calculated from the 2011 census and NHS, using data at the DA level. Neighbourhood environment characteristics were linked to each individual by postal codes using the Postal Code Conversion File Plus (PCCF+) Version 6C (252). Therefore, individuals living in the same DAs were assigned the same values of neighbourhood environment characteristics.

Population density for each DA was calculated by dividing the population count by the land area, expressed in residents per km^2. Following the methods from Pampalon and colleagues (253,254,77), socioeconomic deprivation was constructed using six indicators from the census: the proportion of people without a high school diploma, the average individual income, the employment rate, the proportion of single-parent families, the proportion of people living alone, and the proportion of people who were separated, divorced or widowed. All six indicators concerned people of 15 years or older, except for the proportion of single-parent families. The indicators were standardized to the age and sex structure of the population aged 15 years or older in the Atlantic provinces in 2011 and normalized using Tukey's transformation. To create deprivation indices, the transformed variables were submitted to a principal component analysis, a standard method to reduce data dimensionality (255). Following a Varimax rotation, two independent components with eigenvalues above one were extracted. Marital status, the proportion of single-parent families and the proportion of people living alone were loaded on the first component (referred to as "social deprivation" later), while education, income, and employment were loaded on the second (referred to as "material deprivation") (**Table 3.2**).

Table 3.2 Principle component loadings and explained variance for the six indicators included in the deprivation indices for DAs in Atlantic provinces (n = 4142).

Indicators*	**Component**	
	1	2
Average income	-0.28	0.83
Employment rate	-0.05	0.80
People without high school diploma	0.02	-0.86
People living alone	0.85	0.00
Separated, divorced or widowed people	0.94	-0.10
Single-parent families	0.79	-0.24
Variance explained	39%	36%
Cumulative variance explained	39%	75%

*Indicators were age- and sex-standardized and normalized using Tukey's transformation before being submitted to the PCA

The two components covered different dimensions of area-level deprivation; material deprivation reflected the lack of access to goods and amenities in modern daily life, such as cars, housing, television, heating, while social deprivation depicted fragile social relationships of individuals among family, workplace and community (77). Factor scores for the two extracted components were calculated as material and social deprivation indices for all DAs in the Atlantic provinces (n = 4142), except for 321 DAs for which the information about the six indicators was incomplete due to data suppression or missing data. The DAs were then categorized into tertiles based on material deprivation and social deprivation separately.

3.4.3 Covariates

In addition to the dependent variable and the primary independent variables, potential covariates included sociodemographic factors (age, sex, ethnicity, education, marital status and household income), lifestyle factors (smoking status, alcohol consumption and physical activity), health status (diagnosis of diabetes and myocardial infarction), urbanicity and province of residence that have been shown to have association with dietary intake. Age was categorized into seven groups of 5-year increments (35-39, 40-44, 45-49, 50-54, 55-59, 60-64, and 65-69 years old). Ethnicity was dichotomized as white and non-white, as participants were predominantly white (93.16%). Education level was categorized into three groups: high school or lower, college level, university or higher. Marital status was dichotomized as living with partners (married or living common-law), and without partners (single, divorced or widowed). Household income was categorized as less than \$25,000, \$25,000-49,999, \$50,000-74,999, \$75000-150,000 and more than \$150,000. Physical activity was evaluated using both the short form and long form of the International Physical Activity Questionnaire (IPAQ) (256), which inquired about walking, moderate- and vigorous-intensity activities as well as sitting. The metabolic equivalent minutes per week (MET-min/week) was calculated based on the intensity, duration and frequency of physical activities, in which participants were engaged each week (257). The level of physical activity was categorized into low, moderate and high, according to the IPAQ scoring protocol (**Appendix A.1**) (257). For smoking status, former smokers consisted of those who had smoked at least 100 cigarettes during their lifetime but did not smoke within the past 30 days of the survey, and current smokers were those who had smoked at least 100 cigarettes in their lifetime and smoked in the past 30 days, either daily (regular smokers) or not daily (occasional smokers). All other participants were categorized as non-smokers. For alcohol consumption, respondents were asked to report the frequency of consuming a standard drink (i.e. 5 oz wine, 12 oz beer, a drink with 1.5 oz liquor). Participants were classified as abstainers (never drinking alcohol), former (drank alcohol before but not over the past 12 months), occasional (≤2–3 times/month), regular (≥ once/week but ≤2–3 times/week), and habitual drinkers (≥ 4–5 times/week). Self-reported diagnosis of diabetes and myocardial infarction were recorded as "yes" or "no". Urbanicity was recorded as urban or rural, whereby urban areas were referred to as any census metropolitan areas or census agglomerations with a core population of at least 10,000 (252). In Atlantic Canada, there are 4 census metropolitan areas (i.e. St. John's in Newfoundland and Labrador, Halifax in Nova Scotia, Moncton and Saint John in New Brunswick) and 14 census agglomerations, which are considered as urban areas (258).

3.5 Statistical data analysis

3.5.1 Missing data and multiple imputation

Most independent and covariates had missing values. **Appendix A.2** shows the number of missing observations for each variable. As it was unlikely that the data were missing completely at random (MCAR)[4], complete case analysis may lead to biased results (260). Additionally, the cumulative effect of missingness in a wide range of variables sharply reduced the sample size from 19,937 to 6,458, resulting in loss of power and precision (260).

[4] MCAR: the missingness of a variable is independent of the values of itself or any other observed variable (259).

Multiple imputation is an alternative approach to handle missing data. Instead of assuming data are MCAR, it is based on the assumption that data are missing at random (MAR)[5](260). This method uses patterns of observed values to predict multiple plausible values for the missing data, creating a number of "completed" datasets (260–262). Uncertainty is accounted for in this process because random components are incorporated into different imputed datasets (260–262). Statistical models are run in each dataset to obtain coefficient estimates and variance-covariance matrix, which are then pooled together using Rubin's rule to derive overall estimated coefficients (263).

Multiple imputation was performed using the *Multivariate Imputations by Chained Equation (MICE)* package in R (264). The missing values of education, household income, marital status, ethnicity, smoking status, alcohol consumption, physical activity, bioimpedance-measured BMI, body fat percentage, waist circumference, hip circumference, fat-free mass index, fat mass, trunk fat mass, myocardial infarction and diabetes were imputed. Age, sex, self-reported BMI, self-perceived health, and HEI were included as auxiliary variables in the multiple imputation to make the MAR assumption more plausible and reduce bias, as they were correlated with the variables with missing values (259). Waist-to-hip ratio and trunk fat percentage were passively imputed by calculating the ratios of the imputed variables. A fully conditional specification (FCS) method, also known as MICE, was adopted. Through this method, separate conditional distributions could be specified to impute different types of data, i.e. predictive mean matching method for continuous variables, logistic regression for binary variables and multinomial logistic regression for categorical variables with more than 2 categories (264). Given that the highest

[5] MAR: the missingness of a variable is dependent on the values of itself and other observed variables. Once all causes of missingness was taken into account, the residual missingness can be thought of as MCAR (259).

fraction of missing information was approximately 0.5 in this dataset, 40 imputed datasets were created to achieve sufficient statistical power, according to Graham and colleagues (265). In the end, 200 iterations were performed before reaching convergence (264).

3.5.2 Descriptive analysis

The distributions of continuous variables were examined using means, standard deviations, medians and ranges, and were also graphically represented with histograms and boxplots. Counts and frequencies were calculated for categorical variables. Each variable was examined for skewness and outliers. The means of continuous variables and frequencies of categorical variables were presented by the two categories of diet quality: low-to-intermediate and high diet quality. The basic characteristics were compared using chi-squared tests between cancer survivors and non-cancer controls and between participants who were included in and excluded from the analytical sample. Spearman correlation analysis was conducted among covariates to explore the possibility of multi-collinearity.

3.5.3 Statistical analysis

3.5.3.1 Multi-level models

To study the three research questions, multi-level models, also known as mixed-effect models were conducted to acknowledge the nested data structure, in which individuals are nested within forward sortation areas (FSAs, n = 261). Although neighbourhood data are at the level of DAs, since the number of participants was too few within most DAs, FSAs were selected instead of DAs as the level of clusters in the multi-level models to achieve sufficient sample sizes. In this study, the number of participants within the FSAs ranges from 1 to 534, with an average of 79. The non-independence of observations within the FSAs are accounted for in the mixed-effect models (266). Linear mixed-effect models (LMMs) were used when HEI was analyzed as a continuous variable, while generalized linear mixed-effect models (GLMMs) were used when HEI was analyzed as a dichotomized variable. A random intercept was included in the models to take into account the area-level variation in HEI. Assumptions of the models were examined through residual plots (266).

3.5.3.2 Research question 1: Analysis of HEI by cancer status

3.5.3.2.1 Research question 1a: HEI in cancer survivors and non-cancer controls

The diet quality of cancer survivors and cancer-free individuals were first compared using mean HEI scores and the proportion of high and low-to-intermediate diet quality. Cancer and diet quality were then entered in the multi-level models for further examination. To rule out the potential confounding effect that may distort the relationship between cancer and diet quality, multivariable analysis was carried out to examine potential confounders, including age, sex, household income, education, marital status, ethnicity, smoking status, alcohol consumption, physical activity, BMI, diabetes, myocardial infarction, social deprivation, material deprivation, population density, urbanicity and province of residence. Backward elimination (BE) was used to determine the significant confounders. In this procedure, potential confounders were removed from the model in a stepwise fashion; at each step the least significant variable was eliminated first (267). The procedure continued until all variables in the model had a p-value less than 0.20, as suggested by previous literature (267). The traditional cut-off of 0.05 may result in the elimination of important confounders, introducing bias to the relationship studied (267). To obtain the p-value of a variable in the model based on the multiply-imputed datasets, a Wald test was used to compare the full model and the reduced model from which the selected variable was removed (264).

The final LMM that compared the mean HEIs between cancer survivors and non-cancer controls were adjusted for age, sex, household income, education, marital status, ethnicity, smoking status, alcohol consumption, physical activity, diabetes, social deprivation, urbanicity and province of residence (Model 1a). Almost the same set of variables were adjusted for in the GLMM, except that this model adjusted for population density rather than marital status, ethnicity, social deprivation and urbanicity (Model 1b). The mean differences in HEI scores were obtained from the LMMs, while the odds ratios of high diet quality were derived from the GLMMs. Odds ratios were calculated by exponentiating the main coefficients in the GLMMs. All results were presented with 95% confidence intervals (95% CIs).

Model 1a $HEI = \beta_{0j} + \beta_1\,(cancer) + \beta_2\,(age) + \beta_3(sex) + \beta_4\,(income) + \beta_5\,(education) + \beta_6(marital\ status) + \beta_7\,(ethnicity) + \beta_8\,(smoking) + \beta_9\,(alcohol\ use) + \beta_{10}\,(physical\ activity) + \beta_{11}\,(diabetes) + \beta_{12}\,(urbanicity) + \beta_{13}\,(social\ deprivation) + \beta_{14}\,(province)$

Model 1b $logit(high\ diet\ quality) = \beta_{0j} + \beta_1\,(cancer) + \beta_2\,(age) + \beta_3(sex) + \beta_4\,(income) + \beta_5\,(education) + \beta_6\,(smoking) + \beta_7\,(alcohol\ use) + \beta_8\,(physical\ activity) + \beta_9\,(diabetes) + \beta_{10}\,(population\ density) + \beta_{11}\,(province)$

$$where\ \beta_{0j} = \beta_0 + b_{0j},\ b_{0j} \sim N(0, \sigma_0{}^2)\ ^{6}, \qquad j = FSA$$

As cancer survivors who did not report cancer sites possibly include people with skin cancer, who were excluded when reported, a sensitivity analysis was carried out to examine whether the difference in the mean HEI scores between cancer survivors and non-cancer controls remained similar, when cancer survivors were restricted to those who reported cancer sites other than skin cancer.

3.5.3.2.2 Research question 1b and 1c: HEI by cancer site and years since diagnosis

Among cancer survivors, the association of HEIs with cancer sites and years since diagnosis was studied. As stated earlier, the statistical model using cancer sites as the primary

[6] This equation indicates random intercepts at the FSA level.

explanatory variable analyzed 803 cancer survivors, while the model analyzing years since diagnosis involved 754 cancer survivors (**Figure 3.1**). There were 22 cancer types reported including breast, colon, lung and bronchus, liver, prostate, ovary, pancreas, stomach, esophagus, larynx, trachea, rectum, skin, cervix, uterus, kidney, bladder, brain, thyroid, non-Hodgkin's lymphoma (NHL), leukemia and other types. Skin cancer cases were not included in the comparison as they were excluded from the final analytic sample. Colon and rectal cancer were grouped into "colorectal cancer", while esophageal, liver, pancreatic and stomach cancer were grouped into "gastrointestinal (GI) cancer (excluding colorectal cancer)". As there are disparities in the types of cancers that males and females develop, the analysis was stratified by sex. The cancer type with the largest sample size in each sex was selected as the reference group, which was prostate cancer for males and breast cancer for females. Based on years since cancer diagnosis, four groups were created: those who were diagnosed within 2 years ("≤ 2y"), 2 to 5 years ("2y < yrs ≤ 5y"), 5 to 10 years ("5y< yrs ≤10y") or more than 10 years (">10 years"). Multivariable linear regression models were used to compare the mean HEI scores among cancer survivors with different cancer sites and years since diagnosis, adjusting for confounders shown in Model 2a, 2b and 3. The mean differences in HEIs and 95% CIs were calculated. For the multivariable models that study cancer sites and diet quality (Model 2a and 2b), only female survivors of cervical cancer and colorectal cancer were compared to female breast cancer survivors to ensure sufficient sample sizes in subgroups. In males, only colorectal cancer survivors were compared to prostate cancer. Cancer sites of smaller sample sizes were grouped together as "others (regrouped)", including lung and bronchus, GI (excluding colorectal), ovary, uterus, larynx, trachea, kidney, bladder, brain and thyroid cancer as well as NHL, leukemia and other types.

Model 2a (for males) $HEI = \beta_{0j} + \beta_1\,(cancer\ sites) + \beta_2\,(age) + \beta_3\,(smoking) + \beta_4(alcohol\ use) + \beta_5\,(physical\ activity) + \beta_6\,(myocardial\ infarction) + \beta_7\,(social\ deprivation)$

Model 2b (for females) $HEI = \beta_{0j} + \beta_1\,(cancer\ sites) + \beta_2\,(age) + \beta_3\,(income) + \beta_4\,(education) + \beta_5(marital\ status) + \beta_6(ethnicity) + \beta_7\,(alcohol\ use) + \beta_8\,(physical\ activity) + \beta_9\,(myocardial\ infarction) + \beta_{10}(diabetes) + \beta_{11}\,(social\ deprivation) + \beta_{12}(population\ density) + \beta_{13}(urbanicity) + \beta_{14}(province)$

Model 3 $HEI = \beta_{0j} + \beta_1(years\ after\ diagnosis) + \beta_2(age) + \beta_3(sex) + \beta_4(income) + \beta_5(education) + \beta_6(ethnicity) + \beta_7(smoking) + \beta_8(alcohol\ use) + \beta_9(physical\ activity) + \beta_{10}(myocardial\ infarction) + \beta_{11}(population\ density) + \beta_{12}(urbanicity) + \beta_{13}(province)$

$$where\ \beta_{0j} = \beta_0 + b_{0j},\ b_{0j} \sim N(0, {\sigma_0}^2), \qquad j = FSA$$

3.5.3.3 Analysis of the association between obesity, body composition and HEI

To model the relationship between obesity, body composition and HEI, LMMs and GLMMs were used. BMI, WC, WHR, BF%, TF%, and FFMI were individually treated as the primary independent variable in separate models. In addition to the obesity and body composition measures, age, sex, household income, highest education, marital status, ethnicity, smoking status, alcohol consumption, physical activity, cancer, diabetes, social deprivation, urbanicity and province of residence were identified as significant covariates in the linear mixed models (Model 4a). Almost the same set of variables were adjusted for in the GLMMs, except that the models adjusted for population density rather than marital status, ethnicity, social deprivation and urbanicity (Model 4b).

Model 4a $HEI = \beta_{0j} + \beta_1\,(adiposity\ measure) + \beta_2\,(age) + \beta_3(sex) + \beta_4\,(income) + \beta_5\,(education) + \beta_6\,(marital\ status) + \beta_7\,(ethnicity) + \beta_8\,(smoking) + \beta_9\,(alcohol\ use) + \beta_{10}\,(physical\ activity) + \beta_{11}\,(cancer) + \beta_{12}\,(diabetes) + \beta_{13}\,(social\ deprivation) + \beta_{14}(urbanicity) + \beta_{15}\,(province)$

Model 4b $logit(high\ diet\ quality) = \beta_{0j} + \beta_1\,(adiposity\ measure) + \beta_2\,(age) + \beta_3(sex) + \beta_4\,(income) + \beta_5\,(education) + \beta_6\,(smoking) + \beta_7\,(alcohol\ use) +$

$$\beta_8\,(physical\ activity) + \ \beta_9\,(cancer) + \ \beta_{10}\,(diabetes) + \ \beta_{11}\,(population\ density) + + \beta_{12}\,(province)$$

$$where\ \beta_{0j} = \ \beta_0 + b_{0j}, b_{0j} \sim N(0, {\sigma_0}^2), \qquad j = FSA$$

To assess the effect modification by cancer status and sex on the association between obesity and diet quality, the products of obesity measures with cancer status and sex were added to the models one at a time. The significance of the effect modification was determined using a Wald test by comparing the models with and without the interaction term. After the addition of the product terms, the coefficient estimates were required to be calculated separately for the different categories of the modifying variables. For example, when the effect was significantly modified by cancer status, the coefficient of obesity measures for non-cancer survivors (the reference group) was the coefficient of the main effect. On the other hand, the coefficient of obesity measures for cancer survivors was calculated by adding the coefficient of the product term to that of the main effect. The odds ratios can be subsequently calculated by exponentiating the sum of the coefficients.

