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Investigating the impact of dietary guidelines transition on cardiometabolic risk profile: a forensic analysis using diet quality metrics

Ayesha Sualeheen[1], Ban-Hock Khor[2], Jun-Hao Lim[3], Gaiyal Viliy Balasubramanian[4], Khun-Aik Chuah[5], Zu-Wei Yeak[5], Karuthan Chinna[6], Sreelakshmi Sankara Narayanan[7,8], Kalyana Sundram[9], Zulfitri Azuan Mat Daud[3,10] & Tilakavati Karupaiah[7,8]✉

Evaluating dietary guidelines using diet quality (DQ) offers valuable insights into the healthfulness of a population's diet. We conducted a forensic analysis using DQ metrics to compare the Malaysian Dietary Guidelines (MDG-2020) with its former version (MDG-2010) in relation to cardiometabolic risk (CMR) for an adult Malaysian population. A DQ analysis of cross-sectional data from the Malaysia Lipid Study (MLS) cohort (*n* = 577, age: 20-65yrs) was performed using the healthy eating index-2015 (HEI-2015) framework in conformation with MDG-2020 ($MHEI_{2020}$) and MDG-2010 ($MHEI_{2010}$). Of 13 dietary components, recommended servings for *whole grain*, *refined grain*, *beans and legumes*, *total protein*, and *dairy* differed between MDGs. DQ score associations with CMR, dietary patterns and sociodemographic factors were examined. Out of 100, total DQ scores of MLS participants were 'poor' for both $MHEI_{2020}$ (37.1 ± 10.3) and $MHEI_{2010}$ (39.1 ± 10.4), especially among young adults, males, Malays, and those frequently 'eating out' as well as those with greatest adherence to Sugar-Sweetened Beverages pattern and lowest adherence to Food Plant pattern. Both metrics shared similar correlations with CMR markers, with $MHEI_{2020}$ exhibiting stronger correlations with WC, BF%, TG, insulin, HOMA2-IR, and $_{small}$LDL than $MHEI_{2010}$, primarily attributed to reduced *refined grain* serving. Notably, participants with the highest adherence to $MHEI_{2020}$ scores exhibited significantly reduced odds for elevated TG (AOR 0.44, 95% CI 0.21–0.93, *p* = 0.030), HOMA2-IR (AOR 0.44, 95% CI 0.21–0.88, *p* = 0.022), and hsCRP (AOR 0.54, 95% CI 0.31–0.96, *p* = 0.040, compared to those with the lowest adherence. Each 5-unit increase in $MHEI_{2020}$ scores reduced odds for elevated BMI (− 14%), WC (− 9%), LDL-C (− 32%), TG (− 15%), HOMA2-IR (− 9%) and hsCRP (− 12%). While $MHEI_{2020}$ scores demonstrated better calibration with CMR indicators, the overall sub-optimally 'poor' DQ scores of this population call for health promotion activities to target the public to achieve adequate intake of healthful *fruits*, *non-starchy vegetables* and *whole grain*, and moderate intake of *refined grain*, *added sugar* and *saturated fat*.

[1]Institute for Physical Activity and Nutrition, School of Exercise and Nutrition Sciences, Deakin University, Geelong 3220, Australia. [2]Faculty of Food Science and Nutrition, University Malaysia Sabah, 88400 Kota Kinabalu, Malaysia. [3]Department of Dietetics, Faculty of Medicine and Health Sciences, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia. [4]Dietetics Program, Faculty of Health Sciences, University Kebangsaan Malaysia, 50300 Kuala Lumpur, Malaysia. [5]Nutrition Program, Faculty of Health Sciences, University Kebangsaan Malaysia, 50300 Kuala Lumpur, Malaysia. [6]Faculty of Business and Management, UCSI University, Cheras, 56000 Kuala Lumpur, Malaysia. [7]School of Biosciences, Faculty of Health and Medical Sciences, Taylor's University, 47500 Subang Jaya, Selangor, Malaysia. [8]Food Security and Nutrition Impact Lab, Taylor's University, 47500 Subang Jaya, Selangor, Malaysia. [9]Malaysia Palm Oil Council, Menara Axis, 46100 Petaling Jaya, Selangor, Malaysia. [10]Department of Dietetics, Hospital Sultan Abdul Aziz Shah, Universiti Putra Malaysia, 43400 Serdang, Malaysia. ✉email: tilly_karu@yahoo.co.uk

Dietary guidelines are policy statements serving to guide populations towards making improved dietary choices specific to attaining population nutritional goals. This purpose has evolved since the early 20th century, first as a guide to income-challenged households *vis-à-vis* the great depression and food shortages from the world wars to today's preventative health role[1] to combat rising global mortality attributed to obesity and the non-communicable diseases (NCDs)[2,3]. Specifically high intakes of refined starches, saturated and trans fatty acids and sugars alongside low intakes of fibre and antioxidants are suggested to contribute significantly to Disability Adjusted Life Years from obesity and the NCDs[4] and the task of country-specific dietary guidelines is to minimise these dietary risks.

With the development of food-based dietary guidelines, their language has evolved from the rigid 'avoid' to user friendly terms of 'eat more' or 'eat less' for specific food elements. These terms govern recommendations as per moderation or adequacy, while aiming to address the prevention of obesity and NCDs, which are even plaguing the low-to-middle income countries[5,6]. Quantifying 'moderation' or 'adequacy' of these food elements in terms of energy equivalents or servings is challenging while considering the evidence base for their rationale. This is observed from the debate surrounding recommendations on fat and carbohydrate intake[7,8] despite the shift to food-based guidelines in the United States[9–12] and elsewhere globally[13]. A crucial question arises: *What is the evidence supporting these guidelines to justify the specific moderation of elements like refined grain, saturated fats, added sugar or sodium as well as the imperative for the 'adequacy' of food components such as whole grain, fruits, and vegetables?* This question is especially relevant as Western dietary recommendations have often been adopted throughout Asia without a regional evidence basis.

Two versions of the Malaysian Dietary Guidelines (MDG), the MDG-2010 and the MDG-2020, have adopted the global trend towards food-based approaches. However the new MDG-2020 compared to the earlier version recommends reduction of cereals and grains at all energy levels (by one serving) by choosing preferably whole grain; and increasing total protein servings relative to animal and plant proteins (by ½ serving each) unique to the TEI of 1500kcal but not for other energy levels[14,15]. These changes in the MDG-2020 were intentioned to address the rise of the diet-related NCDs in Malaysia. The country's gross domestic product was recently declared to be impacted by NCDs with almost 33% of Malaysians suffering from the disease burden with nearly 62.1% of cardiovascular disease and 39.7% of diabetes burden attributed to unhealthy diets[16]. The country's latest National Health and Morbidity Survey (2023) indicates prevalence of overweight and obesity (32.6 + 21.8%), diabetes (15.6%), hypercholesterolemia (33.3%), and hypertension (29.2%) show increasing trends from previous years[17]. *Would the revised food-based recommendations in the MDG-2020 calibrate to NCDs risk reduction in the Malaysian population?* To answer this question, we undertook a novel forensics approach to fundamentally apply diet quality (DQ) metrics as a scientific principle and cardiometabolic risk (CMR) indicators and dietary patterns (DPs) as evidence to justify decision-making in the revised MDG recommendations. The closest example described is the forensic taxonomy in mobile health applications to classify DQ of a person as balanced, unbalanced, nearly balanced, and nearly unbalanced based on National Health and Nutrition Examination Survey (NHANES) datasets[18].

We chose to construct DQ to test the Malaysia Lipid Study (MLS) cohort's adherence to dietary guidelines using the healthy eating index (HEI) which is an *à priori* approach adapted to defined dietary guidelines[19,20]. Originally conceptualised for the United States, the HEI allows adaptations to country-specific dietary guidelines to accommodate cultural and sociodemographic disparities in dietary practices[20]; and as dietary guidelines get revised, the HEI tool may be revised accordingly as observed for the United States every five years[21–24]. The HEI and its iterations are now extensively used in nutrition epidemiological studies specifically relating to the NCDs[19,25–27].

We therefore transformed food intake reported by the disease-free MLS population cohort to HEI scores derived from the current MDG-2020[15] and the former MDG-2010[14] benchmarked to the HEI-2015 tool[24]. Datasets for CMR indicators[28] and habitual DPs[29] were also available from the MLS cohort. Beyond metabolic syndrome (MetS) criteria, CMR indicators comprehensively included assessment for inflammation, insulin resistance and lipoprotein subclasses notably the small and large dense LDL particles which are better predictors for atherogenicity than plasma LDL-C. It is expected that findings from this forensic analyses will guide stakeholders to restructure the next scheduled MDG in tandem with a population's CMR indicators and public health's objective to reduce risks for diet-related NCDs.

Results

Metrics of HEI indices

DQ scores (mean ± SD) of the MLS population as per the $MHEI_{2010}$ and $MHEI_{2020}$ metrics are presented in Table 1, with overall scores been significantly different respectively ($MHEI_{2010} = 39.1 \pm 10.4$ *vs* $MHEI_{2020} = 37.1 \pm 10.3$, $p < 0.001$). These differences were mediated by:

- $MHEI_{2020}$ scores lower than the $MHEI_{2010}$ scores for the *beans and legumes* sub-component ($p < 0.001$), were attributed to MDG-2020's increased protein serving recommendation. This difference also reflected in significantly lower *total protein scores* ($p < 0.001$).
- Similarly, *whole grain* and *refined grain* scores were significantly different between $MHEI_{2020}$ and $MHEI_{2010}$, reflecting the lower serving recommendations of the MDG-2020 compared to MDG-2010.
- A reverse scoring trend observed for *refined grain* scores, was attributed to the lower cut-off limit set by the MDG-2020 ($p < 0.001$).