3.5.3.4 Analysis of association between neighbourhood environment and HEI

To study the relationship between neighbourhood environment characteristics and HEI, LMMs and GLMMs were used. Material deprivation, social deprivation and population density were analyzed in tertiles as the primary independent variables in separate models. When one neighbourhood factor was analyzed as the primary independent variable, the other two were assessed for potential confounding effects in the models. In addition to the neighbourhood environment variables, sociodemographic, lifestyle and health-related factors along with urbanicity and province of residence were also examined as potential confounders using backward elimination. The GLMMs that assessed diet quality and neighbourhood characteristics were adjusted for age, sex, household income, highest education, smoking status[7], alcohol consumption, physical activity, cancer, diabetes, and province of residence (Model 5b, 6b and 7b). In addition, population density was identified to be a significant confounder in the association between both material and social deprivation and diet quality in the GLMMs (Model 5b and 6b). Similar sets of confounders were adjusted for in the LMMs with some additions and removals of variables (Model 5a, 6a, and 7a).

Model 5a $HEI = \beta_{0j} + \beta_1\,(material\ deprivation) + \beta_2\,(age) + \beta_3(sex) + \beta_4\,(income) + \beta_5\,(education) + \beta_6\,(ethnicity) + \beta_7\,(alcohol\ use) + \beta_8\,(physical\ activity) + \beta_9\,(cancer) + \beta_{10}(diabetes) + \beta_{11}\,(social\ deprivation) + \beta_{12}(population\ density) + \beta_{13}(urbanicity) + \beta_{14}(\,province)$

Model 6a $HEI = \beta_{0j} + \beta_1\,(social\ deprivation) + \beta_2\,(age) + \beta_3(sex) + \beta_4\,(income) + \beta_5\,(education) + \beta_6\,(marital\ status) + \beta_7\,(ethnicity) + \beta_8\,(alcohol\ use) + \beta_9\,(physical\ activity) + \beta_{10}\,(cancer) + \beta_{11}(diabetes) + \beta_{12}(urbanicity) + \beta_{13}(\,province)$

Model 7a $HEI = \beta_{0j} + \beta_1\,(population\ density) + \beta_2\,(age) + \beta_3(sex) + \beta_4\,(income) + \beta_5\,(education) + \beta_6\,(marital\ status) + \beta_7\,(ethnicity) + \beta_8\,(smoking) + \beta_9\,(alcohol\ use) + \beta_{10}\,(physical\ activity) + \beta_{11}\,(cancer) + \beta_{12}(diabetes) + \beta_{13}(social\ deprivation) + \beta_{14}(\,province)$

Model 5b $logit\,(high\ diet\ quality) = \beta_{0j} + \beta_1\,(material\ deprivation) + \beta_2\,(age) + \beta_3(sex) + \beta_4\,(income) + \beta_5\,(education) + \beta_6\,(alcohol\ use) + \beta_7\,(physical\ activity) + \beta_{98}\,(cancer) + \beta_9(diabetes) + \beta_{10}(population\ density) + \beta_{11}(\,province)$

Model 6b $logit\,(high\ diet\ quality) = \beta_{0j} + \beta_1\,(social\ deprivation) + \beta_2\,(age) + \beta_3(sex) + \beta_4\,(income) + \beta_5\,(education) + \beta_6\,(alcohol\ use) + \beta_7\,(physical\ activity) + \beta_8\,(cancer) + \beta_9(diabetes) + \beta_{10}(population\ density) + \beta_{11}(\,province)$

Model 7b $logit\,(high\ diet\ quality) = \beta_{0j} + \beta_1\,(population\ density) + \beta_2\,(age) + \beta_3(sex) + \beta_4\,(income) + \beta_5\,(education) + \beta_6\,(smoking) + \beta_7\,(alcohol\ use) + \beta_8\,(physical\ activity) + \beta_9\,(cancer) + \beta_{10}(diabetes) + \beta_{11}(\,province)$

$$where\ \beta_{0j} = \beta_0 + b_{0j}, b_{0j} \sim N(0, {\sigma_0}^2), \qquad j = FSA$$

[7] Smoking status was not adjusted for in the association between material deprivation, social deprivation and diet as it might be on the causal pathway.

Effect modification on the association between neighbourhood environment and HEI was also assessed. First, the interaction between neighbourhood environment variables and cancer was tested to determine if the effect of built environment on HEI differed between cancer survivors and non-cancer individuals. Additionally, individual socioeconomic status (income and education) and urbanicity were also examined as potential effect modifiers. The interaction of material deprivation, social deprivation and population density with each other was also evaluated in the model.

Finally, all individual-level and area-level variables, including age, sex, highest education, household income, marital status, ethnicity, physical activity, smoking status, alcohol consumption, BMI, cancer, diabetes, myocardial infarction, material deprivation, social deprivation, population density, urbanicity and province of residence were analyzed at the same time in a LMM and a GLMM. Variables with a p-value less than 0.05 from the Wald test were identified to be significant predictors of HEI in cancer survivors and non-cancer controls (Model 8a and Model 8b).

Model 8a $HEI = \beta_{0j} + + \beta_1\ (age) + \beta_2(sex) + \ \beta_3\ (income) + \ \beta_4\ (education) +$
$\beta_5(maital\ status) + \ \beta_6(ethnicity) + \ \beta_7\ (smoking) + \ \beta_7\ (lcohol\ use) +$
$\beta_8\ (physical\ activity) + \ \beta_9\ (BMI) + \ \beta_{10}\ (diabetes) + \ \beta_{11}(cancer\ status) +$
$\beta_{12}(diabetes) + \beta_{13}(myocrdial\ infarction) + \ \beta_{14}(material\ deprivation) +$
$\beta_{15}(social\ deprivation) + \beta_{16}\ (population\ density) + \beta_{17}(urbanicity) + \ \beta_{18}(province)$

Model 8b $logit\ (high\ diet\ quality) = \beta_{0j} + + \beta_1\ (age) + \beta_2(sex) + \ \beta_3\ (income) +$
$\beta_4\ (education) + \ \beta_5(maital\ status) + \ \beta_6(ethnicity) + \ \beta_7\ (smoking) +$
$\beta_7\ (lcohol\ use) + \beta_8\ (physical\ activity) + \ \beta_9\ (BMI) + \ \beta_{10}\ (diabetes) +$
$\beta_{11}(cancer\ status) + \ \beta_{12}(diabetes) + \beta_{13}(myocrdial\ infarction) +$
$\beta_{14}(material\ deprivation) + \ \beta_{15}(social\ deprivation) + \beta_{16}\ (population\ density) +$
$\beta_{17}(urbanicity) + \ \beta_{18}(province)$

$$where\ \beta_{0j} = \ \beta_0 + b_{0j}, b_{0j} \sim N(0, {\sigma_0}^2), \qquad j = FSA$$

All data cleaning and analysis were performed in R version 3.4.2 (268) and a significance level of 0.05 was used unless otherwise stated. The *lme4* package was used for analyzing data with LMM and GLMMs (269).

Chapter 4: Results

4.1 Descriptive statistics for the analytic sample

A total of 19,973 participants aged 35 to 69 years old were eligible for the final analysis, of whom 1,930 were cancer survivors and 18,043 were non-cancer controls. The mean HEI of all participants was 38.78 out of 60 with a standard deviation of 8.65. As high diet quality was defined as the highest quartile of HEI scores, 5,008 people (25%) had a high-quality diet, as opposed to the remaining 14,965 people who had a low-to-intermediate quality diet. The HEI component scores are presented in **Appendix A.3**. On average, participants received high scores on meat and alternatives (mean: 8.95 out of 10) and low on grain products (mean: 4.32 out of 10). The vast majority of participants reported having whole fruit and vegetables more than juice (93.99%), drinking low-fat milk or milk alternatives (85.22%) and making at least half of grain products whole grain each day (81.53%). However, only 10.68% of participants avoided oil products while eating bread.

Participants' demographic, socioeconomic, lifestyle, health-related and residential characteristics are presented in **Table 4.1**. Participants were 52.6 years old on average. A total of 10% of participants were 35 to 39 years, 11.86% were 40-44 years, 15.30% were 45-49 years, 17.77% were 50-54 years, 18.06% were 55-59 years, 16.63% were 60-64 years and 10.32% were 65-69 years. The sample had a higher percentage of females (69.08%) compared to males, whites (93.16%) compared to non-whites, and people living with partners (80.85%) compared to those living without partners. Most participants had a high socioeconomic status. Over 50% had an annual household income greater than $75,000, while only around 5% had less than $24,999. There were 40.67% and 40.06% of participants holding a college degree and Bachelor's degree or above, respectively, and 19.27% had a high school diploma or less. Most participants had a healthy lifestyle with regard to smoking and physical activity. Less than 10% of participants currently smoked cigarettes at the time of the survey, while 50.84% had never smoked and 39.26% were former smokers. Approximately 50% and 30% reported high and moderate levels of physical activity, respectively. However, approximately 90% of participants were current drinkers at the time of the survey, among whom around 42% drank less than 2–3 times per month and 48% drank at least once a week. The prevalence of diabetes and myocardial infarction was 5.05% and 1.78% in the analytic sample. The majority of participants (71.83%) were from urban areas with a higher percentage residing in Nova Scotia (NS, 62.94%), followed by New Brunswick (NB, 22.60%), Newfoundland and Labrador (NL, 12.58%) and Prince Edward Island (PEI, 1.89%).

Table 4.1 Characteristics of the analytic sample from the Atlantic PATH cohort.

Characteristics	**Overall Analytic Sample**	**Low-to-Intermediate Diet Quality**†	**High Diet Quality**†
	N= 19973 N (%)	N=14965 N (%)	N=5008 N (%)
Age categories			
35-39y	2007 (10.05)	1440 (9.62)	567 (11.32)
40-44y	2369 (11.86)	1698 (11.35)	671 (13.40)
45-49y	3056 (15.30)	2199 (14.69)	857 (17.11)
50-54y	3549 (17.77)	2692 (17.99)	857 (17.11)
55-59y	3608 (18.06)	2788 (18.63)	820 (16.37)
60-64y	3322 (16.63)	2534 (16.93)	788 (15.73)
65-69y	2062 (10.32)	1614 (10.79)	448 (8.95)
Sex			
Female	13797 (69.08)	9705 (64.85)	4092 (81.71)
Male	6176 (30.92)	5260 (35.15)	916 (18.29)
Marital status			
Living without partners	3816 (19.15)	2856 (19.13)	960 (19.21)
Living with partners	16115 (80.85)	12077 (80.87)	4038 (80.79)

Ethnicity			
White	17418 (93.16)	13006 (93.03)	4412 (93.55)
Non-white	1279 (6.84)	975 (6.97)	304 (6.45)
Income			
$0-24,999	852 (4.52)	679 (4.81)	173 (3.66)
$25,000-49,999	3213 (17.06)	2483 (17.59)	730 (15.46)
$50,000-74,999	3973 (21.09)	3057 (21.66)	916 (19.39)
$75,000-149,999	8302 (44.08)	6109 (43.29)	2193 (46.43)
$>150,000	2495 (13.25)	1784 (12.64)	711 (15.05)
Education (completed)			
≤ High school	3836 (19.27)	3140 (21.06)	696 (13.92)
College	8095 (40.67)	6182 (41.47)	1913 (38.27)
≥ Bachelor's degree	7975 (40.06)	5585 (37.47)	2390 (47.81)
Smoking status[‡]			
Non-smoker	10067 (50.84)	7319 (49.33)	2748 (55.34)
Former	7775 (39.26)	5894 (39.73)	1881 (37.88)
Occasional	500 (2.52)	380 (2.56)	120 (2.42)
Regular	1460 (7.37)	1243 (8.38)	217 (4.37)
Alcohol consumption[§]			
Abstainer	830 (4.18)	646 (4.34)	184 (3.69)
Former	1332 (6.71)	1048 (7.04)	284 (5.69)
Occasional	8279 (41.68)	6134 (41.23)	2145 (42.99)
Regular	6254 (31.48)	4592 (30.87)	1662 (33.31)
Habitual	3170 (15.96)	2456 (16.51)	714 (14.31)
Physical activity			
Low	3979 (20.78)	3338 (23.29)	641 (13.30)
Moderate	5876 (30.68)	4482 (31.27)	1394 (28.92)
High	9296 (48.54)	6511 (45.43)	2785 (57.78)
BMI			
Normal	3994 (30.87)	2825 (29.49)	1169 (34.79)
Underweight	77 (0.60)	55 (0.57)	22 (0.65)
Overweight	4922 (38.04)	3725 (38.88)	1197 (35.62)
Obese	3947 (30.50)	2975 (31.05)	972 (28.93)
Diabetes			
Yes	998 (5.05)	749 (5.06)	249 (5.02)
No	18781 (94.95)	14068 (94.94)	4713 (94.98)
Myocardial infarction			
Yes	353 (1.78)	288 (1.94)	65 (1.31)
No	19489 (98.22)	14577 (98.06)	4912 (98.69)

Cancer			
Cancer survivors	1930 (9.66)	1429 (9.55)	501 (10.00)
Non-cancer	18043 (90.34)	13536 (90.45)	4507 (90.00)
Urbanicity			
Urban	14347 (71.83)	10689 (71.43)	3658 (73.04)
Rural	5626 (28.17)	4276 (28.57)	1350 (26.96)
Province			
NL	2512 (12.58)	1993 (13.32)	519 (10.36)
PEI	377 (1.89)	290 (1.94)	87 (1.74)
NS	12571 (62.94)	9394 (62.77)	3177 (63.44)
NB	4513 (22.60)	3288 (21.97)	1225 (24.46)

† High diet quality is defined as having an HEI in the highest quartile, while low-to-intermediate diet quality is having an HEI in the lower three quartiles. ‡ Non-smoker: has never smoked, former: has smoked at least 100 cigarettes before but not within the past 30 days, occasional: smoked at least once within the past 30 days but not daily, regular: smoked daily. All other participants were categorized as non-smokers. §Abstainer: has never drunk alcohol, former: has drunk alcohol before but not over the past 12 months, occasional: drank ≤2–3 times/month over the past 12 months, regular: drank ≥ once/week but ≤2–3 times/week, habitual drinkers: drank ≥ 4–5 times/week.

Greater proportions of high diet quality were observed in female participants, younger participants from 35 to 49 years old, people with a household income of at least $75,000, people with a Bachelor's degree or higher, non-smokers, occasional or regular alcohol drinkers, people with high physical activity level, and people with normal weight (**Table 4.1**). In addition, people living in urban areas as well as those living in Nova Scotia and New Brunswick had better diet quality, indicated by the greater proportions of high diet quality (**Table 4.1**).

Cancer survivor's characteristics were compared to that of non-cancer controls in **Table 4.2**. Cancer survivors were older on average than non-cancer controls (mean age: 57.3 for cancer survivors vs 52.1 years for non-cancer controls). Greater proportions of cancer survivors were females, people living without partners, people with a household income less than $75,000 and people with a high school degree or lower. In addition, cancer survivors were more likely to be former smokers and former alcohol drinkers, and to have a diagnosis of diabetes and myocardial infarction, compared to non-cancer controls. Greater proportions of cancer survivors were from

Nova Scotia, and socially deprived areas. There was no difference between the two groups regarding ethnicity, physical activity, BMI, urbanicity, material deprivation and population density.

Table 4.2 Comparison of characteristics between cancer survivors and non-cancer controls.