Components	Maximum points	Intake per nutrient density (per serving)	Score (mean ± SD)	
			$MHEI_{2010}$	$MHEI_{2020}$
Adequacy				
Total fruit	5	0.28 ± 0.34	1.2 ± 1.4	
Whole fruit	5	0.26 ± 0.33	1.1 ± 1.4	
Non starchy vegetables	5	0.48 ± 0.45	1.4 ± 1.2	
Beans and legumes	5	0.43 ± 0.50[†] 0.21 ± 0.25[††]	2.6 ± 2.0^{a}	1.7 ± 1.6^{a}
Whole grain	10	0.17 ± 0.32	1.2 ± 2.0^{b}	1.4 ± 2.4^{b}
Dairy*	10	0.30 ± 0.43	2.7 ± 3.1^{c}	2.5 ± 3.0^{c}
Total protein food**	5	1.61 ± 0.57[†] 1.4 ± 0.51[††]	4.2 ± 0.9^{d}	3.9 ± 1.1^{d}
Seafood	5	0.37 ± 0.34	2.7 ± 1.9	
Fatty acids (PUFAs + MUFAs/SFAs)	10	1.25 ± 0.27	2.6 ± 2.2	
Moderation				
Refined grain	10	2.73 ± 0.64	2.0 ± 2.7^{e}	0.7 ± 1.9^{e}
Sodium (mg/day)	10	3009 ± 1036	5.6 ± 3.7	
Saturated fats (% of energy)	10	14.07 ± 2.68	4.0 ± 3.1	
Added sugar (% of energy)	10	9.31 ± 4.82	7.8 ± 3.5	
Total score	100		39.1 ± 10.4^{f}	37.1 ± 10.3^{f}
Total score categorisation, % (n)				
Good (> 80)			0.0 (0)	0.0 (0)
Need improvement (51–80)			11.8 (68)	9.2 (53)
Poor (< 51)			88.2 (509)	90.8 (524)

Table 1. Dietary intake and DQ scores for $MHEI_{2010}$ and $MHEI_{2020}$. High intake in moderation components interprets lower scores and vice versa. *gm* grams, kcal kilocalories, *MUFA* monounsaturated fatty acids, *PUFA* polyunsaturated fatty acids, *SAFA* saturated fatty acids, *ser*. serving. *$MHEI_{2010}$ score for dairy was calculated based on 7g protein per serving while $MHEI_{2020}$ score for dairy was calculated based on 8g protein per serving;**The Total protein component includes meat, poultry, seafood, eggs, beans and legumes; [†]refers to 7gm of protein per serving of legume, [††]refers to 14 gm of protein per serving of legume. Paired *t*-test was used to compare scoring between the component and total scores of $MHEI_{2010}$ and $MHEI_{2020}$. Superscript letters (a,b,c,d,e,f) indicate statistically significant differences between groups. Scores sharing the same superscript indicate significant different from each other. All values are in mean ± SD unless otherwise stated.

Separately as components for *fatty acid ratio* and *saturated fat* remained the same for both MDGs, we observed scores significantly differed between palm oil and non-palm oil users (data not shown) per *fatty acid ratio* (2.4/10 *vs* 3.3/10) and *saturated fat* (3.9/10 *vs* 4.6/10), respectively.

DQ categorization

According to the reference HEI score categorisation[24], none of the MLS participants rated a 'good' diet score of >80 when rated by either HEI metrics (Table 1). Majority of the participants rated 'poor' DQ whether by $MHEI_{2010}$ (88.2%) or by $MHEI_{2020}$ (90.8% scores). A small segment was in the 'need improvement' category whether rated by $MHEI_{2010}$ (11.8%) or by $MHEI_{2020}$ (9.2%).

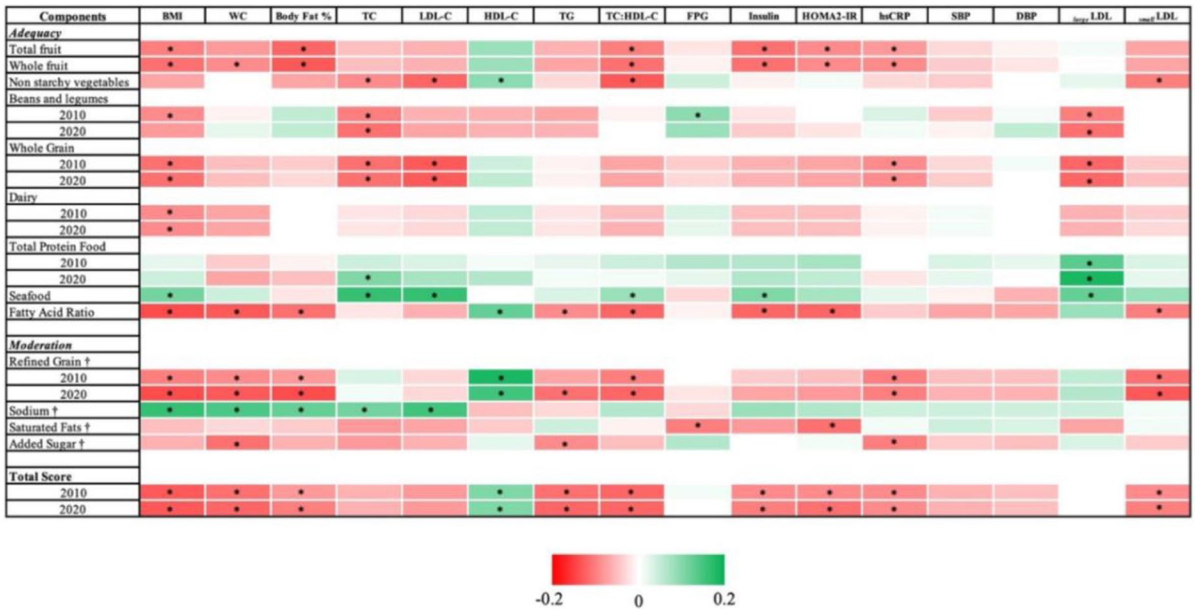
Associations of MHEI indices with cardiometabolic risk (CMR) indicators

Correlation matrices between MHEI metrics and CMR parameters are indicated in Fig. 1 with detailed values provided in Supplementary Table S3.

Overall, total DQ score of $MHEI_{2020}$ shared similar but stronger significant correlations with the CMR markers than the total DQ score of $MHEI_{2010}$ (Supplementary Table S3) that were negative with BMI (rho_{2020} = – 0.13 *vs* rho_{2010} = – 0.13), WC (rho_{2020} = – 0.12 *vs* rho2010 = – 0.11), % of body fat (rho_{2020} = – 0.10 *vs* rho_{2010} = – 0.08), TG (rho_{2020} = – 0.12 *vs* rho_{2010} = – 0.11), TC:HDL ratio (rho_{2020} = – 0.12 vs rho_{2010} = – 0.12), insulin (rho_{2020} = – 0.10 *vs* rho_{2010} = – 0.09), HOMA2-IR (rho_{2020} = – 0.11 *vs* rho_{2010} = – 0.09), hsCRP (rho_{2020} = – 0.09 *vs* rho_{2010} = – 0.09) and $_{small}$LDL (rho_{2020} = – 0.10 *vs* rho_{2010} = – 0.09); whilst positive associations were only observed with HDL-C (rho_{2020} = 0.10 *vs* rho_{2010} = 0.10).

Where recommendations were consistent between MDGs, scores for the adequacy and moderation components were observed to share significant associations with some CMR indicators. These related in terms of adequacy to:

- Both total fruit and whole fruit scores were inversely associated with BMI, % body fat, TC:HDL-C ratio, insulin, HOMA2-IR and hsCRP, whilst whole fruit scores alone were negatively associated with WC.
- Non-starchy vegetables scores elicited negative associations with TC, LDL-C, TC:HDL-C ratio and $_{small}$LDL but associated positively with HDL-C.



Abbreviations: BMI, body mass index; DBP, diastolic blood pressure; FPG, fasting plasma glucose; HDL, high density lipoprotein; HOMA2-IR, homeostatic model assessment of insulin resistance; hs-CRP, high-sensitivity C-reactive protein; LDL-C, low density lipoprotein; $_{small}$ LDL, *small* low density lipoprotein particles; $_{large}$ LDL, *large* low density lipoprotein particles; SBP, systolic blood pressure; TC, total cholesterol; TC:HDL-C, total cholesterol : high density lipoprotein ratio; TG, triglycerides; WC, waist circumference

Statistical data presented in correlation coefficients. Partial correlation using Spearman's rho adjusted for age and gender.

*Denotes significant associations ($p<0.05$)

† Component that is recommended to be consumed in moderation. Therefore, higher intakes relate to lower scores and lower intakes relate to higher scores.

Fig. 1. Heatmap analysis of MHEI correlations with CMR parameters.

- Seafood scores directly associated with BMI, TC, LDL-C, TC:HDL-C ratio, insulin and $_{large}$LDL.
- Fatty acid ratio scores were negatively correlated with BMI, WC, % body fat, TG, TC:HDL-C ratio, insulin, HOMA2-IR, and $_{small}$LDL but positively with HDL-C.

In terms of moderation:

- Sodium scores were positively associated with BMI, WC, % body fat, TC and LDL-C, whereas inverse associations of *saturated fat* with FPG and HOMA2-IR occurred.
- *Added sugar* scores which were moderated to the WHO 2015 benchmark criteria correlated inversely to WC, TG and hsCRP.

Contrarily, when recommendations changed between MDGs, specific component associations with CMR indicators related to:

- *Bean and legumes* scores as per $MHEI_{2010}$ being inversely associated with BMI and positively with FPG, but this impact was lost with the $MHEI_{2020}$ metrics.
- *Total protein* scores by both MHEIs positively associated with $_{large}$LDL. To note, higher *total protein* scores as per $MHEI_{2020}$, showed positive associations towards TC.
- *Whole grain* scores by both indices having consistent negative associations with BMI, TC and LDL-C, hsCRP, and $_{large}$LDL.
- Dairy scores consistently indicating negative correlation with BMI irrespective of MHEI indices.
- Refined grain with both indices having negative associations towards BMI, WC and % body fat, hsCRP and $_{small}$LDL but positive associations with HDL-C. To note, lower *refined grain* cut-offs with $MHEI_{2020}$ were indirectly associated with TG but this impact was not observed with higher cut-off limits as per the $MHEI_{2010}$.