	Cancer survivors N=1930	**Non-cancer** N=18043	**p-value**
	N (%)	N (%)	
Age group			<0.001
35-39	62 (3.21)	1945 (10.78)	
40-44	88 (4.56)	2281 (12.64)	
45-49	173 (8.96)	2883 (15.98)	
50-54	333 (17.25)	3216 (17.82)	
55-59	397 (20.57)	3211 (17.80)	
60-64	479 (24.82)	2843 (15.76)	
65-69	398 (20.62)	1664 (9.22)	
Sex			<0.001
Female	1404 (72.75)	12393 (68.69)	
Male	526 (27.25)	5650 (31.31)	
Marital status			0.003
Living without partners	419 (21.72)	3397 (18.87)	
Living with partners	1510 (78.28)	14605 (81.13)	
Ethnicity			0.059
White	1705 (94.25)	15713 (93.04)	
Non-white	104 (5.75)	1175 (6.96)	
Household income			<0.001
0-24,999	117 (6.49)	735 (4.32)	
25,000-49,999	399 (22.13)	2814 (16.52)	
50,000-74,999	426 (23.63)	3547 (20.83)	
75,000-149,999	677 (37.55)	7625 (44.77)	
>150,000	184 (10.21)	2311 (13.57)	
Education (completed)			0.001
≤ high school	417 (21.70)	3419 (19.01)	
college	804 (41.83)	7291 (40.54)	
≥ Bachelor's degree	701 (36.47)	7274 (40.45)	
Smoking status‡			<0.001
Never	843 (44.14)	9224 (51.55)	
Former	890 (46.60)	6885 (38.48)	
Occasional	40 (2.09)	460 (2.57)	
Regular	137 (7.17)	1323 (7.39)	
Alcohol consumption§			<0.001
Abstainer	82 (4.28)	748 (4.17)	

Former drinker	163 (8.50)	1169 (6.51)	
Occasional drinker	821 (42.81)	7458 (41.56)	
Regular drinker	518 (27.01)	5736 (31.96)	
Habitual drinker	334 (17.41)	2836 (15.80)	
Physical activity			0.126
Low	350 (19.09)	3629 (20.96)	
Moderate	560 (30.55)	5316 (30.70)	
High	923 (50.35)	8373 (48.35)	
BMI			0.300
Normal	390 (29.21)	3604 (31.06)	
Underweight	5 (0.37)	72 (0.62)	
Overweight	513 (38.43)	4409 (37.99)	
Obese	427 (31.99)	3520 (30.33)	
Diabetes			<0.001
Yes	144 (7.52)	854 (4.78)	
No	1770 (92.48)	17011 (95.22)	
Myocardial infarction			0.001
Yes	52 (2.72)	301 (1.68)	
No	1861 (97.28)	17628 (98.32)	
Urbanicity			0.342
Urban	1368 (70.88)	12979 (71.93)	
Rural	562 (29.12)	5064 (28.07)	
Province			<0.001
NL	206 (10.67)	2306 (12.78)	
PEI	44 (2.28)	333 (1.85)	
NS	1355 (70.21)	11216 (62.16)	
NB	325 (16.84)	4188 (23.21)	
Material deprivation			0.318
Least deprived	857 (44.40)	8219 (45.55)	
Intermediate	609 (31.55)	5756 (31.90)	
Most deprived	464 (24.04)	4068 (22.55)	
Social deprivation			0.031
Least deprived	652 (33.78)	6635 (36.77)	
Intermediate	672 (34.82)	5918 (32.80)	
Most deprived	606 (31.40)	5490 (30.43)	
Population density			0.603
Least dense	536 (27.77)	4983 (27.62)	
Intermediate	622 (32.23)	6010 (33.31)	
Most dense	772 (40.00)	7050 (39.07)	

‡ Non-smoker: has never smoked, former: has smoked at least 100 cigarettes before but not within the past 30 days, occasional: smoked at least once within the past 30 days but not daily, regular: smoked daily. All other participants were categorized as non-smokers. §Abstainer: has never drunk alcohol, former: has drunk alcohol before but not over the past 12 months, occasional: drank ≤2–3 times/month over the past 12 months, regular: drank ≥ once/week but ≤2–3 times/week, habitual drinkers: drank ≥ 4–5 times/week.

As many participants (n = 11,200) were excluded due to incomplete information about diet, cancer status, and neighbourhood environment and other reasons stated earlier, the participants who met the inclusion criteria were compared against those who did not (**Table 4.3**). According to the chi-squared tests on the available data, there was significant difference between the two groups with respect to age, sex, marital status, ethnicity, household income, education, BMI, and province of residence as well as social deprivation, material deprivation and population density in the neighbourhoods in which they lived ($p<0.05$, **Table 4.3**). However, the differences in the percentages of people in each category between the two groups were of small magnitude, around or within 2% for most variables, except for marital status, household income, BMI, and province of residence (**Table 4.3**). Compared to people who were excluded, the participants included in the analytic sample were more likely to live with a partner, have a household income over $75,000 a year and live in Nova Scotia, while they were less likely to be underweight (**Table 4.3**).

Table 4.3 Comparison of characteristics between participants who met the inclusion criteria for the analytic sample and those who did not.

	Included N=19,973	**Excluded** N=11,200	**p-value**
	N (%)	N (%)	
Age group			<0.001
35-39y	2007 (10.05)	1087 (9.71)	
40-44y	2369 (11.86)	1359 (12.13)	
45-49y	3056 (15.30)	1510 (13.48)	
50-54y	3549 (17.77)	1872 (16.71)	
55-59y	3608 (18.06)	2056 (18.36)	
60-64y	3322 (16.63)	2000 (17.86)	
65-69y	2062 (10.32)	1316 (11.75)	
Sex			0.001
Female	13797 (69.08)	7938 (70.88)	
Male	6176 (30.92)	3262 (29.12)	

Marital status			<0.001
Living without partners	3816 (19.15)	2519 (22.65)	
Living with partners	16115 (80.85)	8603 (77.35)	
Ethnicity			0.004
White	17418 (93.16)	9875 (92.26)	
Non-white	1279 (6.84)	829 (7.74)	
Household income			<0.001
$0-24,999	852 (4.52)	646 (6.33)	
$25,000-49,999	3213 (17.06)	1957 (19.17)	
$50,000-74,999	3973 (21.09)	2308 (22.60)	
$75,000-149,999	8302 (44.08)	4152 (40.66)	
$>150,000	2495 (13.25)	1148 (11.24)	
Education (completed)			0.001
≤ High school	3836 (19.27)	2085 (18.71)	
College	8095 (40.67)	4769 (42.79)	
≥ Bachelor's degree	7975 (40.06)	4290 (38.50)	
BMI			<0.001
Normal	3994 (30.87)	2255 (29.27)	
Underweight	77 (0.60)	245 (3.18)	
Overweight	4922 (38.04)	2802 (36.37)	
Obese	3947 (30.50)	2403 (31.19)	
Province			<0.001
NL	2512 (12.58)	2011 (18.27)	
PEI	377 (1.89)	790 (7.18)	
NS	12571 (62.94)	3893 (35.37)	
NB	4513 (22.60)	4313 (39.18)	
Material deprivation			0.002
Least deprived	9076 (45.44)	4695 (44.79)	
Intermediate	6365 (31.87)	3535 (33.72)	
Most deprived	4532 (22.69)	2252 (21.48)	
Social deprivation			0.033
Least deprived	7287 (36.48)	3931 (37.50)	
Intermediate	6590 (32.99)	3306 (31.54)	
Most deprived	6096 (30.52)	3245 (30.96)	
Population density			0.005
Low	5519 (27.63)	3142 (28.55)	
Intermediate	6632 (33.20)	3760 (34.16)	
High	7822 (39.16)	4105 (37.29)	

4.2 Research question 1: Diet quality of cancer survivors

4.2.1 Research question 1a: comparison of diet quality between cancer survivors and non-cancer controls

The mean HEI of cancer survivors was 39.07 (SD: 8.82), which was 0.34 points higher than the non-cancer controls (**Table 4.4**). The mean difference in HEI scores increased slightly to 0.45 (95% CI: 0.07, 0.84) and became statistically significant when the LMM was adjusted for age, sex, household income, highest education level, marital status, ethnicity, smoking status, alcohol consumption, physical activity, diabetes, social deprivation, urbanicity and province of residence (**Table 4.4**). The increase of effect size from the unadjusted to the adjusted model was found to be related to the reverse confounding of age, as cancer survivors were more likely to be older adults who tended to have a lower diet quality in this study. Despite the statistical significance, it has to be acknowledged that the difference in the mean HEI scores between the two groups was small given a total HEI score of 60. This is reflected in the unadjusted and adjusted GLMMs, showing that cancer survivors and non-cancer controls had similar odds of high diet quality (**Table 4.4**).

Table 4.4 Mean difference in HEI scores (95% CI) and OR of high diet quality (95% CI) of cancer survivors compared to non-cancer individuals.

	Difference in mean (95% CI)		**OR (95% CI)**	
	Unadjusted	Adjusted†	Unadjusted	Adjusted‡
Cancer status				
Non-cancer	reference	reference	reference	reference
Cancer	0.34 (-0.06, 0.75)	0.45 (0.07, 0.84)*	1.05 (0.95, 1.17)	1.08 (0.97, 1.21)

* $p<0.05$
†Adjusted for age, sex, household income, highest education, marital status, ethnicity, smoking status, alcohol consumption, physical activity, diabetes, social deprivation, urbanicity and province of residence

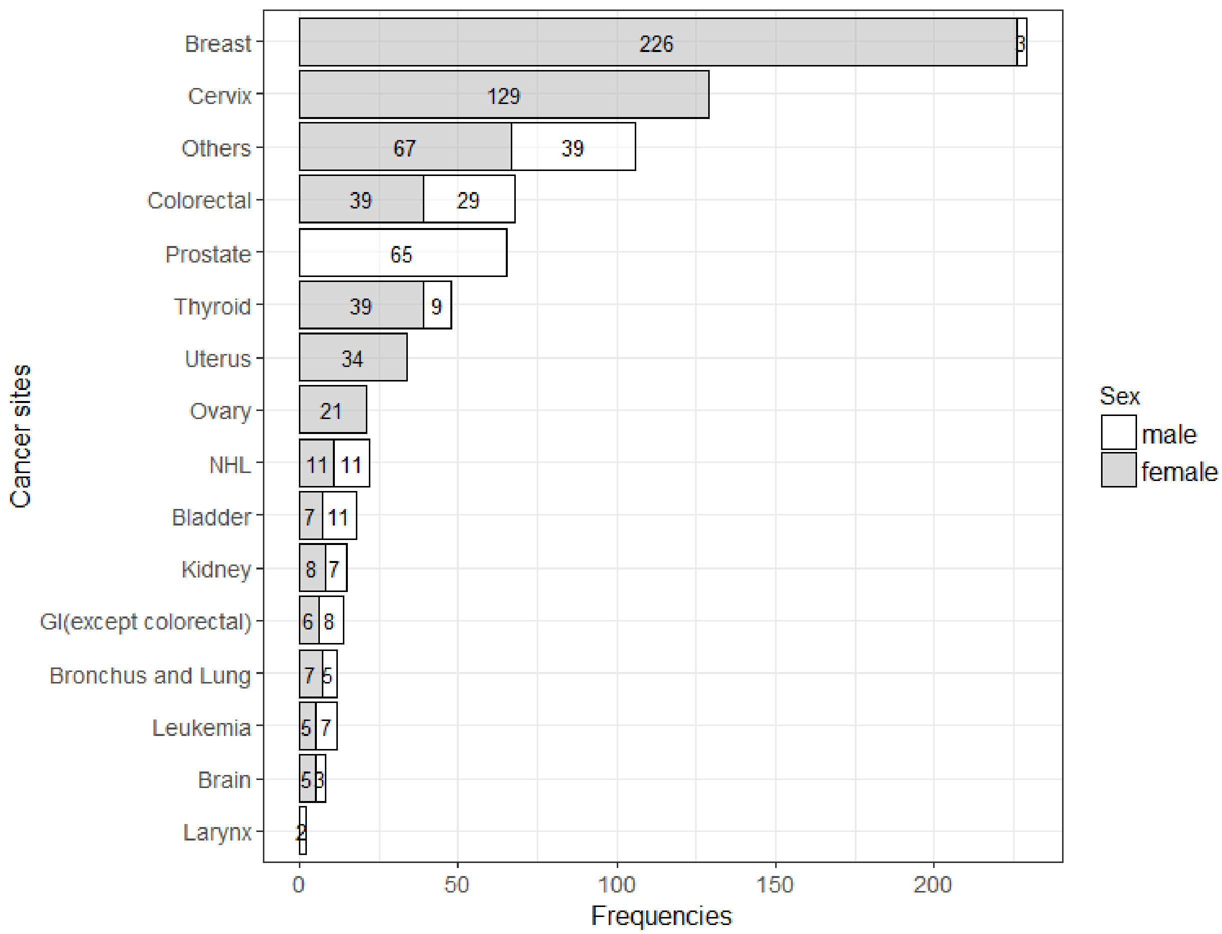
‡ Adjusted for age, sex, household income, highest education, smoking status, alcohol consumption, physical activity, diabetes, population density and province of residence

As cancer-related exclusion criteria could not be applied to cancer survivors with missing information on cancer sites, cancer survivors may consist of some non-melanoma skin cancer cases. A sensitivity analysis showed that cancer survivors who reported their cancer sites had a significantly higher mean HEI by 0.83 (95% CI: 0.24, 1.41) than the non-cancer controls, which was a larger difference than when all cancer survivors were compared to the non-cancer controls. The discrepancy in the results suggests that people with a diagnosis of cancer that did not report the type may have similar diet quality as non-cancer controls. If all non-melanoma skin cancer cases had been completely excluded, the difference in the mean HEI scores between cancer survivors and non-cancer controls might be larger than 0.45. However, the odds of high diet quality did not differ significantly among cancer survivors with reported cancer sites (OR: 1.14, 95% CI: 0.97, 1.36) and non-cancer controls (the reference group).

4.2.2 Research question 1b and 1c: diet quality of cancer survivors by cancer site and years since diagnosis

Among the 803 cancer survivors who provided information about their cancer sites, there were 604 females and 199 males. The most commonly reported cancer sites were breast cancer (n = 229; 226 females and 3 males) and cervical cancer (n = 129, **Figure 4.1**). A total of 65 males reported prostate cancer, while 34 and 21 females reported uterine and ovarian cancer, respectively. In addition, there were 39 colorectal cancer cases in females and 29 in males, 39 and 9 thyroid cancer cases in females and males, and 11 NHL cases in both females and males (**Figure 4.1**). For each of the remaining cancer sites, i.e. bladder, kidney, GI (except colorectal), lung and bronchus, leukemia, brain and larynx, there were fewer than 20 cancer survivors, with roughly equal numbers of males and females (**Figure 4.1**). In addition, 106 cancer survivors reported other types of cancer.

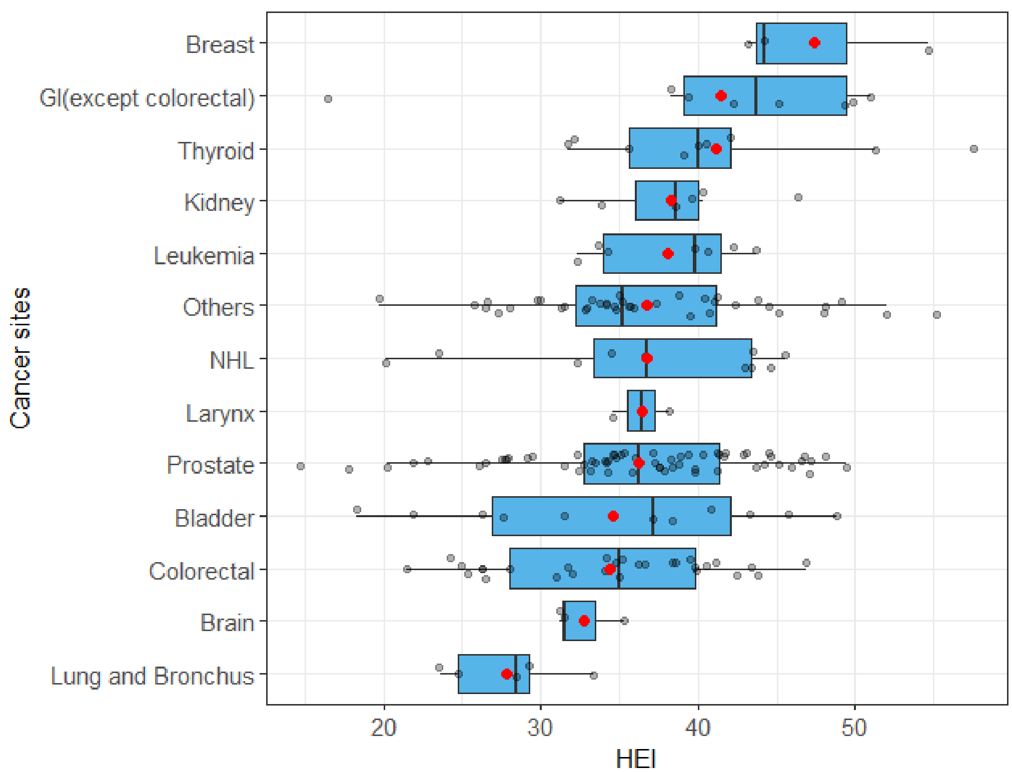
Figure 4.1 Primary cancer sites among cancer survivors by sex.



Cancer survivors' diet quality varied by cancer site. As the sample size and distribution of HEI were different across cancer sites, both the mean and median HEI for each cancer site were presented in **Figure 4.2** and **Figure 4.3** for males and females, separately.

Survivors of prostate cancer, the most common type of cancer in males, had a mean HEI of 36.18, close to the median of 36.24. Cancer survivors of breast cancer (n =3) and GI cancer (excluding colorectal cancer) (n= 8) had the highest and the second highest HEI among males, illustrated by the mean and median HEI scores above 40 (**Figure 4.2**). Conversely, male survivors of lung cancer (n =5) had the lowest mean HEI (27.87). The mean and median HEI of male colorectal cancer (n = 29) was 34.43 and 35.05, respectively **(Figure 4.2**).

Figure 4.2 Boxplots of HEI by cancer site in males. Boxplots show the minimum, first quartile, median (centre line), third quartile and the maximum HEI. Red dots show the mean HEI. Black dots present the HEI for individual participants.



Compared to cancer survivors of prostate cancer, males with breast cancer had a significantly higher mean HEI by 11.22 (95% CI: 2.60, 19.84) and males with lung cancer had a significantly lower mean HEI by 8.31 (95% CI: -15.09, -1.54), according to the unadjusted LMMs (**Table 4.5**). Findings should be interpreted with caution as sample sizes for male breast and lung cancer are small. After adjusting for age, smoking status, alcohol consumption, physical activity, myocardial infarction, and social deprivation, compared to prostate cancer survivors, male survivors of colorectal cancer and all other cancer types did not have significantly different mean HEI scores (data not shown).

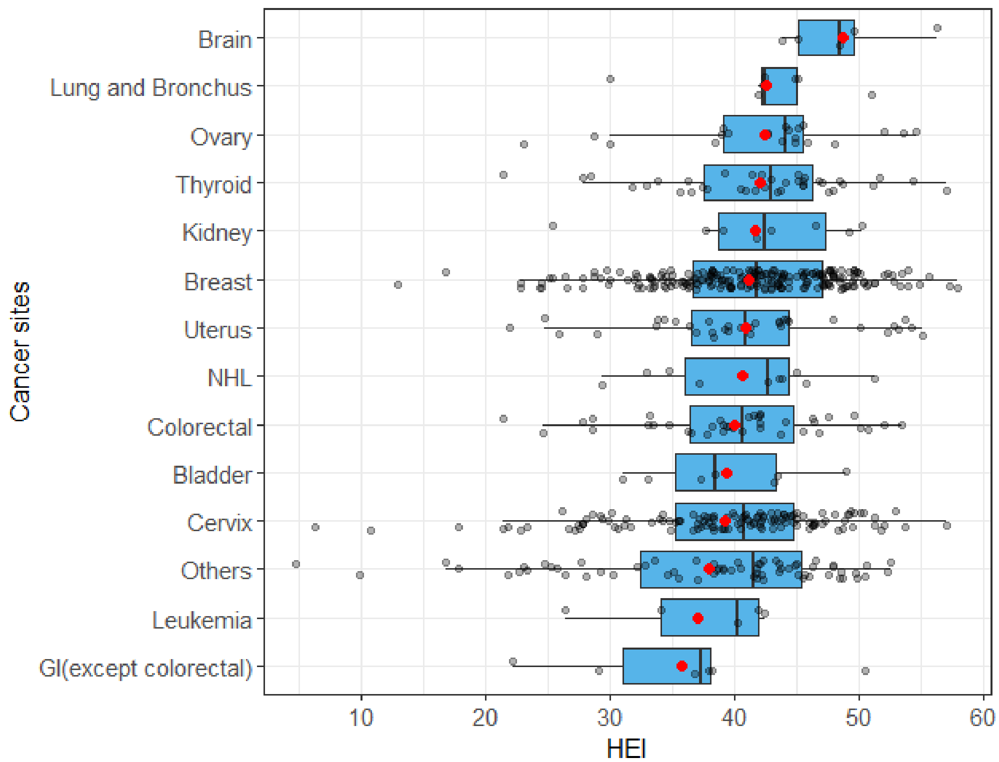
Table 4.5 Mean difference in HEI score (95% CIs) of cancer survivors with different cancer sites compared to cancer survivors with the reference cancer sites (prostate cancer for males and breast cancer for females), results from unadjusted LMMs.

Cancer sites	**Males**	**Females**
Prostate	reference	-
Breast	11.22 (2.60, 19.84)*	reference
Lung & bronchus	-8.31 (-15.09, -1.54)*	1.33 (-4.73, 7.39)
Larynx	0.22 (-10.26, 10.70)	-
Kidney	2.13 (-3.68, 7.94)	0.45 (-5.23, 6.13)
Bladder	-1.64 (-6.40, 3.12)	-1.83 (-7.88, 4.23)
Brain	-3.49 (-12.11, 5.14)	7.49 (0.36, 14.63)*
Thyroid	4.94 (-0.25, 10.13)	0.80 (-1.93, 3.54)
NHL	0.54 (-4.22, 5.30)	-0.53 (-5.40, 4.34)
Leukemia	1.92 (-3.89, 7.73)	-4.18 (-11.31, 2.96)
Others	0.54 (-2.42, 3.50)	-3.21 (-5.40, -1.01)*
Colorectal	-1.75 (-5.01, 1.51)	-1.19 (-3.92, 1.55)
GI (except colorectal)	5.28 (-0.19, 10.75)	-5.41 (-11.94, 1.12)
Ovary	-	1.19 (-2.41, 4.79)
Cervix	-	-1.90 (-3.64, -0.15)*
Uterus	-	-0.23 (-3.13, 2.67)

*$p<0.05$

Among females, the distribution of HEI scores in breast cancer survivors was approximately normal with a mean of 41.20, similar to its median (**Figure 4.3**). The mean and median HEI was the highest for brain cancer survivors (n= 5) at 48.70 and 48.43 and lowest for GI cancer (excluding colorectal cancer) (n= 6) in females at 35.79 and 37.38. Female colorectal cancer survivors (n= 39) and lung cancer survivors (n=7) had a mean HEI of 40.01 and 42.53, respectively, which were similar to that of breast cancer survivors (**Figure 4.3**).

Figure 4.3 Boxplots of HEI by cancer site in females. Boxplots show the minimum, first quartile, median (centre line), third quartile and the maximum HEI. Red dots show the mean HEI. Black dots present the HEI for individual participants.



Compared to female breast cancer survivors, female brain cancer survivors had significantly higher diet quality (7.49, 95% CI: 0.36, 14.63), whereas survivors of cervical cancer and other cancers had significantly lower diet quality (cervical: -1.90, 95% CI: -3.64, -0.15; others: -3.21, 95% CI: -5.40, -1.01) in the unadjusted LMM (**Table 4.5**). After adjusting for age, household income, highest education, marital status, ethnicity, alcohol consumption, physical activity, diabetes, myocardial infarction, social deprivation, population density, urbanicity and province of residence, the only difference that persisted was for cervical cancer survivors who had a lower mean HEI by 1.88 (95% CI: -3.56, -0.19) than breast cancer survivors. There was no difference in the diet quality of breast cancer survivors from that of colorectal cancer and all other cancer types combined (data not shown).

Among the 754 cancer survivors who reported years since diagnosis, most (37.9%) were long-term survivors diagnosed more than 10 years prior (n = 286) (**Table 4.6**), 181 people were diagnosed 5 to 10 years prior, 166 were diagnosed 2 to 5 years prior and 121 were diagnosed 6 months to 2 years prior. According to the unadjusted LMM, there was no significant association between years since diagnosis and HEI (**Table 4.6**). However, after adjusting for confounders, cancer survivors with a diagnosis within the prior 6 months to 2 years had a higher mean HEI by 1.95 (95% CI: 0.32, 3.59), compared to long-term survivors (**Table 4.6**). Cancer survivors who were diagnosed between 2 to 5 years and 5 to 10 years had similar diet quality to long-term survivors.

Table 4.6 Mean difference in HEI score among cancer survivors by years since cancer diagnosis, results from unadjusted and adjusted LMMs.

Years since cancer diagnosis	**N=754 N (%)**	**Unadjusted**	**Adjusted†**
> 10 years	286 (37.93)	reference	reference
5< years ≤10 years	181 (24.01)	0.04 (-1.50, 1.57)	0.34 (-1.08, 1.76)
2 < years ≤ 5 years	166 (22.01)	0.06 (-1.52, 1.64)	0.83 (-0.62, 2.28)
≤ 2 years	121 (16.05)	0.43 (-1.32, 2.18)	1.95 (0.32, 3.59)*

† adjusted for age, sex, household income, education, ethnicity, smoking status, alcohol consumption, physical activity, myocardial infarction, population density, urbanicity, province of residence.

*$p<0.05$

4.3 Research question 2: Association between obesity, body composition and diet quality

Among participants with complete information on anthropometric and bio-impedance analysis measurements (n = 8421 to 12949, depending on the measurements), the prevalence of overweight and obesity as defined by BMI was 38.04% and 30.50%, respectively (**Table 4.7**). A total of 30.87% of participants had a normal weight, while a small proportion (0.60%) were underweight. 57.02% of participants had excess body fat, 48.10% of participants had an obese WC, and 58.19% had an obese WHR.

Table 4.7 Percentage of participants with high diet quality and mean HEI scores for each category of obesity measure.

	Overall Analytic Sample	**Low-to-intermediate Diet Quality** †	**High Diet Quality** †	**HEI score**	
	N (%)	%	%	Mean	SD
BMI					
Normal	3994 (30.87)	2825 (29.49)	1169 (34.79)	39.78	8.59
Underweight	77 (0.60)	55 (0.57)	22 (0.65)	37.71	10.94
Overweight	4922 (38.04)	3725 (38.88)	1197 (35.62)	38.58	8.62
Obese	3947 (30.50)	2975 (31.05)	972 (28.93)	38.66	8.59
BF%					
Normal	5565 (43.98)	4048 (42.24)	1517 (45.08)	39.15	8.76
Obese‡	7384 (57.02)	5536 (57.76)	1848 (54.92)	38.84	8.53
WC					
Normal	6568 (51.90)	4872 (51.89)	1696 (51.94)	38.94	8.68
Obese§	6086 (48.10)	4517 (48.11)	1569 (48.06)	38.83	8.67
WHR					
Normal	5279 (41.81)	3743 (39.96)	1536 (47.15)	39.78	8.44
Obese**	7346 (58.19)	5624 (60.04)	1722 (52.85)	38.26	8.78
TF%Δ					
Low-to-intermediate	6464 (76.76)	5045 (77.39)	1419 (74.61)	37.82	8.81
High	1957 (23.24)	1474 (22.61)	483 (25.39)	38.70	8.54
FFMIΔ					
Low-to-intermediate	9813 (76.24)	7254 (76.15)	2559 (76.50)	39.00	8.66
High	3058 (23.76)	2272 (23.85)	786 (23.50)	38.90	8.53

† High diet quality is defined as having an HEI in the highest quartile, while low-to-intermediate diet quality is having an HEI in the lower three quartiles. ‡ Body fat percentage (BF%) >25% in males and >35% in females. §Waist circumference (WC) >102cm in males and >88cm in females. ** Waist-to-hip ratio (WHR) ≥ 0.90 in males and ≥ 0.85 in females. Δ TF%: trunk fat percentage, FFMI: fat-free mass index, low-to-intermediate: the lower three quartiles, high: the highest quartile

4.3.1 Difference in mean HEI

The mean HEI of normal-weight people (39.78) was higher by more than 1 unit than that of underweight (37.71), overweight (38.58) and obese people (38.66) (**Table 4.7**). The mean HEI scores of people with an obese BF% and WHR were 38.84 and 38.26, respectively, which were lower than those of the normal counterparts. People with a higher TF% had a mean HEI of 38.70, which was higher than the mean HEI of people with a low-to-intermediate TF% (**Table 4.7**). However, differences in FFMIs and WCs were not associated with different mean HEIs.

After imputing missing values for obesity and body composition measures, the unadjusted LMM showed similar results as the descriptive statistics (**Table 4.8**). Compared to the normal BMI, overweight and obese BMI were associated with a significantly lower mean HEI by 1.40 (95% CI: -1.72, -1.07) and 1.38 (95% CI: -1.72, -1.04), respectively. General obesity defined by BF% was associated with a smaller decrease in mean HEI by 0.34 (95% CI: -0.61, -0.06) (**Table 4.8**). As measures of abdominal obesity, WHR was significantly associated with a lower mean HEI, whereas WC was not. People with an obese WHR had a lower mean HEI score by 1.67 (95% CI: -1.95, -1.38) than those with a normal WHR. To the contrary, people with a high TF% had a significantly higher mean HEI by 0.58 (95% CI: 0.18, 0.98) than people with a low-to-intermediate TF% (**Table 4.8**). FFMI was not significantly associated with HEI. After adjusting for confounders, all relationships were attenuated and non-significant except for the relationship between TF% and HEI (**Table 4.8**). The mean HEI of people with a high TF% remained significantly higher than that of people with a low-to-intermediate TF% (mean difference in HEI: 0.45, 95% CI: 0.08, 0.83).

Table 4.8 Association between obesity measures and HEI, results from unadjusted and adjusted LMMs.

	Unadjusted	Adjusted†
BMI		
Normal	reference	reference
Underweight	-1.31 (-3.23, 0.61)	-1.45 (-3.26, 0.36)
Overweight	-1.40 (-1.72, -1.07)*	-0.10 (-0.42, 0.21)
Obese	-1.38 (-1.72, -1.04)*	0.03 (-0.31, 0.37)
BF%		
Normal	reference	reference
Obese‡	-0.34 (-0.61, -0.06)*	-0.10 (-0.38, 0.18)
WC		
Normal	reference	reference
Obese§	-0.20 (-0.47, 0.08)	-0.03 (-0.31, 0.25)
WHR		
Normal	reference	reference
Obese**	-1.67 (-1.95, -1.38)*	-0.03 (-0.31, 0.26)
TF%Δ		
Low-to-intermediate	reference	reference
High	0.58 (0.18, 0.98)*	0.45 (0.08, 0.83)*
FFMIΔ		
Low-to-intermediate	reference	reference
High	-0.27 (-0.60, 0.06)	0.17 (-0.15, 0.49)

*p<0.05, †Adjusted for age, sex, household income, highest education, marital status, ethnicity, smoking status, alcohol consumption, physical activity, cancer, diabetes, social deprivation, urbanicity, and province of residence. ‡ Body fat percentage (BF%) >25% in males and >35% in females. §Waist circumference (WC) >102cm in males and >88cm in females. ** Waist-to-hip ratio (WHR) ≥ 0.90 in males and ≥ 0.85 in females. Δ TF%: trunk fat percentage, FFMI: fat-free mass index, low-to-intermediate: the lower three quartiles, high: the highest quartile

4.3.2 Difference in the odds of high diet quality

The odds ratios from the GLMMs were consistent with the relationships shown above (**Table 4.9**). Compared to people with a normal BMI, people with overweight or obese BMIs were 0.74 times less likely to have a high diet quality (overweight: OR: 0.74, 95% CI: 0.68, 0.80; obese: OR: 0.74, 95% CI: 0.68, 0.81). Obesity defined by BF% and WHR was associated with 0.89 times (95% CI: 0.83, 0.95) and 0.72 times (95% CI: 0.67, 0.77) the odds of high diet quality (**Table 4.9**).

People with high TF% had 1.11 times higher odds of high diet quality (95% CI: 1.01, 1.22). There was no significant association between WC, FFMI and diet quality. However, all associations between obesity and diet quality, including the association between TF% and diet quality, were no longer significant after adjusting for age, sex, household income, highest education, smoking status, alcohol consumption, physical activity, cancer, diabetes, population density, and province of residence (**Table 4.9**).

Table 4.9 ORs (95% CIs) of high diet quality from unadjusted and adjusted GLMMs by categories of obesity measures.

	Unadjusted	**Adjusted**[†]
BMI		
Normal	reference	reference
Underweight	1.04 (0.65, 1.68)	0.99 (0.60, 1.62)
Overweight	0.74 (0.68, 0.80)*	0.95 (0.87, 1.04)
Obese	0.74 (0.68, 0.81)*	0.97 (0.89, 1.07)
BF%		
Normal	reference	reference
Obese[‡]	0.89 (0.83, 0.95)*	0.93 (0.86, 1.01)
WC		
Normal	reference	reference
Obese[§]	0.95 (0.89, 1.02)	0.99 (0.91, 1.07)
WHR		
Normal	reference	reference
Obese[**]	0.72 (0.67, 0.77)*	0.99 (0.92, 1.07)
TF%[Δ]		
Low-to-intermediate	reference	reference
High	1.11 (1.01, 1.22)*	1.10 (1.00, 1.22)
FFMI[Δ]		
Low-to-intermediate	reference	reference
High	0.94 (0.86, 1.02)	1.02 (0.93, 1.11)

* $p<0.05$

†Adjusted for age, sex, household income, education, smoking status, alcohol consumption, physical activity, cancer, diabetes, population density, province of residence.

‡ Body fat percentage (BF%) >25% in males and >35% in females. §Waist circumference (WC) >102cm in males and >88cm in females. ** Waist-to-hip ratio (WHR) ≥ 0.90 in males and ≥ 0.85 in females. Δ TF%: trunk fat percentage, FFMI: fat-free mass index, low-to-intermediate: the lower three quartiles, high: the highest quartile

4.3.3 Stratification by cancer status and sex

The association of HEI with obesity and body composition measures did not vary by cancer status, based on both the LMMs and GLMMs (**Table 4.10**). However, the association between some obesity measures and diet quality was in the opposite direction for cancer survivors and non-cancer controls. For example, cancer survivors who had overweight or obese BMI were 28% (95% CI: 0.96, 1.71) and 31% (95% CI: 0.98, 1.75) more likely to consume a high-quality diet compared to those who had a normal weight, whereas overweight and obese non-cancer controls were 8% (95% CI: 0.84, 1.01) and 5% (95% CI: 0.85, 1.05) less likely to have a high diet quality, although none of the associations reached significance (**Table 4.10**). In addition, obesity defined by BF% had a significant and inverse association with high diet quality among non-cancer controls ($OR_{adjusted}$ = 0.91, 95% CI: 0.84, 0.99), while it was not associated with diet quality among cancer survivors (**Table 4.10**). The significant positive association between high TF% and high diet quality was also only found in non-cancer controls.

Table 4.10 Association between obesity/body composition measures and HEI in cancer survivors and non-cancer controls, results from adjusted LMMs and GLMMs stratified by cancer status†.