Dietary pattern indicators of HEI metrics

Individual component and total scores of both MHEIs against tertiles of adherence behaviours, highest (T3) to lowest (T1), by the MLS cohort are presented in Table 2 for Sugar-Sweetened Beverages, Chinese Traditional, Home Food, Plant Food dietary patterns[29].

Total scores of $MHEI_{2010}$ and $MHEI_{2020}$ shared similar linear trends for the Sugar-Sweetened Beverages and Plant Food patterns (both $P_{trend} < 0.001$), whereby the highest scores, 44.45 ± 11.48 and 42.55 ± 11.29 respectively, corresponded to the highest adherence behaviour (T3) towards the Plant Food pattern. Whereas the lowest scores of 35.73 ± 9.98 and 33.4 ± 9.65 respectively corresponded with highest adherence behaviour (T3) towards the Sugar-Sweetened Beverages pattern. A decreasing linear trend of HEI metrics for adherence to the Chinese Traditional pattern (2010, $P_{trend} < 0.004$; 2020, $P_{trend} = 0.012$) was evident, whereas the Home Food pattern's HEI metrics appeared homogenous to adherence level (both $P_{trend} > 0.05$). For tertiles of individual component scores for these same dietary patterns, significant linear trends were mediated by:

- the Plant Food pattern achieved the highest adequacy scores for *total fruit*, *whole fruit*, *non-starchy vegetables*, and *fatty acids* when serving recommendations were similar for both HEI metrics, as well as elicited highest scores in moderating *refined grain* when recommendations changed between HEIs
- the Sugar-Sweetened Beverages pattern elicited the lowest score trends by adequacy for *total fruit*, *whole fruit*, *non-starchy vegetables*, and *fatty acids*; and as expected moderation of *added sugar* when serving recommendations were similar for both HEI metrics.
- the Home Food pattern benefited highest score trends for *seafood* adequacy as well as *saturated fat* and *added sugar* moderation where serving recommendations were similar for both HEI metrics. However, this pattern elicited consistently the lowest score trends for *whole grain* and *refined grain* for both HEIs.
- the Chinese Traditional pattern elicited the highest score trends for adequacy of *total protein* that were consistent by either HEI metrics, as well as benefited a high score trend in moderating *added sugar*. But this pattern elicited the lowest score trend for moderation of *sodium*.

AORs of cardiometabolic risk (CMR) indicators with HEI metrics

Logistic regression analysis to determine the adjusted odds ratio (AOR) with binary CMR indicators against quintiles of total $MHEI_{2010}$ and $MHEI_{2020}$ scores are presented in Table 3.

Of significance, MLS participants with total HEI scores in the highest quintiles (Q5) for both sets ($MHEI_{2010} = 54.8 \pm 6.83$, $p = 0.019$; $MHEI_{2020} = 52.7 \pm 6.93$, $p = 0.016$) were at 50% reduced risk for BMI ≥ 25 kg/m^2. Specific to only $MHEI_{2020}$ scores, participants in the 4th (AOR 0.42, 95% CI 0.20–0.90, $p = 0.030$) and 5th (AOR 0.44, 95% CI 0.21–0.93, $p = 0.030$) quintiles were at significantly lower risks for elevated TG ≥ 1.7 mmol/L. Furthermore, the risk for elevated HOMA2-IR ≥ 2.0 (AOR 0.44, 95% CI 0.21–0.88, $p = 0.040$) and hsCRP ≥ 1 mg/L (AOR 0.54 95% CI 0.31 – 0.96, $p = 0.040$) significantly decreased for Q5 scores specific to $MHEI_{2020}$.

Given the distinct associations between CMR factors and MDG_{2020} score, we further examined the impact of a 5-unit increase in $MHEI_{2020}$ scores on these variables using binary logistic regression analysis (Fig. 2). The likelihood for the largest reduction would be obtained for hypercholesterolemia risk (LDL-C ≥ 4.9 mmol/l) by 32% followed by a 15% risk lowering for dyslipidemia (TG ≥ 1.7 mmol/l), a 14% reduction for BMI ≥ 25, a 12% reduction in inflammation risk (hsCRP ≥ 1.0 mg/L) and a 9% decrease for increased WC (≥ 90 cm for men, ≥ 80 cm for women) as well as lowered risk of insulin resistance (HOMA2-IR ≥ 2.0).

Factors influencing $MHEI_{2020}$ scores

Sociodemographic and nutrient profiles of the MLS cohort were examined to understand their associations with achieving quintiles of $MHEI_{2020}$ total scores (Table 4). Increasing linear trends with increasing quintiles of HEI scores were influenced by increasing age and being female, and lesser frequency of eating out (all $p < 0.001$). Highly adherent behaviours (Q5) were associated with lowest intake of calories, carbohydrates, total fat, saturated fat, and sodium intakes (all $p < 0.001$). Adherence to DQ increased with Chinese and Indians but reduced with Malay ethnic groups. Income was not a factor influencing the metrics.

Discussion

The MDG transitioned to the food-based model from 2010[13] with the MDG-2010 and MDG-2020 in alignment with public health concerns to manage dietary risks for the development of NCDs[5,30,31]. But *how do these MDGs perform in relation to managing dietary risks related to NCDs?* We showed that DQ metrics generated for a population benchmarked to the MDG-2010 and MDG-2020 could not only be calibrated to targeted health goals but also facilitated a forensic evaluation of the efficacy of specific recommended food component servings towards CMR indicators. The MLS cohort was disease-free and representative of urbanicity and the multi-ethnic society of Malaysia with 70% living in cities[32]. The forensic approach in our study is novel because HEI individual component or total scores as arbitrated by the revised dietary guidelines were comprehensively tested against chronic disease risk, dietary behaviour and socioeconomic determinants.

With the application of HEI-2015 metrics[24] the MLS cohort's DQ elicited similar total scores by either $MHEI_{2020}$ (37.1 ± 10.3) or $MHEI_{2010}$ (39.1 ± 10.4), with no one achieving 'good' scores. In agreement, the NHANES populations' DQ assessment also reflected suboptimal scores (50.47 ± 0.17) categorized as 'poor' (< 51) and none achieving a 'good' DQ score > 80[33]. Moreover, this NHANES population was not disease-free as it included those on lipid lowering (20.1%), hypoglycemic (8.5%) and anti-hypertensive (31%) therapies alongside undergoing counselling for healthful diet behaviors. Comparatively, higher scores (61 to 79) have been reported for other urban Malaysian cohorts[34,35] but these studies used the HEI-1995[21] to develop their DQ metrics, whereas we had adopted the more stringent HEI-2015. Of critical importance, these studies also lacked assessment for the *fatty acid ratio* and *saturated fat* components.

The disparity between total MHEI scores for the respective MDGs was significant with 2.6 % more participants shifting to the 'poor' DQ (< 51) category with $MHEI_{2020}$ compared to $MHEI_{2010}$ scores for the same dietary intake profile. Our forensic analyses revealed only the MDG-2020 recommendations[16] comprehensively linked