	LMM			GLMM		
	Cancer survivors	**Non-cancer controls**	**$P_{interaction}$‡**	**Cancer survivors**	**Non-cancer controls**	**$P_{interaction}$‡**
BMI			0.58			0.12
Normal	reference	reference		reference	reference	
Underweight	-2.41 (-10.11, 5.28)	-1.39 (-3.24, 0.46)		0.86 (0.11, 6.97)	0.99 (0.59, 1.64)	
Overweight	0.48 (-0.52, 1.48)	-0.17 (-0.49, 0.16)		1.28 (0.96, 1.71)	0.92 (0.84, 1.01)	
Obese	0.66 (-0.34, 1.66)	-0.04 (-0.39, 0.32)		1.31 (0.98, 1.75)	0.95 (0.85, 1.05)	
BF%			0.54			0.09
Normal	reference	reference		reference	reference	
Obese^{Ø}	0.14 (-0.68, 0.96)	-0.13 (-0.42, 0.16)		1.14 (0.89, 1.46)	0.91 (0.84, 0.99)*	
WC			0.51			0.19
Normal	reference	reference		reference	reference	
Obese§	0.23 (-0.58, 1.03)	-0.06 (-0.36, 0.24)		1.15 (0.91, 1.46)	0.97 (0.89, 1.06)	
WHR			1.00			0.49
Normal	reference	reference		reference	reference	
Obese**	-0.03 (-0.87, 0.82)	-0.03 (-0.32, 0.27)		1.07 (0.85, 1.35)	0.98 (0.91, 1.07)	
TF%$^{\Delta}$			0.97			0.36
Low-to-intermediate	reference	reference		reference	reference	
High	0.43 (-0.59, 1.46)	0.46 (0.07, 0.84)*		0.97 (0.72, 1.31)	1.12 (1.01, 1.24)*	
FFMI$^{\Delta}$			0.15			0.12
Low-to-intermediate	reference	reference		reference	reference	
High	0.84 (-0.14, 1.82)	0.10 (-0.23, 0.44)		1.25 (0.95, 1.64)	0.99 (0.91, 1.09)	

* $p < 0.05$. †LMMs adjusted for age, sex, household income, highest education, marital status, ethnicity, smoking status, alcohol consumption, physical activity, cancer, diabetes, social deprivation, urbanicity, province of residence. GLMMs adjusted for age, sex, household income, highest education, smoking status, alcohol consumption, physical activity, cancer, diabetes, population density and province of residence. ‡p-value for the interaction between obesity/body composition measures and cancer status in the multivariate LMMs and GLMMs. Ø Body fat percentage (BF%) >25% in males and >35% in females. §Waist circumference (WC) >102cm in males and >88cm in females. ** Waist-to-hip ratio (WHR) ≥ 0.90 in males and ≥ 0.85 in females. Δ TF%: trunk fat percentage, FFMI: fat-free mass index, low-to-intermediate: the lower three quartiles, high: the highest quartile

There was a significant difference in males and females with regard to the association between WC, FFMI and diet quality ($p_{interaction}$ = 0.04 for both), according to the LMMs (**Table 4.11**). Male participants who had a high FFMI had a higher mean HEI by 0.63 (95% CI: 0.07, 1.20) than males with a low-to-intermediate FFMI, while FFMI was not associated with diet quality in females (**Table 4.11**). Despite the fact that the interaction between WC and sex was significant, the sex-stratified analysis showed that there was no association between WC and diet quality in males and females. The GLMMs revealed no significant interaction between any obesity measures and sex (data not shown).

Table 4.11 Mean difference in the HEI score of participants with obese vs normal WC and participants with high vs low-to-intermediate FFMI, results from multivariate LMMs stratified by sex†.

	Male	**Female**	**$P_{interaction}$‡**
WC			0.04
Normal	reference	reference	
Obese§	0.39 (-0.11, 0.89)	-0.21 (-0.53, 0.11)	
FFMI			0.04
Low-to-intermediate	reference	reference	
High$^{\Delta}$	0.63 (0.07, 1.20)*	-0.04 (-0.41, 0.33)	

* $p<0.05$

†Adjusted for age, sex, household income, highest education, marital status, ethnicity, smoking status, alcohol consumption, physical activity, cancer (yes/no), diabetes (yes/no), social deprivation, urbanicity, province of residence

‡p-value for the interaction between adiposity measures (i.e. WC and FFMI) and sex in the multivariate LMM model.

§Waist circumference (WC) >102cm in males and >88cm in females. $^{\Delta}$ FFMI: fat-free mass index, low-to-intermediate: the lower three quartiles, high: the highest quartile

4.4 Research question 3: Association between neighbourhood environment and diet quality

Among all participants in the analytic sample, most (n= 9076, 45.44%) were from the least materially deprived areas from the Atlantic provinces (**Table 4.12**). Only 4532 (22.69%) were from the most materially deprived areas. There was a relatively similar percentage of people from areas with different levels of social deprivation, with 36.48% from the least socially deprived, 30.52% from the most deprived and 32.99% from areas with an intermediate level of social deprivation (**Table 4.12**). In addition, the sample was comprised of 7822 (39.16%) participants from densely populated areas and 5519 (27.63%) from least dense areas.

Table 4.12 Percentage of participants with high diet quality and mean HEI scores by categories of neighbourhood environment.

	Overall Analytic Sample	**Low-to-intermediate Diet Quality**†	**High Diet Quality**†	**HEI Score**	
	N= 19973	N=14965	N=5008	N=19973	
	N (%)	%	%	Mean	SD
Material Deprivation					
Least deprived	9076 (45.44)	6705 (44.80)	2371 (47.34)	39.08	8.55
Intermediate	6365 (31.87)	4793 (32.03)	1572 (31.39)	38.71	8.62
Most deprived	4532 (22.69)	3467 (23.17)	1065 (21.27)	38.32	8.86
Social Deprivation					
Least deprived	7287 (36.48)	5407 (36.13)	1880 (37.54)	39.19	8.39
Intermediate	6590 (32.99)	4944 (33.04)	1646 (32.87)	38.81	8.61
Most deprived	6096 (30.52)	4614 (30.83)	1482 (29.59)	38.27	8.97
Population Density					
Least dense	5519 (27.63)	4144 (27.69)	1375 (27.46)	39.03	8.42
Intermediate	6632 (33.20)	4912 (32.82)	1720 (34.35)	38.88	8.68
Most dense	7822 (39.16)	5909 (39.49)	1913 (38.20)	38.53	8.78

† High diet quality is defined as having an HEI in the highest quartile, while low-to-intermediate diet quality is having an HEI in the lower three quartiles.

4.4.1 Association between material deprivation and diet quality

People living in the least materially deprived areas had a mean HEI of 39.08 (**Table 4.12**). Compared to residents of least materially deprived areas, those living in the areas of intermediate and highest level of material deprivation had lower mean HEI scores by 0.60 (95% CI: -0.90, -0.30) and 0.85 (95% CI: -1.20, -0.49), respectively (**Table 4.13**). However, no significant association was found between material deprivation and diet quality, after the LMM adjusted for individual sociodemographic factors, lifestyle behaviours, health-related characteristics, social deprivation, population density, urbanicity and province of residence (**Table 4.13**). Based on the unadjusted GLMMs, people living in the most deprived and intermediate areas were associated with 13% (95% CI: 0.80, 0.96) and 9% (95% CI: 0.84, 0.99) lower odds of high diet quality, respectively, compared to those living in the least deprived areas. However, as with the multivariable LMMs, the multivariable GLMMs suggested no significant association (**Table 4.14**).

Table 4.13 Mean difference in the HEI score (95% CI) of participants living in more materially-deprived areas vs least deprived areas, results from unadjusted and adjusted LMMs.

	Unadjusted	**Adjusted**†
Material deprivation		
Least deprived	reference	reference
Intermediate	-0.60 (-0.90, -0.30)*	-0.25 (-0.54, 0.05)
Most deprived	-0.85 (-1.20, -0.49)*	-0.15 (-0.51, 0.21)

* $p<0.05$

†Adjusted for age, sex, household income, education, ethnicity, alcohol consumption, physical activity, cancer, diabetes, population density, social deprivation, urbanicity, province of residence

Table 4.14 OR of high diet quality (95% CI) among participants living in more materially-deprived areas vs least deprived areas, results from unadjusted and adjusted GLMMs.

	Unadjusted	Adjusted†
Material deprivation		
Least deprived	reference	reference
Intermediate	0.91 (0.84, 0.99)*	0.98 (0.90, 1.06)
Most deprived	0.87 (0.80, 0.96)*	1.01 (0.91, 1.11)

* p<0.05

† Adjusted for age, sex, household income, education, alcohol consumption, physical activity, cancer, diabetes, population density and province of residence.

The association between material deprivation and diet quality varied by urbanicity ($p_{interaction}$ = 0.005, **Table 4.15**). There was a positive association between material deprivation and diet quality in urban areas, whereas an inverse association in rural areas. In urban areas, there was a 13% increased odds of high diet quality in the most deprived areas (95% CI: 1.00, 1.28, p = 0.05), compared to the least deprived areas (**Table 4.15**). In rural areas, however, there was a 21% reduced odds of high diet quality (95% CI: 0.66, 0.95) with the highest level of material deprivation (**Table 4.15**). The association between material deprivation and diet quality was not modified by other factors including cancer status, household income, highest education, population density and material deprivation (data not shown).

Table 4.15 OR of high diet quality (95% CI) among participants living in more materially-deprived areas vs least deprived areas, results from adjusted GLMMs stratified by urbanicity†.

Urbanicity	Material deprivation	OR (95% CI)	$P_{interaction}$‡
Urban	Least deprived	reference	0.005
	Intermediate	1.00 (0.91, 1.10)	
	Most deprived	1.13 (1.00, 1.28)	
Rural	Least deprived	Reference	
	Intermediate	0.84 (0.70, 1.00)	
	Most deprived	0.79 (0.66, 0.95)*	

* p<0.05

† Adjusted for age, sex, household income, education, alcohol consumption, physical activity, cancer, diabetes, population density and province of residence
‡p-value for the interaction between material deprivation and urbanicity in the multivariate GLMM

4.4.2 Association between social deprivation and diet quality

Residents living in the least socially deprived areas had a mean HEI of 39.19, which was higher than that of residents living in more deprived areas (**Table 4.12)**. Compared to the least socially deprived areas, there was a decreasing trend in the mean HEI of people living in areas with intermediate and the highest level of social deprivation (intermediate-level deprivation: -0.41, 95% CI: -0.71, -0.11; highest-level deprivation: -0.87, 95% CI: -1.20, -0.54) (**Table 4.16**). After adjusting for individual-level confounders as well as urbanicity and province of residence, the highest level of social deprivation remained significantly and inversely associated with high diet quality, whereby the mean HEI was 0.56 units lower (95% CI: -0.88, -0.25) in the most socially deprived areas compared to the least deprived areas (**Table 4.16**). The GLMMs, however, did not detect any significant association between social deprivation and diet quality both before and after adjusting for confounders (**Table 4.17**). In addition, the association was not modified by cancer status, household income, highest education, marital status, population density, material deprivation and urbanicity (data not shown).

Table 4.16 Mean difference in the HEI score (95% CI) of participants living in more socially-deprived areas versus least deprived areas, results from unadjusted and adjusted LMMs.

	Unadjusted	**Adjusted†**
Social deprivation		
Least deprived	reference	reference
Intermediate	-0.41 (-0.71, -0.11)*	-0.28 (-0.57, 0.01)
Most deprived	-0.87 (-1.20, -0.54)*	-0.56 (-0.88, -0.25)*

* $p<0.05$
†Adjusted for age, sex, household income, education, marital status, ethnicity, alcohol consumption, physical activity, cancer, diabetes, urbanicity and province of residence

Table 4.17 OR of high diet quality (95% CI) among participants living in more socially-deprived areas versus least deprived areas, results from unadjusted and adjusted GLMMs.

	Unadjusted	**Adjusted**[†]
Social deprivation		
Least deprived	reference	reference
Intermediate	0.96 (0.88, 1.04)	0.99 (0.91, 1.07)
Most deprived	0.93 (0.85, 1.01)	0.97 (0.89, 1.07)

[*] p<0.05

[†] Adjusted for age, sex, household income, education, alcohol consumption, physical activity, cancer, diabetes, population density and province of residence.

4.4.3 Association between population density and diet quality

The mean HEI of people living in areas of low population density was 39.03, which was slightly higher than that of people living in more dense areas (**Table 4.12**). The unadjusted LMMs showed that the difference in mean HEI scores did not reach significance across areas of different population density (**Table 4.18**). After adjusting for individual-level sociodemographic, lifestyle, and health-related factors as well as social deprivation and province of residence, people living in the most densely populated areas were found to have significantly lower mean HEI by 0.39 units (95% CI: -0.77, -0.01) than people living in the least dense areas (**Table 4.18**). However, the difference in diet quality with different population density was of a small magnitude and did not reach significance in the GLMMs before and after adjusting for confounders (**Table 4.19**). According to the adjusted GLMM, residents of the densest areas tended to be 7% less likely ($OR_{adjusted}$: 0.93, 95% CI: 0.84, 1.02) to consume a high-quality diet than residents of the least dense areas, but the odds ratio was not statistically significant (**Table 4.19**).

Table 4.18 Mean difference in the HEI score (95% CI) of participants living in more densely populated areas versus the least populated areas, results from unadjusted and adjusted LMMs.

	Unadjusted	**Adjusted**†
Population density		
Least dense	reference	reference
Intermediate	-0.24 (-0.58, 0.09)	-0.28 (-0.60, 0.04)
Most dense	-0.31 (-0.69, 0.07)	-0.39 (-0.77, -0.01)*

* p<0.05

†Adjusted for age, sex, household income, education, marital status, ethnicity, smoking status, alcohol consumption, physical activity, cancer, diabetes, social deprivation, province of residence

Table 4.19 OR of high diet quality (95% CIs) among participants living in more densely populated areas vs the least populated areas, results from unadjusted and adjusted GLMMs.

	Unadjusted	**Adjusted**†
Population density		
Least dense	reference	reference
Intermediate	1.04 (0.96, 1.14)	1.03 (0.94, 1.13)
Most dense	0.99 (0.90, 1.09)	0.93 (0.84, 1.02)

* p<0.05

†Adjusted for age, sex, household income, education, smoking status, alcohol consumption, physical activity, cancer, diabetes, province of residence

The decrease in mean HEI with increasing population density was more evident in urban areas than in rural areas (**Table 4.20**). In urban areas, living in the densest areas was associated with a lower mean HEI by 0.72 units (95% CI: -1.20, -0.25) and 0.85 times lower odds of having a high-quality diet (95% CI: 0.75, 0.96), compared to living in the least dense areas (**Table 4.20**). To the contrary, in rural areas, increasing population density was associated with better diet quality. There was a higher mean HEI by 0.54 (95% CI: 0.05, 1.03) and 1.16 times higher odds of high diet quality (95% CI: 1.01, 1.33) in areas of intermediate population density than those living in the least dense areas (**Table 4.20**). The association between population density and diet quality was not modified by other factors including cancer status, household income, highest education, material deprivation and social deprivation (data not shown).

Table 4.20 Mean difference in HEI score (95% CIs) and ORs of high diet quality among participants living in more densely populated areas versus the least populated areas, results from adjusted LMMs and GLMMs stratified by urbanicity.

Urbanicity	Population density	LMM† Mean difference in HEI (95% CI)	$P_{interaction}$§	GLMM‡ OR (95% CI)	$P_{interaction}$§
Urban	Least dense	Reference	<0.001	reference	0.04
	Intermediate	-0.84 (-1.28, -0.40)*		0.93 (0.83, 1.05)	
	Most dense	-0.72 (-1.20, -0.25)*		0.85 (0.75, 0.96)*	
Rural	Least dense	reference		reference	
	Intermediate	0.54 (0.05, 1.03)*		1.16 (1.01, 1.33)*	
	Most dense	-0.18 (-0.95, 0.58)		1.09 (0.87, 1.35)	

* p<0.05
†LMM adjusted for age, sex, household income, highest education, marital status, ethnicity, smoking, alcohol consumption, physical activity, diabetes, cancer, diabetes, social deprivation, urbanicity, province of residence; ‡GLMM adjusted for age, sex, household income, education, smoking, alcohol consumption, physical activity, cancer, diabetes, province of residence
§ p-value for the interaction between population density and urbanicity in the multivariate LMM and GLMM.

In order to determine significant predictors of diet quality, all individual-level and area-level characteristics were assessed in the LMM and GLMM at the same time (**Table 4.21**). Age, sex, highest education, alcohol consumption, physical activity, and urbanicity were found to be significant predictors ($p < 0.05$) among cancer survivors, when the GLMM was used to predict whether diet quality was high or low-to-intermediate. Sex was a notably strong predictor in cancer survivors, as males were 0.37 times less likely (95% CI: 0.28, 0.49) to consume high-quality diet than females (**Table 4.21**). Compared to people who had low physical activity level, people with high and moderate level of physical activity were 2.53 (95% CI: 1.79, 3.59) and 1.63 (95% CI: 1.13, 2.36) times more likely to have high diet quality (**Table 4.21**). Higher odds of high diet quality were also seen in people who had a Bachelor's degree or higher compared to those who had a high school degree or lower and in people living in rural areas compared to those living in urban areas. In addition to the predictors reported for cancer survivors, household income, smoking status, diabetes, and province of residence also significantly predicted diet quality among non-cancer controls.

In terms of predicting HEI scores, the LMMs showed that age, sex, highest education, smoking status, physical activity, myocardial infarction, province of residence were significant predictors among both cancer survivors and non-cancer controls, while household income, alcohol consumption, and diabetes were additional predictors of HEI in the non-cancer controls. Overall, BMI, material deprivation, social deprivation and population density were not predictive of diet quality in any of the models.

Table 4.21 Predictors of diet quality in cancer survivors and non-cancer controls, results from the final LMMs and GLMMs. Significant predictors with an overall p-value <0.05 from the Wald test are bolded.

	LMM		**GLMM**	
	Cancer survivors	**Non-cancer controls**	**Cancer survivors**	**Non-cancer controls**
Age group				
5-year increment	**-0.37 (-0.63, -0.12)***	**-0.13 (-0.20, -0.06)***	**0.92 (0.86, 0.99)***	**0.96 (0.94, 0.98)***
Sex				
Female	Reference	Reference	Reference	Reference
Male	**-3.82 (-4.73, -2.92)***	**-4.36 (-4.63, -4.09)***	**0.37 (0.28, 0.50)***	**0.39 (0.35, 0.42)***
Marital status				
Without partners	Reference	Reference	Reference	Reference
With partners	-0.57 (-1.63, 0.48)	0.30 (-0.04, 0.65)	0.92 (0.68, 1.24)	1.03 (0.93, 1.14)
Ethnicity				
White	Reference	Reference	Reference	Reference
Non-white	-0.44 (-2.10, 1.22)	-0.27 (-0.76, 0.22)	1.18 (0.74, 1.88)	0.98 (0.85, 1.14)
Income				
$0-24,999	Reference	Reference	Reference	Reference
$25,000-49,999	2.10 (0.32, 3.87)*	**1.19 (0.51, 1.87)***	1.13 (0.67, 1.92)	**1.12 (0.91, 1.38)**
$50,000-74,999	1.86 (0.02, 3.70)*	**1.05 (0.37, 1.74)***	1.27 (0.74, 2.18)	**1.04 (0.84, 1.29)**
$75,000-149,999	2.05 (0.15, 3.95)*	**1.58 (0.89, 2.27)***	1.16 (0.66, 2.02)	**1.19 (0.96, 1.48)**
$>150,000	1.95 (-0.28, 4.19)	**2.16 (1.38, 2.94)***	0.99 (0.51, 1.92)	**1.25 (0.99, 1.59)**
Education				
≤ High school	Reference	Reference	Reference	Reference
College	**0.72 (-0.29, 1.72)**	**1.10 (0.76, 1.43)***	**1.05 (0.78, 1.42)**	**1.33 (1.19, 1.48)***
≥ Bachelor's degree	**2.18 (1.05, 3.30)***	**2.62 (2.25, 2.99)***	**1.43 (1.03, 1.98)***	**1.79 (1.59, 2.01)***

Smoking status‡				
Never	Reference	Reference	Reference	Reference
Former	**-0.09 (-0.90, 0.72)**	**-0.26 (-0.53, 0.00)**	1.10 (0.87, 1.39)	**0.94 (0.87, 1.01)**
Occasional	**-1.00 (-3.66, 1.67)**	**-0.72 (-1.48, 0.05)**	1.00 (0.45, 2.22)	**0.94 (0.75, 1.18)**
Regular	**-2.53 (-4.09, -0.98)***	**-3.04 (-3.53, -2.56)***	0.83 (0.51, 1.34)	**0.53 (0.45, 0.63)***
Alcohol consumption§				
Abstainer	Reference	Reference	Reference	Reference
Former drinker	1.81 (-0.44, 4.05)	**0.18 (-0.58, 0.93)**	**1.50 (0.74, 3.05)**	**0.97 (0.77, 1.23)**
Occasional drinker	2.19 (0.26, 4.13)*	**0.65 (0.03, 1.28)***	**1.81 (0.97, 3.37)**	**1.03 (0.85, 1.25)**
Regular drinker	2.63 (0.61, 4.64)*	**1.37 (0.73, 2.01)***	**1.60 (0.84, 3.05)**	**1.15 (0.95, 1.39)**
Habitual drinker	1.61 (-0.52, 3.74)	**0.96 (0.28, 1.65)***	**1.08 (0.54, 2.15)**	**1.01 (0.82, 1.24)**
Physical activity				
Low	Reference	Reference	Reference	Reference
Moderate	**2.14 (0.98, 3.29)***	**2.11 (1.76, 2.46)***	**1.63 (1.13, 2.36)***	**1.53 (1.37, 1.71)***
High	**3.92 (2.84, 5.00)***	**3.43 (3.10, 3.76)***	**2.53 (1.79, 3.59)***	**2.34 (2.10, 2.60)***
BMI				
Normal	Reference	Reference	Reference	Reference
Underweight	-2.47 (-10.28, 5.33)	-1.40 (-3.25, 0.44)	0.92 (0.11, 8.03)	0.99 (0.60, 1.65)
Overweight	0.50 (-0.54, 1.53)	-0.16 (-0.49, 0.17)	1.27 (0.94, 1.72)	0.93 (0.84, 1.02)
Obese	0.66 (-0.42, 1.74)	-0.03 (-0.39, 0.34)	1.22 (0.89, 1.67)	0.95 (0.86, 1.06)
Diabetes				
No	Reference	Reference	Reference	Reference
Yes	1.27 (-0.19, 2.73)	**1.69 (1.12, 2.27)***	1.27 (0.83, 1.92)	**1.47 (1.23, 1.74)***
Myocardial infarction				
No	Reference	Reference	Reference	Reference
Yes	**-3.94 (-6.25, -1.62)***	**1.20 (0.26, 2.14)***	0.69 (0.30, 1.61)	1.22 (0.90, 1.65)

Urbanicity				
Urban	Reference	Reference	Reference	Reference
Rural	0.61 (-0.41, 1.64)	0.23 (-0.16, 0.62)	**1.40 (1.05, 1.88)***	0.96 (0.87, 1.06)
Province				
NL	Reference	Reference	Reference	Reference
PEI	**0.80 (-2.09, 3.69)**	**1.36 (0.14, 2.59)***	1.06 (0.46, 2.46)	**1.18 (0.87, 1.61)**
NS	**-0.21 (-1.62, 1.20)**	**0.54 (-0.02, 1.10)**	1.17 (0.77, 1.77)	**1.18 (1.03, 1.35)***
NB	**1.47 (-0.11, 3.05)**	**1.64 (1.06, 2.23)***	1.41 (0.89, 2.24)	**1.43 (1.24, 1.65)***
Material deprivation				
Least deprived	Reference	Reference	Reference	Reference
Intermediate	0.22 (-0.73, 1.17)	-0.26 (-0.56, 0.05)	0.93 (0.71, 1.23)	1.00 (0.91, 1.09)
Most deprived	0.25 (-0.85, 1.36)	-0.12 (-0.50, 0.25)	1.02 (0.74, 1.40)	1.03 (0.92, 1.15)
Social deprivation				
Least deprived	Reference	Reference	Reference	Reference
Intermediate	-0.07 (-1.00, 0.86)	-0.23 (-0.53, 0.07)	0.98 (0.75, 1.28)	1.00 (0.92, 1.09)
Most deprived	-0.72 (-1.80, 0.35)	-0.35 (-0.71, 0.00)	0.92 (0.67, 1.26)	0.99 (0.90, 1.10)
Population density				
Least dense	Reference	Reference	Reference	Reference
Intermediate	0.54 (-0.53, 1.60)	-0.35 (-0.70, 0.00)*	1.12 (0.83, 1.53)	1.03 (0.93, 1.13)
Most dense	-0.63 (-1.85, 0.59)	-0.37 (-0.79, 0.05)	1.02 (0.71, 1.45)	0.91 (0.81, 1.03)

* $p<0.05$

‡ Non-smoker: has never smoked, former: has smoked at least 100 cigarettes before but not within the past 30 days, occasional: smoked at least once within the past 30 days but not daily, regular: smoked daily. All other participants were categorized as non-smokers.

§Abstainer: has never drunk alcohol, former: has drunk alcohol before but not over the past 12 months, occasional: drank ≤2−3 times/month over the past 12 months, regular: drank ≥ once/week but ≤2−3 times/week, habitual drinkers: drank ≥ 4–5 times/week.

Chapter 5: Discussion

A cancer diagnosis is a critical time point for healthy lifestyle modifications, which could be beneficial for managing symptoms, overall survival and general well-being. Although cancer survivors may be motivated to improve their diet, many still fail to meet dietary recommendations (27,28). Using baseline data from a large-scale study (Atlantic PATH) in Atlantic Canada, the present cross-sectional study examines how cancer survivors' diet quality compares to that of non-cancer controls and how diet quality varies by cancer sites and years since diagnosis. Since weight status and body composition may change after a cancer diagnosis for some people, this study also investigates whether the relationship between diet quality, obesity and body composition differs between cancer survivors and non-cancer controls. It further studies how neighbourhood deprivation and population density are linked to diet quality.

This chapter reviews the key findings of the study with comparison to previous literature, discusses strengths and limitations and suggests implications of the results for each research question. It then summarizes additional strengths and limitations that are common to the entire study and provides a conclusion.

5.1 Research question 1: Diet quality of cancer survivors

5.1.1 Summary of findings in comparison with literature

This study is among the first in Canada to investigate cancer survivors' overall diet quality. While food and nutrient intakes have been studied in cancer survivors and non-cancer controls, a comparison of overall diet quality has only been shown in a limited number of studies in countries other than Canada, which have not reached consensus on their findings (28–35). In addition, Canadians may have distinct dietary patterns from people in other countries, making it important to investigate this question in a Canadian context (107). This study reported overall diet quality for specific cancer sites and years since diagnosis as well, which is limited in the literature. Findings suggested that cancer survivors had better diet quality than non-cancer controls, and that diet quality differed by cancer site and years since diagnosis, with relatively low quality being observed in male lung cancer survivors, female cervical and GI (except colorectal) cancer survivors and long-term cancer survivors.

5.1.1.1 Diet quality of cancer survivors compared to non-cancer controls

The broader evidence based on diet among cancer survivors is conflicting, with studies suggesting better, similar or poorer diets compared to non-cancer controls. The finding of better diet quality in cancer survivors in the present study is consistent with previous large-scale studies that showed a higher prevalence of consuming 5 or more fruit and vegetables per day in cancer survivors than non-cancer controls (30–32). In Wang et al.(30), cancer survivors were 41% more likely to consume 5 or more fruit and vegetables a day than people without a history of cancer. A separate study of 17,158 cancer survivors and 245,283 non-cancer controls showed a 14% higher odds of consuming 5 or more fruit and vegetables per day (32). Higher consumption of fruit and vegetables has also been observed in prostate cancer survivors compared to non-cancer controls (31). However, several studies showed contradicting results that cancer survivors or breast cancer survivors do not have significant difference in intakes of fruit and vegetables, red and processed meat and macronutrients, including total fat, proteins and carbohydrates, compared to non-cancer controls (34–36,270). These studies differ in the composition of cancer survivors; some studied breast or prostate cancer survivors exclusively, in contrast to others studying all cancer survivors except for non-melanoma skin cancer. The mean survival time since diagnosis in these studies ranged from 9.5 to 12.5 years, while it is 10.6 years here (34–36,270). As intakes of foods and nutrients only reflect one or a few aspect(s) of diet quality, most of the previous studies are not directly comparable to the present study.

The results from this study are in contrast to a US study that compared overall diet quality between cancer survivors and non-cancer controls as well as an Australian study that examined adherence to the Australian Dietary Guidelines among breast cancer survivors and controls (28,29). Zhang and colleagues showed that the mean HEI score is 1.1 units lower out of a total score of 100 in US cancer survivors in comparison to non-cancer controls, although in a sensitivity analysis that further adjusted for smoking status, diet quality did not differ by cancer status (29). In the Australian study, Potter et al. found a similar diet quality between breast cancer survivors and non-cancer controls. It is unclear whether the discrepant results are true differences or reflect varying study methodology. Both Zhang et al. and Potter et al. minimally adjusted models (age, sex and race in Zhang et al. and no confounders adjusted in Potter et al.), while this study adjusted for demographic, socioeconomic, lifestyle, health-related and neighbourhood environment factors (28,29). The studies also differ in the methods of dietary assessments and HEI scores. The diet scores used in their studies included alcohol intake as a dietary component, whereas alcohol consumption is not a component of the adapted Canadian HEI used here (29). Cancer survivors in this study were more likely to drink habitually than non-cancer controls, which would negatively impact their diet quality if alcohol consumption was considered in the construction of HEI. In addition, diet was assessed by food frequency questionnaire (FFQ) in the present study, while 24-hour diet recall was used in Zhang et al (29). FFQ is commonly used to capture usual diet intake over a long period of time based on the consumption frequency of foods from a finite list predefined by researchers (271). On the other hand, 24-hour diet recall asks people to report dietary intake over the past 24 hours which may not reflect typical diet intakes or capture episodically consumed foods unless the recall is repeated (271).

It is worth mentioning that although there was a difference in the mean HEI scores between cancer survivors and non-cancer controls, when categorized into high and low-to-intermediate diet quality, the odds of having a high diet quality did not differ between the two groups. The contradicting findings from the two models may be explained by the outcome variable. HEI was dichotomized to facilitate interpretation of results versus the continuous HEI in the LMMs. However, dichotomized HEI leads to loss of information, which in turn reduces statistical power (272). In addition, people who have HEI scores close to the cut points may be misclassified (272).

5.1.1.2 Diet quality of cancer survivors by years since diagnosis

Cancer survivors who were diagnosed within the prior 2 years had the highest diet quality. In support of this finding, a study showed that cancer survivors within two years of diagnosis had a higher prevalence of consuming 5 or more fruit and vegetables than people who were diagnosed more than 2 years prior (30). Studies on related lifestyle behaviours also indicate that long-term maintenance of healthy behaviours is challenging among cancer survivors, illustrated by a higher prevalence of smoking in long-term cancer survivors (32). Weight gain and increase in waist circumferences have also been observed in breast cancer survivors over time (270). Conversely, other studies have found no association between time since diagnosis and intake of dietary components including fruit and vegetables, whole grains, red meat, solid fats, added sugar and alcohol (32,270). The discrepancy in results may be partly attributed to the heterogeneity of cancer survivors in the studies who have varied from exclusively breast cancer survivors, all cancer types, to all cancer types except for non-melanoma skin cancer cases or those diagnosed <1 year prior, leading to variation in prognosis and mean survival of study population (30,32,36).

5.1.1.3 Diet quality of cancer survivors by cancer sites

The comparison of HEI by cancer site drew on the most common cancers in each respective sex as the reference group, female breast cancer survivors and male prostate cancer survivors. The present study showed that the mean HEI scores of breast and prostate cancer were 41 and 36 out of a possible 60, respectively, suggesting higher diet quality in female breast cancer survivors than male prostate cancer survivors, consistent with a previous study (29). This could partly be attributed to the fact that females have higher diet quality than males in general, or reflect the greater tendency towards healthy eating in breast cancer survivors due to emerging evidence about diet and breast cancer survival (159). Although overall diet quality may be higher, not all aspects of diet (macronutrients and dietary components) are healthier among breast cancer survivors. Coups and Ostroff (34) reported that compared to males with prostate cancer, females with breast cancer were more likely to meet recommendations for fat intake (<30% calories from fat), but less likely to meet recommendations for fruit and vegetables (≥ 5 servings/day) and fibre intake (>25g/day). Thus, although breast and prostate cancer are the referent groups for the present study, both groups are in need of improvement in some aspects of diet.

Similar to Zhang et al. (29), among male cancer survivors, those with lung cancer have the lowest diet quality among all cancer types. This may be reflective of the high prevalence of smoking in lung cancer survivors, which may be associated with a lower diet quality (30,134). Overall poor cancer prognosis and survival and side effects of treatments in lung cancer survivors may also be contributing factors. In addition, among females, the lowest diet quality was seen in cancer survivors with non-colorectal GI cancer, which consists of esophagus, stomach, pancreas and liver cancer. The anorexia-cachexia syndrome is relatively common in lung and non-colorectal GI cancer survivors and is characterized by reduced appetite and loss of muscle mass (53,273,274).

Cancer survivors who have cachexia are more likely to have poor survival and functional status, which in turn may affect dietary intake (273). However, these results should be interpreted with caution as sample sizes for most cancer types (including lung and non-colorectal GI cancer) are small, as seen from the large confidence intervals. Therefore, the potential confounding effect of age, SES and other diet-related factors was not considered for most cancers, except for colorectal, cervical, prostate and female breast cancer which have large sample sizes.

Relative to breast cancer survivors, cervical cancer survivors had a significantly poorer diet quality after statistical adjustment. This corresponds to the results of Coups and Ostroff's study, which showed that a lower percentage of cervical cancer survivors met the recommendations for fat intake than breast cancer survivors (34). Smoking is a risk factor for cervical cancer. Compared to prostate, colon, and female breast cancer survivors, cervical cancer survivors were found to be more likely to be current smokers, who were at risk of low diet quality (34). Therefore, smoking status may potentially distort the relationship between cancer site and diet quality. To take into account the potential confounding effect by smoking, a sensitivity analysis in this study further adjusted for smoking status even though it was not found to be a significant confounder when using the backward elimination method. After adjusting for smoking status, the attenuated difference in diet quality between breast cancer and cervical cancer survivors suggested that the lower diet quality in cervical cancer survivors may be partly explained by smoking.