Components	Tertiles	Sugar-sweetened beverage pattern	Chinese traditional pattern	Home food pattern	Plant food pattern
Adequacy components (higher score means higher intake)					
Total fruit	T1	1.46 ± 1.49†	1.16 ± 1.38	1.33 ± 1.57	0.29 ± 0.72†
	T2	1.14 ± 1.41	1.25 ± 1.50	1.12 ± 1.28	0.70 ± 0.48†
	T3	0.98 ± 1.22†	1.18 ± 1.29	1.13 ± 1.30	2.65 ± 1.33†
	P_{trend}	**0.002**	0.81	0.23	**< 0.001**
Whole fruit	T1	1.42 ± 1.49†	1.10 ± 1.36	1.26 ± 1.52	0.25 ± 0.66†
	T2	1.09 ± 1.37	1.20 ± 1.46	1.07 ± 1.25	0.64 ± 0.45†
	T3	0.88 ± 1.15	1.10 ± 1.25	1.06 ± 1.28	2.56 ± 1.32†
	P_{trend}	**< 0.001**	0.69	0.28	**< 0.001**
Non-starchy vegetables	T1	1.65 ± 1.36†	1.45 ± 1.27	1.35 ± 1.25	1.10 ± 1.16†
	T2	1.36 ± 1.2	1.41 ± 1.29	1.35 ± 1.16	1.21 ± 1.16†
	T3	1.19 ± 1.07	1.34 ± 1.12	1.50 ± 1.26	1.90 ± 1.21†
	P_{trend}	**0.001**	0.67	0.36	**< 0.001**
Beans and legumes					
2010	T1	2.67 ± 2.04	2.89 ± 2.01†	2.76 ± 1.96	2.48 ± 2.0
	T2	2.71 ± 1.99	2.30 ± 1.96†	2.58 ± 2.01	2.6 ± 1.95
	T3	2.39 ± 1.89	2.58 ± 1.92	2.43 ± 1.96	2.7 ± 1.97
	P_{trend}	0.22	**0.014**	0.27	0.52
2020	T1	1.96 ± 1.79	2.09 ± 1.74	1.93 ± 1.66	1.79 ± 1.74
	T2	1.92 ± 1.68	1.68 ± 1.73	1.90 ± 1.79	1.86 ± 1.70
	T3	1.69 ± 1.64	1.80 ± 1.63	1.74 ± 1.69	1.92 ± 1.69
	P_{trend}	0.22	0.05	0.50	0.75
Whole grain					
2010	T1	1.50 ± 2.44†	1.38 ± 2.18	1.61 ± 2.49†	0.95 ± 1.87
	T2	1.10 ± 1.82	1.21 ± 2.14	1.10 ± 1.86	1.25 ± 2.06
	T3	0.89 ± 1.74†	0.90 ± 1.74	0.77 ± 1.55	1.34 ± 2.18
	P_{trend}	**0.011**	0.07	**< 0.001**	0.13
2020	T1	1.82 ± 2.83†	1.71 ± 2.58	1.96 ± 2.91†	1.16 ± 2.16
	T2	1.38 ± 2.23	1.48 ± 2.52	1.37 ± 2.24	1.56 ± 2.50
	T3	1.12 ± 2.14†	1.14 ± 2.15	0.97 ± 1.94†	1.66 ± 2.64
	P_{trend}	**0.016**	0.07	**< 0.001**	0.08
Dairy					
2010	T1	2.63 ± 3.07	2.84 ± 3.23	3.00 ± 3.22	2.73 ± 3.11
	T2	2.80 ± 3.18	2.65 ± 3.10	2.92 ± 3.30	2.83 ± 3.27
	T3	2.80 ± 3.16	2.74 ± 3.09	2.30 ± 2.83	2.69 ± 3.05
	P_{trend}	0.82	0.84	0.06	0.91
2020	T1	2.42 ± 2.88	2.64 ± 3.09	2.77 ± 3.04	2.51 ± 2.95
	T2	2.58 ± 2.99	2.44 ± 2.91	2.69 ± 3.11	2.6 ± 3.07
	T3	2.59 ± 3.02	2.51 ± 2.88	2.12 ± 2.68	2.48 ± 2.89
	P_{trend}	0.81	0.80	0.07	0.92
Total protein food					
2010	T1	4.17 ± 0.98	4.23 ± 0.88	4.17 ± 1.00	4.23 ± 0.91
	T2	4.29 ± 0.88	4.00 ± 1.01†	4.17 ± 0.90	4.25 ± 0.88
	T3	4.14 ± 0.88	4.37 ± 0.83†	4.25 ± 0.86	4.12 ± 0.96
	P_{trend}	0.29	**< 0.001**	0.65	0.30
2020	T1	3.85 ± 1.11	3.84 ± 1.10	3.85 ± 1.16	3.94 ± 1.08
	T2	3.98 ± 1.04	3.69 ± 1.08	3.83 ± 1.04	3.92 ± 1.04
	T3	3.84 ± 1.03	4.13 ± 0.96†	3.98 ± 0.98	3.81 ± 1.06
	P_{trend}	0.38	**< 0.001**	0.37	0.45
Seafood	T1	2.77 ± 1.91	2.97 ± 1.91	2.58 ± 1.88†	2.81 ± 1.91
	T2	3.09 ± 1.87	2.64 ± 1.95	2.90 ± 1.83	2.89 ± 1.85
	T3	2.77 ± 1.81	3.01 ± 1.72	3.15 ± 1.86†	2.93 ± 1.84
	P_{trend}	0.14	0.09	**0.012**	0.78
Continued					

Components	Tertiles	Sugar-sweetened beverage pattern	Chinese traditional pattern	Home food pattern	Plant food pattern
Fatty acid ratio	T1	2.89 ± 2.63†	2.47 ± 2.26	2.71 ± 2.22	2.49 ± 2.03
	T2	2.59 ± 2.13	2.44 ± 2.30	2.41 ± 2.19	2.27 ± 2.00
	T3	2.33 ± 1.88	2.91 ± 2.14	2.69 ± 2.32	3.03 ± 2.59
	P_{trend}	**0.048**	0.74	0.36	**0.004**
Moderation components (higher score means low intake)					
Refined grain					
2010	T1	1.90 ± 2.82	2.30 ± 2.86	3.02 ± 3.21†	1.72 ± 2.36†
	T2	1.64 ± 2.48†	2.03 ± 2.80	1.82 ± 2.48†	1.88 ± 2.43
	T3	2.51 ± 2.79†	1.74 ± 2.49	1.17 ± 2.0†	2.49 ± 3.26†
	P_{trend}	**0.005**	0.13	**< 0.001**	**0.012**
2020	T1	0.71 ± 2.16	0.81 ± 2.15	1.24 ± 2.6†	0.41 ± 1.30
	T2	0.46 ± 1.52	0.72 ± 2.06	0.47 ± 1.51	0.44 ± 1.49
	T3	0.79 ± 1.93	0.44 ± 1.36	0.24 ± 1.03	1.13 ± 2.57†
	P_{trend}	0.21	0.14	**< 0.001**	**< 0.001**
Sodium	T1	5.90 ± 3.60	6.80 ± 3.46†	5.35 ± 3.62	5.69 ± 3.58
	T2	5.46 ± 3.72	5.87 ± 3.61†	5.94 ± 3.68	5.67 ± 3.79
	T3	5.48 ± 3.66	4.18 ± 3.44†	5.58 ± 3.68	5.49 ± 3.65
	P_{trend}	0.41	**< 0.001**	0.29	0.85
Saturated fat	T1	3.63 ± 3.07	4.38 ± 3.18†	3.45 ± 3.14	3.71 ± 2.87†
	T2	4.25 ± 3.07	3.55 ± 2.79†	3.94 ± 2.86	3.86 ± 3.16
	T3	4.20 ± 3.07	4.15 ± 3.20	4.71 ± 3.11†	4.52 ± 3.19†
	P_{trend}	0.09	**0.024**	**< 0.001**	**0.022**
Added sugar	T1	9.62 ± 1.28†	7.36 ± 3.88†	7.47 ± 3.72	7.43 ± 3.65
	T2	8.28 ± 3.13†	7.53 ± 3.58	7.47 ± 3.60	7.62 ± 3.54
	T3	5.36 ± 4.06†	8.36 ± 2.99†	8.32 ± 3.18	8.24 ± 3.32
	P_{trend}	**< 0.001**	**0.012**	**0.025**	0.06
Total scores					
2010	T1	42.00 ± 10.79	41.13 ± 10.67†	39.83 ± 11.43	35.66 ± 8.16
	T2	39.56 ± 9.69	37.85 ± 10.97	38.58 ± 10.28	37.45 ± 9.53
	T3	35.73 ± 9.98†	38.03 ± 9.47	38.88 ± 9.62	44.45 ± 11.48†
	P_{trend}	**< 0.001**	**0.004**	0.46	**< 0.001**
2020	T1	40.32 ± 10.59	39.00 ± 10.39†	37.48 ± 11.42	33.78 ± 7.95
	T2	37.79 ± 9.51	36.10 ± 11.03†	36.70 ± 10.10	35.47 ± 9.43
	T3	33.43 ± 9.65†	36.48 ± 9.25	37.36 ± 9.32	42.55 ± 11.29†
	P_{trend}	**< 0.001**	**0.012**	0.73	**< 0.001**

Table 2. Associations of dietary patterns with diet quality scores for $MHEI_{2010}$ and $MHEI_{2020}$. Data expressed as mean ± standard deviation. One-way ANOVA with Bonferroni test used for comparisons between diet quality scores and tertiles of dietary patterns. †Indicates significance within tertiles of dietary patterns. Significant values are in bold.

to both adiposity and CMR indicators with the highest quintile of $MHEI_{2020}$ scores linked to reduced risks for hypertriglyceridemia by 56%, insulin resistance by 45% and inflammation by 46%. Highest adherence to both MDGs (Q5) benefited a 50% reduced risk for increased BMI (≥ BMI 25) which is consistent with a systematic review that all versions of HEI scores are inversely linked to obesity[36] and specifically to the application of HEI-2015 metrics to large populations[33,37].

On an individual component basis, scores were similar between $MHEI_{2020}$ and $MHEI_{2010}$ when serving recommendations as per the respective MDGs did not change. Of relevance the plant food component provided vital evidence that higher scores for *total* and *whole fruit*, and *non-starchy vegetables* potentiated variously beneficial negative associations with BMI, WC, body adiposity, lipid profile, insulinemic and inflammatory status. It appears MDG recommendations for these healthful components are justified when considering minimal intake of plant foods as a dietary risk to promoting NCDs[31]. Of concern, suboptimal score trends were the norm for healthful foods such as *total* (1.2/5, 24%) and *whole fruit* (1.1/5, 22%), and *non-starchy vegetables* (1.4/5, 28%). Poorest scores for these food components associated with greatest adherence (T3) to the Sugar-Sweetened Beverages dietary pattern unlike the higher scores achieved by adherence to the Plant Food dietary pattern.

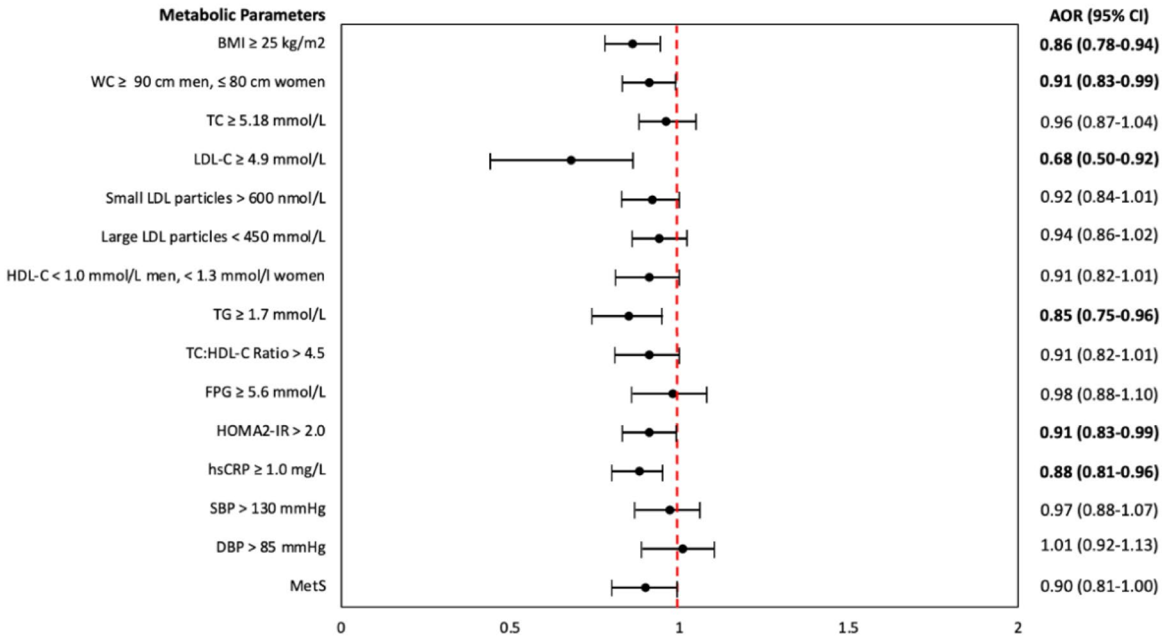
The choice of grains is critical in population health with the potential to moderate clinically relevant metabolic markers associated with development of obesity and NCDs[38]. Despite lower grain cut-off limits set for $MHEI_{2020}$ (3-5 servings of cereals, cereal-based products, and tubers) compared to $MHEI_{2010}$ (4 servings of cereal foods), expected beneficial associations were still elicited[33,38]. Indeed, the opposing effects of *whole grain* and *refined*