5.1.2 Strengths and limitations

The investigation of all cancer types combined provides an overview of cancer survivors' diet quality on average, increasing the generalizability of the results to the overall cancer survivor population. In addition, the stratified analysis takes into account the variation within the group of cancer survivors due to different cancer sites and survival years. The use of the Atlantic PATH cohort which has detailed questionnaire and measurement data enabled more extensive consideration of the potential confounding effect of age, sex, socioeconomic, lifestyle, health-related, and neighbourhood environment characteristics for the comparison of diet quality of several major cancers, while the previous studies mostly only provided descriptive statistics (29,34).

There are a few limitations. The cross-sectional design makes it difficult to conclude whether cancer survivors improved their diet after diagnosis or not. However, as poor diet is a contributing factor to the development of some cancers (17), including breast and colorectal cancer (two of the major cancer types in this study), cancer survivors are likely to have a poorer diet than their non-cancer counterparts prior to or at diagnosis. Therefore, the difference in this study may support cancer diagnosis as a 'teachable moment', after which dietary improvements may occur. However, it is also possible that cancer survivors had a healthier diet due to selection bias or more specifically survivor bias, as illustrated by the mean survival time of 10.6 years post diagnosis in this study. Compared to the non-participating cancer survivors, the analytic sample of the present study may predominately consist of cancer survivors with better prognoses who may be engaged in more healthy lifestyle behaviours, including healthy eating, than those with shorter survival who died early (270).

This study relied on self-reported cancer to identify cancer survivors, which is prone to non-response bias. This may explain why there is a higher prevalence of cervical cancer and lower prevalence of lung cancer in the Atlantic PATH cohort than what is reported for the entire Canadian population (1,243). It is worth mentioning that almost half of the cancer survivors did not report their cancer-specific information, and thus non-melanoma skin cancer cases were not completely excluded, which may have attenuated the results. People with incomplete cancer-specific information were excluded from the analysis on cancer sites and years since diagnosis, which may have introduced selection bias and reduced generalizability of results. Additionally, the primary cancer site was used for people with diagnoses of multiple cancers whose diet quality may be influenced by the second or third type of cancer.

5.1.3 Implications

Although cancer survivors were found to have a higher mean HEI than non-cancer controls in the present study, the magnitude of the difference is small compared to a total score of 60. It is difficult to gauge whether this difference has clinical implications. For example, a difference of 0.45 points could be translated into consuming approximately 0.35 more servings of fruit and vegetables a day or 2.5 servings a week. Guidelines for health including diet guidelines for cancer survivors and nutrition studies are typically based upon cutpoints (e.g. 5 servings a day) for simplicity, although in reality, such threshold effects (e.g. 5.25 servings versus 4.9 servings) are rare (13,30,32,275). It is thus unclear whether an increase of less than a serving of fruits and vegetables per day could be expected to be associated with better health. Further, previous evidence linking HEI to CVD, cancer or all-cause mortality mostly studied HEI scores in quantiles or per standard deviation increase (198,276,277). Therefore, risk reduction has only been recorded for mean HEI difference of at least 5 units. It is unknown whether a less than one-unit difference in HEI is meaningful for overall health. However, this slight increase fits with public health recommendations (e.g. Canadian Cancer Society) for reducing cancer risk by ‘starting small’.

Overall, the results suggest there is a large room for dietary improvement among cancer survivors and non-cancer controls as the mean HEIs of both groups fell below 40 out of a maximum of 60 points. Given that cancer survivors are at increased risk of developing comorbidities that are diet related such as diabetes and cardiovascular disease, it is crucial to target health behaviour promotion efforts to cancer survivors. The results suggest that several subgroups of cancer survivors may deserve specific focus. Resources are predominantly directed to breast cancer survivors at present, likely reflecting the large breast cancer survivor population, but additional guidance may be warranted for cancer survivors who may have poorer or similar diet quality compared to breast cancer survivors, such as those with cervical, prostate, lung, non-colorectal GI and colorectal cancer. As well, long-term survivors may need additional support to encourage sustained dietary changes.

To better understand cancer survivors' diet, longitudinal studies are needed to determine diet changes after diagnosis and throughout the cancer trajectory. Although longitudinal studies are challenging to conduct due to the time-consuming and resource-demanding nature, Atlantic PATH will eventually be able to follow a large cohort over time from before to after cancer diagnosis. Identification of cancer cases through cancer registries could be used to reduce non-response and misclassification of cancer information, while incentives, repeated questionnaires, and multiple methods of data collection could be used to reduce non-response to other self-reported questions (278). A study that involves a larger sample size of cancer survivors than Atlantic PATH, such as the pan-Canadian CPTP, is required to provide more comprehensive estimation of cancer-site-specific diet quality.

5.2 Research question 2: Associations between diet quality, obesity and body composition

5.2.1 Summary of findings in comparison to literature

The present study indicates that obesity and body composition are not associated with diet quality, except for TF% that had a weak positive association with diet quality. These associations did not significantly differ in cancer survivors and non-cancer controls. Sex was a modifier of some associations, whereby FFMI was significantly and positively associated with diet quality only in males. The study adds to the growing body of evidence on diet quality and obesity including the consideration of body composition and fat distribution. It also highlights the potential sex differences in body composition and dietary intake.

Most research studying the association of diet quality with general and abdominal obesity have shown that people with a lower BMI or WC have better diet quality (50,164,201,279–281). Numerous research that links higher fruit and vegetable intakes, healthy diet patterns or higher diet scores with reduced risk or prevalence of obesity forms the basis for dietary recommendations and interventions (50,164,201,279–281). However, inverse associations have not always been shown in the literature, some of which presented null associations (197,282). Even among studies that presented statistically significant associations, some only showed a small effect (101,201,283). For example, Tande. et al. (201) reported the odds of abdominal obesity as measured by WC was 1.4% lower in males, and 0.8% lower in females with each one-unit increase in HEI. It is unclear if this small effect is clinically meaningful.

The inconsistent findings may be partly explained by the different confounders considered. In the present study, people with a high BMI, BF% and WHR had poorer diet quality in the bivariate analysis when no confounding factors were taken into account. However, all associations were attenuated with adjustment for sociodemographic, lifestyle, health-related and residential characteristics. This suggests that many factors other than diet may be confounding the associations and are important to consider when assessing relationships between body fatness and diet. For example, there is some evidence that physical activity may have a stronger relationship with body fatness than diet in both males and females (283). In the present study, physical activity significantly confounded the relationship between diet quality and obesity. Among previous research, the list of confounders was not as comprehensive as this study, whereby some did not adjust for physical activity or SES and most did not adjust for neighbourhood environment (197,201,284–287). However, unlike many other studies, this study could not adjust for energy intake due to lack of information, which will be discussed in section 5.2.2 (201,284–287).

The conflicting findings may be further explained by the heterogeneity in the study population's characteristics, such as weight status and sex distribution. There is some evidence that BMI is more strongly associated with diet quality in people who have a higher BMI (101). A Canadian study of the CCHS data that used a finite mixture model found two distinct latent distributions of BMI in the study population; 80% of people fell into the low-BMI distribution with a mean BMI of 25kg/m^2, while 20% fell into the high-BMI distribution with a mean BMI of 33kg/m^2. A one unit increase in HEI was associated with a lower BMI by 0.10 kg/m^2 only in the high-BMI people, whereas there was no significant association for the low-BMI people. The mean BMI of the analytic sample in the present study is approximately 28kg/m^2. Therefore, it is possible that diet quality is only associated with adiposity in a proportion of people in this study with the heaviest BMI which is masked when associations in the total analytic sample are considered. In addition, the present study is overrepresented by females (69%), for whom a weaker association has been shown between diet quality and general or abdominal obesity compared to that for males, according to a systematic review (50).

Sex was also detected as an effect modifier of associations between diet quality, WC and FFMI in the present study. Males and females differ in their body composition and fat distribution. For a given BMI, females generally have more fat mass and less lean mass (182,183). Furthermore, females tend to accumulate adipose tissues on their hips and thighs, whereas males accumulate fat around the abdominal region, which may lead to differential relationships between diet and body composition measures (184). There are also sex differences in health behaviours. Compared to females, males tend to have a poorer diet but higher levels of physical activity, which may affect the association between diet quality and body composition (283). Consistent with the systematic review by Asghari et al. that showed a stronger association between diet quality and obesity in males, the present study found that FFMI was positively associated with diet quality only in males (50). Other studies have also linked a higher FFMI with dietary diversity and a Mediterranean diet, as well as higher protein intake, which is correlated with better diet quality (100,205,206,288,289).

One of the objectives of the present study was to investigate whether the association of diet quality with obesity and body composition differed between cancer survivors and non-cancer controls. Although no significant effect modification was found, the direction of associations differed whereby BF% was significantly inversely associated with diet quality among non-cancer controls but was not associated with diet quality among cancer survivors. Similarly, there were positive although non-significant associations for overweight or obese BMI and diet quality among cancer survivors and inverse among non-cancer controls. This may reflect the complex and multifaceted nature of obesity as well as the heterogeneity of cancer types among survivors. Both cancer itself and the corresponding treatments may be contributing factors to weight. Some cancer types, such as breast, prostate and colorectal cancer are more likely to be overweight or obese due to the treatment modalities and/or obesity-related etiology (9,10,17,60). Conversely, other cancer types such as lung, and cervical cancer are not etiologically linked with obesity according to up-to-date evidence (17). Further, cancer types such as lung and pancreatic cancer and advanced cancers are likely associated with weight loss as a result of metabolic changes, insufficient oral intake induced by side effects of treatments and psychological issues (53). When different cancer types are considered collectively, it thus may result in an unclear diet-obesity relationship. The nonsignificant diet-obesity relationship in cancer survivors may also reflect that it is challenging to achieve or maintain a healthy body weight through dietary approaches alone in long-term cancer survivors, which is similar in the general population. The evidence is lacking for successful and effective diet-based interventions for cancer survivors as most are short-term without follow-up (168,169).

FFMI tended to be positively associated with diet quality, especially among cancer survivors, although associations were not significant. This may suggest a modest benefit of healthy eating for maintaining lean mass, which is of clinical relevance to cancer survivors because loss of lean mass predicts poorer cancer survival (53). Further longitudinal research is required to confirm the effect of a healthy diet on the preservation of lean body mass in cancer survivors.

5.2.2 Strengths and limitations

A strength of this study is the use of multiple adiposity measures to assess body fat and fat distribution. Most large epidemiological studies are limited to traditional measures, such as BMI and WC, which are low cost and easy to measure, but are less accurate than other methods such as BIA. BIA also permitted the evaluation of associations between diet quality and FFMI, which is difficult to assess without more advanced body composition assessment. The availability of BF%, TF% and FFMI within the Atlantic PATH thus provides more information about obesity-diet relationships than many previous studies, since body composition measures may have a more direct relationship with health than anthropometric estimates (290). Further, all measures of obesity and body composition were objectively measured instead of relying on self-reported data, which is prone to misreporting.

There are also limitations to the study that should be considered when interpreting the results. As mentioned before, the cross-sectional study design makes it challenging to conclude the temporal relationship. It is possible that people who were overweight or obese initiated weight management strategies through healthy eating, leading to a higher diet quality. The possibility of selective misreporting of dietary intake and social desirability bias also needs to be considered, as obese people are more likely to underreport energy and dietary intakes, especially for unhealthy foods, such as snacks and desserts (291). The dietary data in Atlantic PATH does not permit calculation of caloric intake and thus it was not possible to account for energy intake or identify potential implausible reporters. Failure to adjust for misreporting errors attenuated or reversed the relationship between energy intake, energy density and obesity in prior studies (291,292). However, there is also evidence showing that adjusting for misreporting error did not alter the direction and significance of the association between diet quality scores and obesity (102,283). In addition, although BIA provides more information on body composition than BMI and WC, it is not the gold standard of body composition. BIA is less accurate than dual energy x-ray absorptiometry, computed tomography or magnetic resonance imaging, and thus may lead to misclassification of body composition measures (179,293,294). However, it is unlikely that the misclassification of the measured body composition is differential by diet quality. These methodological limitations may partly explain the null association between most adiposity measures and diet quality as well as the higher mean HEI in people with higher TF%, which appears to contradict the notion of the clustering of healthy behaviours.

5.2.3 Implications

The study findings illustrate the complexity of diet-obesity relationships. Healthy eating may be one factor that affects obesity or body composition, but factors like sociodemographic characteristics, physical activity, health status and neighbourhood environment also need to be considered simultaneously when assessing relationships and also when considering approaches to promote healthy body weight. When it comes to cancer survivors, the issue becomes even more complex as cancer and cancer treatments can also affect dietary intake, weight status and body composition (9,10,17,53,60). Depending on the cancer type and stage, body weight might change in either direction (9,10,17,53,60). Current survivorship guidelines from ACS emphasize healthy eating recommendations along with physical activity to support a healthy weight among cancer survivors. However, guidelines should also include educational materials to empower healthcare professionals to provide cancer-site-specific recommendations, guiding cancer survivors to prevent weight gain or unintentional weight loss from disease or treatments. Cancer survivorship guidelines should consider the social, economic, physical and regulatory environment that may influence diet, obesity and health behaviours. Individuals, health professionals, communities and policy makers should all work together to facilitate broad strategies to support healthy lifestyles.

With regard to research implications, the finding that the association between diet quality and obesity varies depending on the measurement assessed suggests that future research should consider multiple obesity measures to capture body fatness and fat distribution when possible. To better understand the diet-obesity relationships, a more comprehensive measure of diet is required to allow calculation of total energy intake and to account for the potential confounding effect of misreporting. To further explore these relationships in cancer survivors, future studies with the power to examine relationships between diet, body composition, and obesity within specific cancer types of similar stage are needed. Clarity around the direction of relationships between diet and body weight among cancer survivors and non-cancer controls can be gained through investigation of follow-up data from the Atlantic PATH project and other cohorts in the CPTP.

5.3 Research question 3: Association between neighbourhood environment and diet quality

5.3.1 Summary of findings in comparison to literature

The present study provides evidence linking neighbourhood environment with diet quality. Diet quality decreased with increasing social deprivation and population density, although some relationships remained significant only in selected models. There was no association between neighbourhood material deprivation and diet quality after adjustment for individual-level SES and other factors. Urbanicity was found to modify the relationship between diet quality, material deprivation and population density. In urban areas, diet quality was lowest in the least materially deprived or most densely populated neighbourhoods, whereas the reverse was true in rural areas. The study adds to the limited evidence on neighbourhood environment and diet. Findings showed that different dimensions of neighbourhood deprivation acted in distinct manners in relation to diet quality. This study also suggested a significant association between population density and diet quality, and revealed an urban-rural disparity in the association between neighbourhood environment and diet.

Previous evidence on neighbourhood deprivation and diet is inconsistent; some studies indicated reduced diet quality with increasing deprivation while others suggested no association (75,236,237). Two large-scale Australian studies, including one using a nationally representative sample, showed that people living in more deprived areas had poorer adherence to the Australian dietary guidelines as measured by a dietary quality index (236,237). A previous Canadian study in Calgary (75), however, showed no significant association between neighbourhood deprivation and the Canadian HEI with and without adjustment for individual-level SES and food environment (75). A systematic review of observational studies examining health behaviours by neighbourhood deprivation showed higher odds of smoking and physical inactivity with increasing neighbourhood deprivation but inconsistent results regarding fruit and vegetable intakes (295). Two out of four studies found lower fruit and vegetable intake in deprived areas, whereas the other two reported no associations (295).

The inconsistent findings could be due to heterogeneity in study methods in terms of statistical adjustment, operationalization of neighbourhood deprivation and dietary assessment or due to true geographical differences. Both education and income have a positive association with diet quality (122–124). As Backholer et al. (236) reported, individual-level education tended to have a larger effect size on diet quality than area-level deprivation (236,237). As area-level deprivation is the aggregation of residents' SES, it is important to adjust for individual-level income and education when studying neighbourhood deprivation, especially for material deprivation to disentangle the effect of neighbourhood environment from that of individual SES (236,237). However, the two Australian studies did not account for this potential confounding effect, while the present study did.

Differences in the operationalization of neighbourhood deprivation makes it difficult to compare results. The majority of studies use a composite score, which is mainly based on education, income and employment (75,236,237,295). Some studies have included additional factors covering other dimensions of deprivation, such as family composition, marital status, the value of housing, car ownership, ethnicity, English language proficiency and residential overcrowding in the determination of the composite score (75,236,237). My study used similar indicators as in another Canadian research by McInerney et al (75). However, McInerney et al. considered material and social deprivation altogether in a single index rather than individually as in this study, which is an approach suggested by Pampalon et al. (77).While previous literature only focused on material deprivation or examined material and social deprivation in combination, the present study suggested that the two dimensions of deprivation differed in their relationships to diet quality and interaction with urbanicity.