		Q1	Q2		Q3		Q4		Q5	
	$MHEI_{2010}$	**25.9 ± 3.96**	**33.2 ± 1.79**		**38.3 ± 1.75**		**43.3 ± 2.22**		**54.8 ± 6.84**	
Score range	**$MHEI_{2020}$**	**24.2 ± 4.03**	**31.3 ± 1.88**		**36.5 ± 1.66**		**41.3 ± 1.98**		**52.7 ± 6.93**	
CMR parameters	**MDG years**	**Reference**	**OR (95% CI)**	***p***	**OR (95% CI)**	***p***	**OR (95% CI)**	***p***	**OR (95% CI)**	***p***
BMI ≥ 25 kg/m²	2010	1	0.94 (0.55–1.59)	0.82	0.81(0.47–1.39)	0.45	0.93 (0.54–1.61)	0.81	**0.50 (0.28–0.89)**	**0.019**
	2020	1	0.70 (0.41–1.19)	0.19	0.93 (0.54–1.58)	0.78	0.60 (0 0.34–1.02)	0.06	**0.50 (0.28–0 0.88)**	**0.016**
WC ≥ 90 cm[a], ≥ 80 cm[b]	2010	1	1.30 (0.75–2.24)	0.34	0.98 (0.56–1.71)	0.95	1.43 (0.82–2.51)	0.20	0.69 (0.39–1.24)	0.22
	2020	1	0.88 (0.51–1.51)	0.64	1.21 (0.70–2.09)	0.50	0.79 (0.45–1.38)	0.41	0.67 (0.37–1.19)	0.17
TC ≥ 5.18 mmol/l	2010	1	0.69 (0.40–1.20)	0.19	0.74 (0.42–1.29)	0.30	0.80 (0.46–1.40)	0.44	0.58 (0.33–1.03)	0.06
	2020	1	0.72 (0.41–1.24)	0.23	0.78 (0.45–1.35)	0.37	0.82 (0.47–1.43)	0.49	0.61 (0.34–1.09)	0.09
LDL-C ≥ 4.9 mmol/l	2010	1	0.45 (0.10–2.02)	0.30	0.44 (0.09–2.01)	0.29	0.23 (0.04–1.35)	0.10	0.20 (0.03–1.18)	0.07
	2020	1	0.49 (0.11–2.17)	0.35	0.39 (0.08–1.80)	0.23	0.25 (0.04–1.40)	0.11	0.19 (0.03–1.13)	0.07
$_{Small}$LDL particles > 600 nmol/l	2010	1	1.07 (0.60–1.91)	0.79	1.09 (0.60–1.97)	0.76	1.24 (0.69–2.24)	0.46	0.63 (0.33–1.17)	0.14
	2020	1	1.09 (0.61–1.94)	0.77	1.25 (0 0.70–2.23)	0.46	0.97 (0.54–1.76)	0.92	0.63 (0.34–1.18)	0.15
$_{Large}$LDL particles < 450 mmol/l	2010	1	**1.88 (1.11–3.21)**	**0.02**	0.82 (0.48–1.41)	0.49	1.14 (0.66–1.96)	0.61	0.97 (0.55–1.69)	0.92
	2020	1	1.41 (0.83–2.38)	0.20	0.85 (0.50–1.45)	0.56	0.90 (0.52–1.53)	0.69	0.81 (0.46–1.42)	0.47
HDL-C < 1.0 mmol/l[a], < 1.3 mmol [b]	2010	1	0.84 (0.42–1.68)	0.63	1.30 (0.68–2.50)	0.42	1.33 (0.69 -2.55)	0.38	0.70 (0.34–1.42)	0.32
	2020	1	0.81 (0.41–1.61)	0.55	1.07 (0.56–2.05)	0.84	1.23 (0.65–2.34)	0.52	0.69 (0.34–1.40)	0.31
TG ≥ 1.7 mmol/l	2010	1	0.71 (0.36–1.43)	0.34	0.52 (0.24–1.11)	0.09	0.58 (0.28–1.22)	0.15	0.52 (0.24–1.10)	0.08
	2020	1	0.59 (0.30–1.19)	0.14	0.52 (0.25–1.07)	0.08	**0.42 (0.20–0.90)**	**0.03**	**0.44 (0.21–0 0.93)**	**0.030**
TC:HDL-C ratio > 4.5	2010	1	1.05 (0.56–1.95)	0.87	1.03 (0.53–1.96)	0.92	1.12 (0.58 -2.14)	0.73	0.60 (0.30–1.22)	0.16
	2020	1	0.85 (0.46–1.60)	0.62	0.92 (0.49–1.74)	0.81	0.87 (0.46–1.67)	0.68	0.60 (0.30–1.20)	0.15
FPG ≥ 5.6 mmol/l	2010	1	0.83 (0.41–1.70)	0.62	0.57 (0.26–1.23)	0.15	0.96 (0.47–1.95)	0.92	0.93 (0.45–1.89)	0.84
	2020	1	0.90 (0.44–1.83)	0.77	0.59 (0.28–1.27)	0.18	0.84 (0.41—1.72)	0.62	0.94 (0.46–1.91)	0.86
HOMA2-IR > 2.0	2010	1	1.31 (0.72–2.40)	0.36	1.13 (0.60–2.11)	0.69	0.81 (0.42–1.57)	0.54	0.54 (0.26–1.09)	0.08
	2020	1	0.72 (0.39–1.35)	0.31	1.15 (0.63–2.08)	0.64	0.63 (0.33–1.20)	0.16	**0.44 (0.21–0.88)**	**0.022**
hsCRP ≥ 1.0 mg/L	2010	1	1.03 (0.60–1.76)	0.90	1.02 (0.59–1.77)	0.92	1.16 (0.66–2.05)	0.58	0.62 (0.35–1.09)	0.10
	2020	1	0.80 (0.47–1.36)	0.41	0.89 (0.51–1.55)	0.69	1.00 (0.57–1.76)	0.99	**0.54 (0.31–0.96)**	**0.040**
SBP > 130 mmHg	2010	1	0.87 (0.47–1.59)	0.65	0.53 (0.27–1.02)	0.06	0.56 (0.29–1.07)	0.08	0.89 (0.47–1.66)	0.72
	2020	1	1.05 (0.57–1.94)	0.87	0.60 (0.32–1.15)	0.13	0.59 (0.31–1.14)	0.12	0.98 (0.52–1.84)	0.94
DBP > 85 mmHg	2010	1	1.02 (0.51–2.03)	0.94	0.87 (0.42–1.80)	0.72	1.19 (0.59–2.38)	0.61	1.26 (0.63–2.51)	0.50
	2020	1	0.96 (0.47–1.95)	0.90	1.38 (0.69–2.73)	0.36	1.10 (0.54–2.25)	0.78	1.25 (0.62–2.53)	0.53

Table 3. Comparisons of associations of MHEIs with cardiometabolic risk parameters. *BMI* body mass index, *CMR* cardiometabolic risk, *DBP* diastolic blood pressure, *FPG* fasting plasma glucose, *HDL-C* high density lipoprotein cholesterol, *HOMA2-IR* homeostatic model assessment of insulin resistance, *hsCRP* high-sensitivity C-reactive protein, *LDL-C* low density lipoprotein cholesterol, *OR* Odds ratio, *SBP* systolic blood pressure, *TC* total cholesterol, *TC:HDL-C* total cholesterol:high density lipoprotein cholesterol ratio, *TG* triglycerides, *WC* waist circumference. [a]Cut-off for male; [b]Cut-off for female; Data expressed as mean ± standard deviation for total MHEI 2010 and 2020 scores unless otherwise stated. Binary logistic regression analysis adjusted for age and gender determined associations between dichotomous metabolic parameters and quintiles of total MHEI 2010 and 2020 scores. Significant values (p-value > 0.05) are highlighted bold.

grain scores were clearly evident for BMI, WC, % body fat, and hsCRP with both MHEIs. Of note, *refined grain* cut-offs though set lower with $MHEI_{2020}$ compared to $MHEI_{2010}$ (1.1 *vs* 1.4 serving) inversely associated with blood TG which was not observed with $MHEI_{2010}$. Most countries' dietary guidelines support non-quantitative recommendations for *whole grain*[13] and Malaysia followed this trend as per the statements 'half of your grain products from whole grain' in MDG-2010 and 'at least half of your cereals and cereal-based products from whole grain' in MDG-2020. But suboptimal *whole grain* scores were evident for this cohort typical of the Malaysian population who predominantly consume white rice, noodles, and refined grain products as cereal staples[39–41]. Further, suboptimal scores for *wholegrain* and *refined grain* scores aligned to highest Sugar-Sweetened Beverages adherence (T3) and lowest Home Food (T1) and Plant Food (T1) dietary patterns.

Total protein servings increased for MDG-2020 *vs* MDG-2010 but scores yielded as per both HEI metrics were optimal (4.2/5 and 3.9/5) and reflective of the high intakes of animal foods in Southeast Asian countries[42]. But the higher protein scores as per MDG-2020 elicited significantly positive associations towards TC**,** not observed with the $MHEI_{2010}$ score. The *seafood* servings similar to both MDGs, elicited scores positively linked to both increased TC and increased LDL-C which concurs with findings from a large women's cohort (*n*=26034) reporting fish intake positively associated risks with higher TC and LDL-C[43]. TG lowering benefits were also not associated with *seafood* scores as per the MHEI metrics unlike other studies reporting on consumption of lean fish and fish-derived proteins[43,44] or *n*-3 rich fish oil supplements[45]. Differing conclusions possibly depend on



Note- Binary logistic regression for odds ratio (95% CI) of better metabolic status against odd ratio of poor metabolic status set as 1.0 (reference standard). Significant values (p>0.05) are highlighted in bold.

Abbreviations- AOR, adjusted odds ratio; BMI, body mass index; DBP, diastolic blood pressure; FPG, fasting plasma glucose; HDL-C, high-density lipoprotein-cholesterol; HOMA2-IR, homeostatic model assessment of insulin resistance; hsCRP, high-sensitivity C-reactive protein; MetS, Metabolic syndrome; LDL-C, low-density lipoprotein cholesterol; SBP, systolic blood pressure; TC, total cholesterol; TC:HDL-C, total cholesterol : HDL-C ratio; TG, triglycerides; WC, waist circumference.

Fig. 2. Associations between Dichotomous CMR Parameters with 5-unit increase in MHEI2020 Score.

the type of fish been consumed (cold water or tropical) or the preferred Malaysian cooking style for fish which is either deep-frying in palm oil or in gravy with coconut milk[46,47].

Contrarily, a specific TC lowering benefit, but not LDL-C lowering was observed with higher *beans and legumes* scores elicited by both metrics. A systematic review and meta-analyses of available evidence from randomized controlled trials (n=112) suggested that substitution of 1 to 2 servings of plant protein for animal protein, could decrease LDL-C by ~4% in adults with and without hyperlipidemia[48]. Sullivan et al.[33] in assessing the NHANES data with HEI-2015 metrics suggested a HDL-C raising benefit associated with a combined *greens and bean* component without any effect on total cholesterol or LDL-C but this was a population reported to be taking cholesterol, blood pressure and glucose lowering medications. In contrast our study which assessed plant components separately for a disease-free population, noted the *non-starchy vegetables* component was inversely associated with TC and LDL-C and positively with HDL-C whilst mediating anti-atherogenic lipoprotein patterns.

Achieving adequacy of an ideal *fatty acid ratio* favouring polyunsaturated and monounsaturated fatty acids and moderating saturated fatty acid intake are the global benchmarks to reduce cardiovascular disease risk[49,50]; and this approach has been consistent for both MDGs[51]. Poor scores for *fatty acid ratio* (2.6/10, 26%) and for *saturated fat* (4.0/10, 40%) of the MLS cohort were expected as palm oil was the main vegetable fat consumed by 83.9% of the MLS cohort concurring with its predominant use as a cooking oil in Malaysia[28]. Higher scores as per the *fatty acid ratio* component associated with reduced risks for BMI, WC, adiposity, lipid profile and insulinemic status, whereas none of these risk benefits associated with the *saturated fat* scores excepting reduced risks for FPG and insulin resistance. However, an analysis for this cohort in terms of palm oil use (Supplementary Table S4) noted a lack of significance for CMR parameters, whereas carbohydrate-fat permutations relating to higher fat and higher carbohydrate diets were earlier shown to be associated with CMR[28]. Further secondary analyses identified Sugar-Sweetened Beverages and Plant Food dietary patterns associated with poor or better CMR respectively[29]. Whereas in this current analysis we observed poorest HEI scores as regards achieving a balanced *fatty acid ratio* were attributed to the Sugar-Sweetened Beverages pattern and better scores to the Plant Food pattern. Whilst moderation for *saturated fat* intake associated with those highly adherent to the Home Food and Plant Food dietary patterns.

Poor *dairy* scores irrespective of MHEI metrics favoured a negative association with BMI. This finding paralleled the NHANES of 13,544 U.S. adults, whereby lower BMIs were significantly associated with consistent consumption of dairy despite varied fat composition[37]. Generally, the MLS population were consuming insufficient *dairy* as indicated by $MHEI_{2010}$ (2.7/10, 27%) and MHEI $_{2020}$ (2.5/10, 25%) metrics which included calcium-fortified soymilk. This is a public health concern as it indirectly reflects on median calcium intake as

Characteristics	Q1 n = 116	Q2 n = 115	Q3 n = 115	Q4 n = 118	Q5 n = 113	*p*	Linear trend, β ± SE
Score range	24.2 ± 4.03	31.3 ± 1.88	36.5 ± 1.66	41.3 ± 1.98	52.7 ± 6.93	**< 0.001**	–
Age (years)	34.2 ± 9.78	35.7 ± 11.2	38.5 ± 11.7	39.3 ± 10.7	43.7 ± 11.4	**< 0.001**	2.27 ± 0.32*
Gender, male n (%)	64 (29.5)	51 (23.5)	39 (18.0)	31 (14.3)	32 (14.7)	**< 0.001**	–
Ethnicity, n (%)							
Malay	70 (30.7)	54 (23.7)	46 (20.2)	32 (14)	26 (11.4)		–
Chinese	29 (14.3)	46 (22.7)	38 (18.7)	41 (20.2)	49 (24.1)	**< 0.001**	–
Indians	17 (11.6)	15 (10.3)	31 (21.2)	45 (30.8)	38 (26.0)		–
Monthly income (RM)	4198 ± 3338	4108 ± 4185	4462 ± 3099	4784 ± 3467	4641 ± 3156	**0.55**	158 ± 104
Nutrients							
Calories (Kcal)	1984 ± 410	1894 ± 417	1779 ± 417	1722 ± 317	1741 ± 402	**< 0.001**	− 66.1 ± 11.6*
Proteins (gm)	64.8 ± 18.4	67.5 ± 19.7	60.9 ± 18.1	61.5 ± 15.4	62.7 ± 21.0	**0.001**	− 1.01 ± 0.55
Carbohydrates (gm)	264 ± 64	251 ± 55	240 ± 60	236 ± 49	241 ± 56	**0.044**	− 6.41 ± 1.68*
Total fat (gm)	73.5 ± 17.9	68.9 ± 21.8	63.4 ± 18.5	58.4 ± 15.3	58.4 ± 20.8	**< 0.001**	− 4.08 ± 0.56*
Saturated fats (gm)	33.9 ± 8.1	31.1 ± 9.4	28.2 ± 8.0	26.3 ± 7.2	23.7 ± 7.9	**< 0.001**	− 2.52 ± 0.23*
Sodium (mg)	3500 ± 1116	3285 ± 1083	2868 ± 943	2732 ± 833	2650 ± 939	**< 0.001**	− 225 ± 29.1*
Eating out frequency	12.9 ± 6.4	11.1 ± 7.0	10.1 ± 8.0	8.5 ± 6.0	7.2 ± 5.7	**< 0.001**	− 1.40 ± 0.19*

Table 4. Sociodemographic and nutrient profiles according to quintiles of $MHEI_{2020}$ score. Data is expressed as mean ± standard deviation. One way ANOVA with Bonferroni test used for comparisons between sociodemographic variables and quintiles of total MHEI 2020 score. Significant values (p > 0.05) highlighted bold. Linear regression analysis is used to determine linear trends between quintiles of total MHEI2020 scores and sociodemographic variables. *Kcal* kilocalories, *gm* gram, *mg* milligram, *RM* Ringgit Malaysia. *Represent significance (p>0.05) for linear trends.

percentage of RNI for Malaysia 2017 was less than 40% in urban men (366.98mg against 1000mg) as well as in urban women (351.54mg against 1000-1200mg)[39,51]. Increased consumption of dairy amounting to 5 cups of either fermented or unfermented milk in the *South Asian Chennai Urban Rural Epidemiological Study* (CURES) study was associated with a lower risk of MetS defined by BMI, blood glucose, blood pressure and HDL-C criteria[52]. CURES showed increased consumption of dairy (5 cups fermented and unfermented) lowered risk for high FPG, protective against high blood pressure, low HDL-C and MetS vs low intake (compared to an intake of 1.4 cups per, lower risk of high body mass index, CMR (high BP, FPG and low HDL-C).

More than three-quarter of the MLS cohort were adherent to the moderation for *added sugar* (7.8/10, 78%) and high scores were negatively associated with WC, TG and inflammatory status. But the lowest adherence to moderating *added sugar* occurred with the Sugar-Sweetened Beverages pattern (5.36 ± 4.06) whereas those highly adherent were following the Home Food (8.32 ± 3.18) or Chinese Traditional (8.36 ± 2.99) or Plant Food (8.24 ± 3.32) patterns. The recommendation to moderate *added sugar* was introduced with the MDG-2020 and moderated for 3 to 6 tsp as per energy levels[15]. However, to ensure a uniform approach and maintain comparability between MDG-2020 and MDG-2010—which lacks specific sugar moderation recommendations—we adopted the WHO cut-off of <10% TEI for HEI metrics[53]. It is important to note that this choice does not affect the comparative evaluation of the MDGs since we applied the same WHO benchmarks to both guidelines. Furthermore, adopting the WHO benchmarks for *added* sugar revealed significant correlations with obesity and CMR parameters (e.g. WC, TG and hsCRP) that were not observed under the MDG-2020 guideline limit (reported in Supplementary Table S5). These findings suggest the need for future revisions of the MDG to consider more stringent *added sugar* moderation cut-offs to more effectively address diet-related NCDs. *Sodium* moderation required limiting daily consumption < 2300 mg for both MHEIs. But despite the MLS cohort achieving moderate adherence to sodium (5.6/10,56%), heightened risks for increased BMI, WC, adiposity and lipid profile were indicated without any association to blood pressure. Higher sodium intake has been associated with greatest adherence to the Chinese Traditional dietary pattern[29,54] and eating out behaviors[29].