Social deprivation differs from material deprivation as it captures marital status and family structure (lone-parenthood and living alone) of residents in the neighbourhoods. The inverse association between social deprivation and diet quality is consistent with previous evidence on social facilitation of diet. Mothers of single-parent families have been found to have poor diet quality due to limited resources to purchase foods (296). Non-partnered, lone-living adults aged 50 years and above who have infrequent contact with friends consume less varieties of fruit and vegetable (119). This population usually eats alone, which reduces their enjoyment of meals, decreases overall diet intake, and increases nutritional risk (297). The lack of social support for grocery shopping and preparation, as well as the absence of social control on eating behaviours from people's social networks may also lead to poor diet quality (297). In addition, lack of social support may hinder people's ability to cope with stress, which may in turn affect diet quality (297). Individual-level social factors other than marital status were not available in the Atlantic PATH and therefore, it is unclear whether and how neighbourhood social deprivation is associated with diet quality independent of individual social factors.

The urban-rural disparity in the association between material deprivation and diet quality indicated that "food deserts" are more common in rural areas than urban areas of Atlantic Canada, which may reflect the differences in food environment by urbanicity. A UK study reported that the distance to the nearest stores selling fresh produce is further in lower-income neighbourhoods than in higher-income neighbourhoods in rural areas (298). However, the reverse was true for urban areas (298). Several Canadian studies conducted in urban regions, such as Montreal and

Edmonton, have found that although access to fast food outlets increases with increasing deprivation, so does access to supermarkets (73,227,229). This may partly contribute to the finding that diet quality increased with increasing material deprivation with marginal significance in the present study. In addition, rural areas are characterized by poorer residents and higher food costs (299). Thus, people living in rural areas may be more likely to be impacted by a disadvantaged environment than people living in urban areas. However, the present study contradicts a study of 380 youths aged 12-16 years in Halifax, which revealed lower diet quality with increasing deprivation of their school areas in urban regions, whereas no association was found in suburban and rural regions (300). Direct comparison between studies is however limited by differences in the study population and neighbourhood of interest (school neighbourhood versus residential neighbourhood).

Similar to material deprivation, the relationship between population density and diet quality also varies by urbanicity. Although the association between population density and obesity has previously been reported, the present study is amongst the first to examine its relationship with diet (68,69). The SPOTLIGHT study conducted in 5 urban European regions showed that residential density alone does not have a significant impact on the intake of fruits, vegetables, soft drinks and sweets (301). However, residents in neighbourhoods with a low residential density and median income had lower vegetable intake compared to residents in neighbourhoods with a high residential density and median income (301). In the present study, population density and material deprivation do not have a synergistic effect; however, population density significantly interacted with urbanicity, whereby diet quality increased with population density in rural areas but decreased with population density in urban areas.

The underlying mechanisms for the urban-rural disparities remain unclear. The positive association between population density and diet quality in rural areas is in line with the hypothesis, as high population density may be associated with higher land use mix and greater access to food stores (70,75,302). The inverse association in urban areas may be explained by the small predefined neighbourhoods and individual variation in the utilization of food stores. Neighbourhoods defined by disseminations areas were small in urban regions due to a generally high population density. Therefore, grocery shopping may take place in neighbouring or more distant areas, such as places where people go to work or school and where people engage in recreational activities. Within a given food environment, people may also vary in where and how they use food stores. For example, one study showed that low-income families in urban areas reported travelling further for grocery shopping rather than going to the closest grocery stores to access more affordable food (303).

5.3.2 Strengths and limitations

A strength of the study is that it makes the effort to disentangle the association between diet quality and neighbourhood characteristics from the effect of individual-level SES by adjusting for individual-level education and income. However, the use of the 2011 NHS as one of the data sources for neighbourhood deprivation is a limitation. The voluntary nature of the survey may lead to non-response bias. For example, as indicated previously, people who have a household income at the extremes are less likely to provide income information (304). Consequently, the mean household income may be underestimated for the least deprived neighbourhoods, or overestimated in the most deprived areas. The misclassification of neighbourhood deprivation may contribute to an underestimation of the difference in HEI across deprivation tertiles. However, the 2011 census and NHS were the best and most representative sources of neighbourhood environment data during the data collection period of this study, which was from 2009 to 2015. Other censuses were collected in 2006 or before or in 2016 or after. Another limitation is the use of dissemination areas to estimate neighbourhoods, which may not represent what residents perceive. The size of self-defined neighbourhoods by residents varies with individual-level and area-level characteristics, such as age, gender, education, length of residence and population density (305). In addition, depending on the places where people engage in daily activities (e.g. work, school, recreation) and the time spent, places other than home environment might also influence dietary behaviours. Future studies can explore how to use self-defined neighbourhood in large-scale studies.

5.3.3 Implication

The study has implications for nutrition promoting strategies and policies to reduce dietary inequalities. In addition to nutrition interventions targeting individual behavioural changes, it is important to highlight the need for interventions targeting structural environment as well because this study showed that the environment where people live may influence their dietary quality independent of individual-level factors (306). Although the magnitude of difference in diet quality by neighbourhood characteristics was small, strategies aimed at changing the neighbourhood environment can impact a large population.

Intervention efforts should include all neighbourhoods due to the generally low dietary quality, but more emphasis may be warranted in areas where residents have lower diet quality, such as more materially deprived or less densely populated neighbourhoods in rural areas, less materially deprived or more densely populated neighbourhoods in urban areas, and more socially deprived areas regardless of urbanicity. Rural areas may deserve more attention as the lower diet quality in deprived areas may indicate poorer access to healthy and affordable foods, which may amplify individual disadvantages, a phenomenon known as “deprivation amplification” (307).

Previous evidence has shown that community interventions and policy approaches at the neighbourhood level may be effective including increasing the availability of fresh produce and healthy foods, providing subsidies for healthy foods, offering community meal and food assistance programs to encourage healthy eating (308–310). Research on mediators of the association between neighbourhood characteristics and diet quality is required for a better understanding of the underlying mechanisms to help design and prioritize interventions aimed at reducing diet and health inequalities.

5.4 Additional strengths and limitations

In addition to the aforementioned strengths and limitations specific to each research question, there are some that are common to the entire study. First, the study involves a large number of participants from diverse neighbourhoods of all Atlantic provinces, which increases the generalizability of findings to this region. The Atlantic provinces according to National data have a higher incidence of cancer and higher incidence of unhealthy behaviours including smoking, obesity and low fruit and vegetable consumption. Studying relationships between diet, obesity and cancer in this population is thus particularly important. Second, the use of HEI allows the assessment of overall diet quality. Based on the amount and types of foods and beverages consumed, the HEI measures adherence to the EWCFG, which provides a better description of diet quality than fruit and vegetable intake. Fruits and vegetables are commonly used as an indicator of diet quality due to their ease of measure but are not as strongly linked to health outcomes including cancer risk as other diet components (e.g. processed meat) or overall diet. Third, multiple imputation was used to handle missing data, which offers advantages over complete-case analysis and single imputation (e.g. mean imputation). Compared to complete-case analysis, multiple imputation maintains the full sample and statistical power by filling in missing values; it also reduces the potential selection bias from complete case analysis when data are not missing completely at random. Compared to single imputation, multiple imputation allows uncertainty in the imputed values by creating multiple completed datasets. Other strengths of the study include the statistical models, which considered the potential geographical clustering of observations, as well as the simultaneous analysis of individual- and neighbourhood-level variables. The analyses using covariate adjustment as in this study have an advantage over the analyses matched on covariates because this type of analyses retains the full sample and provides more generalizable results.

However, there are a few limitations of the study that need to be considered for future research. First, the cross-sectional study design makes it difficult to infer temporal relationship and causality. As all variables were measured at the same time, it is unclear whether there were any dietary changes among cancer survivors and if so, whether they preceded or were subsequent to diagnosis. The diet-obesity association is also subject to reverse causality. With respect to the analysis of neighbourhood environment, it is possible that neighbourhood environment influences diet quality or that people who have a healthier diet select where they live based on their preference on neighbourhood characteristics.

Secondly, the study is susceptible to selection bias. Participants were predominately female and of white ethnicity, which is typical of volunteer cohort studies. Compared to the general population aged 35 to 69 years old in Atlantic Canada from the 2011 Canadian Census, the study participants were more likely to be females, have a higher education and income, have a non-white ethnicity and reside in Nova Scotia, leading to potential selection bias (243). Similarly, compared to excluded participants with missing information about HEI or cancer diagnosis, participants who were included in the analytic sample with complete data were more likely to live with a partner, have a higher income and live in Nova Scotia, and less likely to be underweight or obese. Based on results from this study and previous studies, the differences in marital status, income, weight status and residential regions may suggest differences in diet quality between the included and excluded participants as well (50,118,123). The differences between study participants and non-participants and differences between respondents and non-respondents of diet and cancer questions may both lead to selection bias. The over-representation of participants by Nova Scotians reflects increased completion of the questionnaire at the non-mobile assessment centre in Halifax and may result in reduced generalizability of findings to other areas of the Atlantic provinces.

Most variables aside from body composition measures were self-reported data which are prone to reporting bias. For example, self-reported health conditions, including cancer, may lead to misclassification of cancer cases to controls or occasionally vice versa (311). People also tend to overreport their physical activity levels, overreport intake of healthy foods and underreport intake of energy and unhealthy foods due to social desirability, which is especially common among obese people (179,312). As mentioned earlier, although misreporting may attenuate or reverse the relationship between diet and obesity (291,292), there is also evidence showing that adjusting for misreporting error did not alter the direction and significance of the association between diet quality scores and obesity (102,283). Garriguet also indicated that misreporting only minimally affect the Canadian HEI scores (99). It is important to note that the Canadian HEI is not consistently correlated with energy intake (99,100). Thus, although energy intake is not available in this study, it is unclear how misreporting or energy intake would affect the HEI scores and corresponding associations.

The HEI used in this study also has other limitations. It is not directly comparable to other US and Canadian HEI indices as the scoring scheme was modified from the Canadian HEI due to fewer dietary questions being included in the Atlantic PATH questionnaire. The majority of the HEI scores used in the present study are assigned to the amount of foods consumed for the adequacy and moderation components, while one sixth of the total HEI scores (10 points) are assigned to the types of food consumed or the healthy dietary behaviours in line with EWCFG directional statements for healthy eating (e.g. whole fruit versus fruit juice, whole grains versus refined grains or low-fat versus high-fat dairy). As with the Canadian HEI, it is based on age- and sex-specific recommendations instead of recommendations per 1000 calories as in the US HEI. This may reflect that the HEI is based on current guidelines in EWCFG which is in turn largely focusing on meeting nutrient requirements rather than the role of diet in obesity and chronic disease prevention (313). In practice, the type and amount of food and nutrient density in one's diet are important for health and energy balance. However, the relative importance of the type versus the amount has not been quantified and therefore, the appropriate weighting in the construction of the HEI is unknown. Secondly, one of the great challenges in nutrition research, is the variability in what constitutes a 'healthy diet'. EWCFG has been criticized by some calling it 'obesogenic' and is in the process of being revised (313). It is possible that my findings may have differed if an alternative measure of healthy eating was used. However, as the HEI reflects the current national guidelines for healthy eating in Canada, it was among the best available tools to measure overall diet quality for examining the research questions. The development of a new HEI should be considered in future research to include the updated scientific evidence in the anticipated release of EWCFG. Furthermore, the validity and reliability of the HEI used in the present study have not been formally assessed. However, it successfully represents a broad range of recommendations from EWCFG, suggesting content validity. Also, it provides a relative scale to compare diet quality. Better diet quality has been observed in females, people with higher income and education, non-smokers and physically active people in this study, indicating construct validity.

Grouping the lower three quartiles of HEI into a single group (i.e. low-to-intermediate diet quality) may be a limitation as it subsumes a great amount of variability within the group. However, a sensitivity analysis omitting the intermediate HEI groups and comparing the lowest HEI quartile to the highest quartile in the GLMMs did not change the direction of relationships. The significance did not materially change for most associations, except that cancer survivors were found to have higher odds of high diet quality compared to non-cancer controls, people with high TF% had higher odds of diet quality compared to people with low-to-intermediate TF% and people living in the most dense areas had lower odds of high diet quality compared to those living in the least dense areas. As the results were similar with both approaches and omitting the second and third quartile drastically reduced the sample size, the analyses remained focusing on comparing low-to-intermediate diet quality with high diet quality.

Lastly, the study used the forward sortation areas (FSA) as the unit of clusters for the multi-level models to account for the potential nested data structure. FSAs are specific areas derived from the geographic system designed for mail delivery versus administrative areas (e.g. census division) that are defined by Statistics Canada and generally correspond to regional municipalities, counties, districts and regions. Both measures may not accurately reflect population clusters and variability between clusters. However, the cluster unit mainly influences the random effect from the multi-level models, which showed unexplained variation at the area level after controlling for explanatory variables and is not the main effect of interest. Instead, the present study focused on the interpretation of the fixed effect shown by the coefficients of explanatory variables (e.g. neighbourhood deprivation, population density).

5.5 Conclusion

The present study indicates that cancer survivors in the Atlantic Provinces have a better diet quality than non-cancer controls. Due to the small difference between the two groups and large room for diet improvements for both, the study highlights the need for dietary interventions, especially among cancer survivors, as they are at a higher risk for chronic conditions and mortality (4,6). Diet recommendations and support should be provided near diagnosis when cancer survivors may be more receptive to diet improvement and in frequent contact with healthcare providers and continued into long-term survivorship care to encourage maintenance of a healthy diet.

Diet quality was not independently associated with obesity in the present study, suggesting that other factors like physical activity are also integral parts of obesity and health promotion efforts. However, a large body of literature has consistently shown that diet is an important component of body weight, and our results should not be taken as evidence to the contrary (50,164,201,279–281). Dietary support for cancer survivors is especially important as both unhealthy diet and obesity are risk factors for additional adverse health outcomes.

Interventions are more likely to be effective if they involve individuals, communities and policy makers. The present study provided evidence that neighbourhood social deprivation had inverse association with diet quality. In rural areas, there was lower diet quality in neighbourhoods with increasing material deprivation and decreasing population density, while the reverse was true for urban areas. Intervention programs concerning neighbourhood food environment should be targeted to these at-risk communities, especially the deprived and less dense rural areas where people with low SES may have poor access to healthy and affordable foods. From a policy perspective, further research is warranted to understand the facilitators and barriers of healthy eating in urban and rural neighbourhoods separately to prioritize policies supporting healthy food choices.

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Appendices

Appendix A

A.1 IPAQ cutoffs for physical activity levels.

The table below shows the cutoffs in the IPAQ scoring protocol to categorize physical activity.

Physical activity categories	**Criteria**
Low	• No activity is reported *OR* • Some activity is reported but not enough to meet Categories "moderate" or "high".
Moderate	Any one of the three criteria below: • 3 or more days of vigorous activity of at least 20 minutes per day *OR* • 5 or more days of moderate-intensity activity and/or walking of at least 30 minutes per day *OR* • 5 or more days of any combination of walking, moderate-intensity or vigorous intensity activities achieving a minimum of at least 600 MET-minutes/week.
High	Any one of the two criteria below: • Vigorous-intensity activity on at least 3 days and accumulating at least 1500 MET-minutes/week *OR* • 7 or more days of any combination of walking, moderate- or vigorous-intensity activities accumulating at least 3000 MET-minutes/week

A.2 Summary of missing data

This table presents the number and percentage of missing data for variables in the final analytic sample.

Variables	Missingness N (%)	Variables	Missingness N (%)
Dependent variable		**Covariates**	
HEI	0 (0)	Age	0 (0)
Independent variables		Sex	0 (0)
Cancer status	0 (0)	Education	67 (0.34)
BMI (Bio-impedance)	7033 (35.21)	Income	1138 (5.70)
BMI (self-reported)	10045 (50.29)	Marital status	42 (0.21)
Waist circumference	7319 (36.64)	Ethnicity	1276 (6.39)
Hip circumference	7343 (36.76)	Smoking status	171 (0.86)
Waist-to -hip ratio	7348 (36.79)	Alcohol consumption	108 (0.54)
Body fat percentage	7024 (35.17)	Physical activity	822 (4.12)
Fat mass	7056 (35.33)	Self-perceived health	66 (0.33)
Fat-free mass index	7102 (35.56)	Myocardial infarction	131 (0.66)
Trunk fat mass	11525 (57.70)	Diabetes	194 (0.97)
Trunk fat percentage	11552 (57.84)	Urbanicity	0 (0)
Material deprivation	0 (0)	Province	0 (0)
Social deprivation	0 (0)	FSA	0 (0)
Population density	0 (0)		

A.3 HEI component scores

This table presents the mean HEI component scores and standard deviations for the first five items of the HEI scoring scheme and shows the percentages of participants meeting healthy eating recommendations for the last ten items.

Component	**Mean (SD)**
Vegetables and fruit	6.75 (2.78)
Grain products	4.32 (2.38)
Milk and dairy products	6.74 (3.26)
Meat and alternatives	8.95 (2.09)
Snack/dessert/non-diet soft drink	5.63 (3.15)
	%
Eat at least one serving of dark green vegetables each day	75.55
Have vegetables and fruit servings more than juice	93.99
Make at least half of grain products whole grain each day	81.53
Do not eat bread with oil products	10.68
Drink lower fat milk or milk alternatives	85.22
Have meat alternatives such as beans, lentils, and tofu	30.13
Eat fish	38.83
Do not eat saturated fat or its products	77.99
Never or rarely season food with soy sauce or fish sauce at the table	79.80
Never or rarely add salt to food at the table	66.26