This forensic analysis yielded valuable insights on the relationship of MHEI scores to the pro- or anti-atherogenic patterns of LDL subclass profiles. Higher overall scores by either MHEI metrics negatively associated with the pro-atherogenic $_{small}$LDL which were influenced by moderation in *refined grain* and achieving adequate consumption of *non-starchy vegetables* and higher adherence to *fatty acid ratio*. The Mitchelstown Cohort in Ireland involving 1,986 middle- to older-aged adults did show higher scores for a healthful plant-based diet indices compared to a lower score associated inversely with $_{small}$LDL and positively with $_{large}$LDL[55]. Although we could not find MHEI total scores associating positively with the anti-atherogenic $_{large}$LDL, individual food components such as *total protein* by either metrics and *seafood* bore positive associations whilst conversely *beans and legumes* and *whole grain* bore negative associations. A more specific application of HEI-2015 metrics to assessing lipoprotein subclass profile was reported for middle-to-older age adults (*n* = 1862) attending a primary care center in Ireland[56]. Correlation analysis with DQ metrics highlighted significantly inverse associations with $_{small}$LDL whilst associations reversed with $_{large}$LDL.

Although we have used DQ metric scores triangulated with CMR profile, understanding the nutrient composition related to scores is also critical. Nutritionally, highly adherent DQ scores (Q5) were shown to be associated with the lowest intake of calories, carbohydrates, total fat, saturated fat and sodium intakes (all $p < 0.001$) by either metrics. These nutritional characteristics underpin the core high fat, high sugar and high sodium nutrient profiles that increase the risk for obesity and NCDs[31]. Mechanistically higher energy diets facilitate greater sodium intakes as reflected in the dietary patterns reported for this population[29] as well as the high fat-high carbohydrate diets characteristic of the atherogenic and insulinemic status of the MLS participants[28].

It is well observed that sociodemographic factors influence DQ of a population[34,57–59] and we too scrutinized demographic elements to identify DQ issues in the MLS population. Least adherence to MDG-2020 as indicated with Q1 of $MHEI_{2020}$ scores were shown by young adults, male, and Malay ethnic group consuming meals eaten outside that were highest in calories, protein, fat, saturated fat, and sodium whilst monthly income was not an associated factor, in agreement with a previous DQ study in Malaysia[34]. But clearly highly adherent behaviours were also associated with the lowest frequency of eating out.

Overall, the MDG-2020 guidelines measured by HEI-2015 metrics facilitated a more comprehensive coverage of CMR indicators although the total DQ scores were rated 'poor'. Therefore, improvement in the scores is called for with targeted population health messaging. By weighting all CMR indicators together, we found each 5-unit increase in $MHEI_{2020}$ scores extrapolated to reducing the odds for increased BMI by 14%, WC by 9%, LDL-C by 32%, TG by 15%, insulin resistance by 9%, inflammation by 12% and overall, not developing MetS by 10%.

Based on this forensic analyses, enhanced health promotion activities for the MDG_{2020} to Malaysians should advocate:

- Encouraging increased inclusion of plant-based foods in the diet.
- Replacing or substituting *refined grain* with *whole grain*.
- Encouraging lower intakes of *added sugar.*
- Increasing *fatty acid ratio* by partial substitution of cooking oils with PUFA-rich oils.
- Encouraging and consuming home prepared meals rather than eating out.

Our study underscores the critical need for a comprehensive forensic scrutiny of both past and present national dietary guidelines, by taking into account the efficacy of the quantity and quality of food groups in relation to CMR outcomes, dietary behaviours as well as sociodemographic characteristics. We identified the usability of MHEI metrics related to food components to facilitate the precise alignment of dietary guidelines towards cardiometabolic health and to identify preventative health promotion strategies targeting indicators of obesity and diet-related chronic diseases for a population[57,60,61]. This study possesses several key strengths that address the rising trends in the prevalence of NCDs indicators in Malaysia[30]. Firstly, we employed a comprehensive array of cardiometabolic risk biomarkers that provides a robust basis for evaluating the dietary guidelines. Secondly, we have used three 24-hour dietary recalls with open-ended dietary assessment enabling collection of dietary details such as preparation methods, ingredients used in mixed dishes, and the brand name of commercial products[62]. Thirdly, food compositional analyses by our laboratory allowed referencing a food fatty acid database which facilitated a more realistic assessment of DQ when applying the HEI-2015 metrics. Of importance, our study design of the MLS cohort was ethnically representative of diverse multi-ethnic groups, and therefore our findings could be generalised to similar Asian communities in the Southeast Asian region.

A limitation of this study is its cross-sectional nature does not allow the causality of relationship between DQ indices and cardiometabolic parameters. Therefore, acquiring longitudinal clinical and dietary data in this population is warranted to confirm the observed associations as well as accommodate changes in nutrition transitions. Secondly, we have modified the nutrient density cut-offs of HEI-2015 in conformation with MDG_{2010} and MDG_{2020} which limits the usability of these DQ indices to culturally different global regions. However, the study's methodology is still robust to guide policy implementation, monitoring and re-structuring in tandem with a population's cardiometabolic risk indicators concurrent with using artificial intelligence to facilitate rapid data generation.

Conclusion
In conclusion, DQ metrics of the HEI-2015 triangulated with a CMR profile of the MLS population facilitated a forensic analysis of the MDGs for 2010 and 2020, revealing only the MDG_{2020} recommendations could be comprehensively linked to reduced risks for obesity, hypertriglyceridemia, insulin resistance and inflammation. Key differences between risk profiles of the MHEI metrics were arbitrated by changes to serving sizes for grain and protein groups in the MDG_{2020}. Suboptimal 'poor' DQ scores by either $MHEI_{2020}$ and $MHEI_{2010}$ were generated by low intakes of healthful plant foods inclusive of *fruit*, *non-starchy vegetables* and *whole grain* and high intakes of *refined grain*, *added sugar* and *saturated fat*. Suboptimal DQ scores were traced to high adherence to the Sugar-Sweetened Beverages dietary pattern and eating out frequently whereas the reverse occurred with the Plant Food pattern.

Methods
The forensic analyses applied in this study required testing associations of DQ scores derived from reported dietary data of the MLS population with CMR indicators available as primary data[28] along with their food behaviours[29]. DQ scores were first derived using the HEI-2015[24]. The following sections enumerates the steps taken for this forensic analysis.

Study population

The MLS cohort (n = 577), recruited through a cross-sectional study, represented a typical urban-living adult Malaysian population profile, which is a predominantly palm oil consuming cohort with multi-ethnic makeup of Malays, Chinese and Indians. The primary findings detailed the description of this cohort's macronutrient intake associating with cardiometabolic risk[28], whilst the secondary analyses revisited biomarker risks in the context of dietary patterns[29]. Essentially recruited participants were chronic disease diagnosis-free, reported no smoking/alcohol history and ranged in age between 20 and 65 years. The MLS study was conducted in accordance with the Declaration of Helsinki guidelines with all procedures involving human subjects approved by the Medical Ethics Committee of the National University of Malaysia (UKM 1.5.3.5/138/NN-047-2012), and the protocol registered with the National Medical Research Register, Malaysia (ID: NMRR-15-33-23993). All participants had provided written informed consent.

Dietary database

Nutrients of principal interest to this secondary analysis relevant to the Malaysian Dietary Guidelines[14,15] were calories, protein, carbohydrates, fats, saturated fats and sodium. The required information was extracted from the MLS dietary database which was built for each participant's 24-hour dietary recalls randomized for two weekdays and one weekend. These dietary records were analysed with Nutritionist Pro™ software (First DataBank Corporation, Axxya Systems, Stafford, TX, USA) referencing the Malaysian Food Composition[63], Singapore Food Composition[64] and the United States Department of Agriculture standard reference database[65]. A detailed description about the primary dietary analysis has been described elsewhere[28,29].

Framework for diet quality development

The MDGs that were published in 2010[14] and 2020[15] served to frame DQ metrics of the MLS cohort's dietary intake. We adapted both these MDGs to conform to the HEI-2015 metrics[24] and accordingly termed them as Malaysian Healthy Eating Index-2010 ($MHEI_{2010}$) and Malaysian Healthy Eating Index-2020 ($MHEI_{2020}$).

Determining standards of MHEI components

The original HEI-2015 uses a nutrient density-based approach to set serving size standards per 1000 kcal or as percentage of kcal purposive to differentiating dietary quality from quantity. But the metrics tool also enables least restrictive standards to achieve nutrient adequacy at varying energy levels as per age or gender[22–24]. We applied this approach to each food group and subgroup recommendations specific to both MDGs (2020 and 2010). Serving size for MDG components was equated to a 1800kcal diet as the median standard for a range of energy levels (1500 to 2500 kcal in MDG-2010 and 1500 to 2000kcal in MDG-2020), providing a balanced representation of the energy requirement outlined in both MDGs. The weightage and scoring for each component in these modified versions were aligned to the HEI-2015 (Supplementary Table S1).

Components of $MHEI_{2010}$ and $MHEI_{2020}$

The $MHEI_{2010}$ and $MHEI_{2020}$ yielded 13 dietary components each, nine of which assessed adequacy of the diet (total fruit, whole fruit, total non-starchy vegetables, beans and legumes, whole grain, total protein, seafood, and fatty acid ratio) and the remaining four components (refined grain, sodium, added sugar and saturated fats) being assessed for moderation in their consumption. All dietary components from HEI-2015 along with their scoring algorithm were maintained, except for the desegregation of beans from greens and beans group and seafood from seafood and plant protein group. For both MDG-2020 and MDG-2010, beans and legumes and seafood were accounted as two separate dietary components. Our rationale for decoupling plant proteins from animal protein was because vegetarian practices were inherent to multiculturalism in Malaysia[39]. The components of $MHEI_{2010}$ and $MHEI_{2020}$ with the standards for minimum and maximum scoring are detailed in Supplementary Table S1 and the serving size derivation is provided in Supplementary Table S2.

Adequacy components. For both MDGs, the dietary recommendations for fruits and vegetables were in concordance with each energy level i.e. 2.0 and 3.0 servings respectively[14,15]. Therefore, when prorated to nutrient density, the values on median energy level were identical for both dietary indices. The HEI-2015 further adds *whole fruit* as a sub-component to differentiate nutritional value and fibre content from *fruit juice*[24] which led to the *whole fruit* and *total fruit* differentiation in the $MHEI_{2010}$ and $MHEI_{2020}$. The scoring for adequacy components were assigned 'zero' value when there was 'no intake', with scores increasing in proportion up to the set standard for maximum scoring. The scores between zero and the standard were prorated linearly[22].

However, inherent disparities for some components between MDGs required adjustments in serving size, and the characteristics for these adjustments are summarized below:

- *Total grain* This component ranged between 4.0 to 8.0 servings day^{-1} for 1500 to 2500 kcal energy levels as per MDG-2010[14] but became reduced to 3.0 to 5.0 servings day^{-1} for 1500 to 2000 kcal energy levels as per MDG-2020[15]. Servings were equally allocated between *whole grain* and *refined grain* as per both MDG recommendations. Notably, *whole grain* is considered as an adequacy component whilst *refined grain* required moderation according to the HEI-2015[24]. Thus, when converting to nutrient density, the maximum score for *whole grain* was set at ≥ 1.4 serving for MDG-2010 and ≥ 1.1 servings for MDG-2020. Conversely, the maximum score for *refined grain* was ≤ 1.4 servings for MDG-2010 and ≤ 1.1 servings for MDG-2020.
- *Total protein* This component included *meat, fish, poultry, eggs*, and *beans and legumes*. But *fish* and the *beans and legumes* components were accounted in accordance with both MDG serving recommendations[14,15]. Serv-

ings for *total protein* varied from 2.0 to 4.0 servings for 1500 to 2500 kcal energy levels as per MDG-2010 compared to MDG-2020's higher servings of 3.0 to 4.0 for 1500 to 2000 kcal energy levels. Specific to *beans and legumes*, serving size ranged from 0.5 serving for 1500 kcal to 1.0 serving for a 2000 to 2500 kcal as per the MDG-2010 but became standardized to 1.0 serving across all energy levels for the MDG-2020. Of note, protein content of the animal protein serving was uniform (14gm/serving) for both guidelines but differed for the *beans and legumes* component (MDG-2010 = 7gms *vs* MDG-2020 = 14 gms). When expressed as nutrient density, the recommendation for *total protein* component became similar between the two guidelines with values on for the median (1800 kcal) energy requirement selected as the criteria for maximum scoring. Although the recommendation for *beans and legumes* was 0.6 ser./1000 kcal for both dietary indices, the nutrient density per serving of protein varied.

- *Dairy* The recommendation ranged between 1.0 and 3.0 servings for each energy level as per MDG-2010[14] but became standardized to 2 0.0 servings for each energy level as per MDG-2020[15]. When adjusted to nutrient density, the serving value for the median energy level become 1.1 for both MHEIs. Nevertheless, it is worth noting that MDG-2010 specified 7 g protein per serving while MDG-2020 increased this recommendation to 8 g protein per serving for dairy.
- *Fatty acid ratio* The Malaysian reference nutrient intake (RNI) 2017 has recommended 30% of total energy intake (TEI) from fats which includes < 10% TEI from saturated fats and the remaining 20% from mono- and poly- unsaturated fatty acids[51]. Therefore, in tandem with the RNI message, we selected the ratio of unsaturated to saturated fatty acids as ≥ 2 for maximum scoring. The criteria for minimum score of 'zero' was assigned to the value of ≤ 1 which was the 15th percentile of this population's distribution for intake[22].

Moderation components. The criteria to set the scoring standard for moderation components are stated below:

- *Refined grain* Following the HEI-2015, *refined grain* was categorised as a moderation component[24], making up to 50% of total grain intake for both MDGs[14,15], thereby setting half of the *total grain* serving as the cut-off for the maximum score. Converting to nutrient density, the value of 1.4 ser./1000 kcal as per MDG-2010 and 1.1 ser./1000 kcal as per MDG-2020 became the cut-offs for maximum scoring. Since the criteria to set the cut-off for minimum scoring was absent, we doubled the maximum cut-off and set it as the criteria for minimum scoring for both dietary indices.
- *Sodium* The RNI 2017 provides two levels for maximum sodium intake which are 2300 mg/day and 1500 mg/day[51]. We opted for the tolerable upper intake of 2300 mg/day as the maximum scoring. The criteria for minimum score of zero was assigned the value of 4000 mg/day which was the 85th percentile of this study population's distribution for sodium intake[22].
- *Saturated fats* We followed the RNI 2017's recommendation of < 10% of TEI which was selected as maximum scoring and the value of 17% (85^{th} percentile) finalized for the minimum score of zero[22].
- *Added sugar* The MDG-2010 did not have a recommendation for added sugar intake, whereas the MDG-2020 recommends 6 to 8 servings (1 serving = 1 tsp) of added sugar for 1500 to 2000 kcal energy levels. To set a uniform approach we adopted the World Health Organization (WHO) standard cut-off for added sugar which is < 10% of TEI[53] for the maximum score and ≥ 15% (85^{TH} Percentile) of TEI for the minimum score[12].

Disaggregation of mixed foods
The mixed food dishes were disaggregated into simple/ basic ingredients and assigned to their respective food groups[23,66]. For example, the ingredients for *nasi goreng* (local fried rice) were disaggregated into rice, meat, fish, and vegetables and allocated into *refined grain, total protein, fish* and *vegetable* components respectively[66].

Health risk indicators

The MLS cohort (*n*=577) This population's cardiometabolic risk (CMR) parameters[28] were body mass index (BMI), waist circumference (WC), total cholesterol (TC), low density lipoprotein-cholesterol (LDL-C), high density lipoprotein-cholesterol (HDL-C), triglycerides (TG), small LDL particles ($_{small}$LDL), large LDL particles ($_{large}$LDL), fasting plasma glucose (FPG), and insulin, calculated homeostasis model assessment of insulin resistance (HOMA2-IR), high sensitivity C-reactive protein (hsCRP), systolic (SBP), and diastolic (DBP) blood pressure.

Individual component and total scores of the $MHEI_{2010}$ and $MHEI_{2020}$ were also compared with previously derived dietary patterns of the MLS cohort[29], which were established by principal component analysis using each participant's 24-hour dietary recalls randomized for two weekdays and one weekend. These dietary patterns were Sugar Sweetened Beverages, Chinese Traditional, Home Food and Plant Food patterns, and their tertiles representing highest (T3) to lowest (T1) adherence behaviours of participants were integrated with data on the total and component scores of both MHEIs.

Sociodemographic, income and lifestyle variables

Participants' demographic data collected for the MLS study[28,29] relating to ethnicity, household income, dietary history, and eating out practices were also integrated with this study's analyses.

Statistical analysis

Descriptive data reporting HEI metrics as per food group and nutrient components were presented as mean and standard deviation with the normality being tested using *Kolmogorov–Smirnov* test. The *Chi-square test* was applied to categorical variables and data presented as frequency (%). The *paired t-test* was applied to mean score comparisons between $MHEI_{2010}$ and $MHEI_{2020}$. The relationship between HEI metrics and CMR parameters was determined using *partial correlation*, adjusted for age and gender. The total and component scores of each MHEI were integrated with data from the dietary patterns of the MLS cohort[29]. ANOVA was applied to examine the differences between MHEI scores and adherence to habitual food behaviours. In case of significance *Tukey post hoc* was applied to further test score differences within tertiles of dietary patterns. Additionally, binary logistic regression analysis adjusted for age and gender was applied to determine the odds for CMR as per MHEI metrics. CMR parameters were treated as binary (dependent or outcome variable) variables and MHEI scores as continuous (independent variable or predictor variable). The cut-offs for CMR indicators were as follows; BMI ≥ 25kg/m^2, WC ≥ 90 cm for men, ≥ 80 cm for women, TC ≥ 5.18 mmol/l, LDL-C ≥ 4.9 mmol/l, $_{small}$LDL particles > 600 nmol/l, $_{large}$LDL particles < 450 mmol/l, HDL-C < 1.0 mmol/l for men, < 1.3 mmol for women, TG ≥ 1.7 mmol/l, TC:HDL-C ratio > 4.5, FPG ≥ 5.6 mmol/l, HOMA2-IR > 2.0, hsCRP ≥ 1.0 mg/L, SBP > 130 mmHg, DBP > 85 mmHg and metabolic syndrome (MetS) diagnosis. Finally, the odds for improving a CMR indicator for a 5-unit increase in MHEI scores was assessed as a health outcome linked to increasing adherence to the dietary guidelines. All statistical analysis was performed using SPSS® version 23 (SPSS Inc., Chicago, USA). All reported *p-values* were two-tailed, and significance interpreted as $p < 0.05$.

Data availability

All datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

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Author contributions

T.K.: conceived and designed the study; A.S., B.H.K., G.V.B., K.A.C. and Z.W.Y.: conducted the study; A.S., B.H.K. and K.C.: analyzed the data; A.S. B.H.K. and J.H.L.: wrote the manuscript; S.S.N., K.S., Z.A.M.D.: revised the manuscript; All authors reviewed and approved the final manuscript.

Competing interests

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Additional information

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Correspondence and requests for materials should be addressed to T.K.