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POSITION STATEMENT

Critical evaluation of the questionnaires assessing adherence to the Mediterranean diet that are based on servings☆

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Abstract *Background and aims:* The Mediterranean Diet (MD) is characterized by a high intake of vegetables, fruit, legumes, nuts, and olive oil, and moderate fish, dairy, and wine intake. A high adherence to MD has been associated with numerous health benefits, including reduced risk of chronic diseases such as cardiovascular disease, cancer, and type 2 diabetes. The clinical assessment of MD adherence is complicated by the absence of a univocally accepted tool and by the abundance of questionnaires developed to determine adherence, whose reliability and validity is uncertain. In this inter-associative document, we critically evaluated servings-based questionnaires for the assessment of MD adherence, aiming to identify the most valuable tool for the use in clinical practice.

Methods and results: For each questionnaire, we analyzed the structure, evidence on health-related outcomes and agreement with the recommendations of MD. We found that most questionnaires do not accurately reflect the principles of MD in terms of the food groups and their optimal consumption frequency. Additionally, the comparison of questionnaires revealed low agreement and some concerns with regard to the scoring assumptions.

Conclusions: Among the available questionnaires, we suggest the use of the 15-Items Pyramid based Mediterranean Diet Score (PyrMDS), which is the one with fewer flaws and a strong supporting body of theoretical and scientific evidence. The use of the PyrMDS may facilitate the assessment of MD adherence in clinical practice, which is instrumental in reducing the risk of non-communicable chronic diseases.

☆ Italian Diabetology Society (SID), Italian Association of Diabetologists (AMD) and Italian Association of Dietetics and Clinical Nutrition (ADI) inter-associative study group of nutrition in diabetes

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1. Introduction

The Mediterranean Diet (MD) is considered the healthy diet *par excellence* on the basis of a huge number of publications, which consistently show a robust relationship between poor adherence to the MD dietary pattern and increased prevalence and/or incidence of a number of chronic non-communicable diseases (type 2 diabetes, arterial hypertension, cardiovascular and neurodegenerative diseases, and some solid tumors) [1–4]. Indeed, the European Society of Cardiology (ESC) 2021 cardiovascular disease prevention guidelines [5], the Italian Diabetology Society (SID) and Italian Association of Diabetologists (AMD) 2022 guidelines [6] and expert consensus on the treatment of type 2 diabetes (T2D) [7] indicate MD as the most effective dietary intervention. In addition, recent evidence has also shown efficacy of MD in the secondary prevention of major cardiovascular events [8].

Nevertheless, recent population studies have shown a progressive shift away from MD in the last decades, in Italy, particularly in Southern regions, and in many other Mediterranean countries [9,10]. Although hypertension, T2D, obesity and dyslipidemia are all chronic medical conditions for which dietary intervention is most effective (and recommended by national and international guidelines), adherence to MD is low even in these populations [11,12].

As healthcare providers, we should understand which barriers are causing this therapeutic inertia. Probably, the most important is that we neither have a satisfying method to assess adherence to MD, nor a tool to provide individualized suggestions on how to improve diet quality. Assessing adherence to MD is not a common clinical practice and is limited by most health care providers' lack of solid knowledge on dietetics, and by time constraints and uncertainty on how to make the assessment. Not only a thorough estimate of dietary habits is extremely time-consuming, but even when it is obtained, how all the data can be transformed into a meaningful estimate of adherence remains rather obscure. In the last 25 years, an impressive number of questionnaires has been proposed, and possibly, it is this excess of information that has fueled uncertainty and somehow discouraged their clinical use. In addition, some of the proposed questionnaires are too complex to be used in a clinical setting, particularly those requiring structured food frequency analysis (food frequency questionnaires, FFQ), the definition of quartiles of consumption of each item in the whole population, and/or those based on grams instead of servings.

In this inter-associative document of the study group of nutrition in diabetes of the Italian Diabetology Society (SID), Italian Association of Diabetologists (AMD) and Italian Association of Dietetics and Clinical Nutrition (ADI), we wish to describe the characteristics and the *pro* and *cons* of the most widely used MD questionnaires that are based on servings. To better appreciate the differences between questionnaires, a simulation of their performance is also presented. Finally, on the basis of a variety of evidence and theoretical arguments, we recommend the use of one questionnaire as the most valuable among those analyzed and offer an open web-based tool to implement its use in everyday clinical practice (www.siditalia.it/divulgazione/alimentazione-e-diabete).

2. Methods

We conducted a systematic review of the English literature regarding questionnaires for the estimation of MD adherence falling in the category of the *a priori* (i.e. assuming that the benefit of the diet is driven by the pattern rather than by the individual components). For source selection, we searched the PubMed and Scopus databases for articles published from 2000 up to October 2022, using the terms 'Mediterranean Diet', 'questionnaire', 'score', and 'adherence' either alone or in different combinations. The references of relevant articles were also manually searched. Studies were deemed eligible if they included questionnaires developed in the last 20 years, based on servings and consisting of a limited (for the sake of simplicity) number (max 16) of questions/items. Questionnaires without adequate validation and/or available data on health-related outcomes were excluded.

3. Results

The literature search yielded 965 articles, 388 duplicates were discarded and the abstracts of the remaining 577 articles were screened manually. The full text of 86 articles was singularly examined for eligibility, and, ultimately, 27 studies met the inclusion criteria. The final 27 articles were based on 8 different questionnaires, which are individually analyzed below.

3.1. 9-Items Short Mediterranean Diet Questionnaire (SMDQ) or Cardioprotective Mediterranean Diet Index

3.1.1. Description

SMDQ was proposed by Martinez-Gonzalez et al. in 2004 [13] and originated from a simplification of a previous score, obtained using quintiles of consumption of 8 items presumed *a priori* to positively (olive oil, fiber, fruits, vegetables, fish/marine items, alcohol) or negatively (meat/meat products, white bread + rice + pasta) reflect adherence to MD. A 118-items FFQ in g/day was used to collect this information [14]. A threshold for each item was chosen on based on the dose-response relationships between quintiles of consumption of each food group and the odds of having had a myocardial infarction in a small (n = 342) case-control study [15]. The questionnaire was further simplified by translating consumption from g/day in servings per day, or week, and by replacing the item of fiber consumption with 3 additional questions/points: a) fruit $\geq$1/day and vegetables $\geq$1/day, b) legumes $\geq$2/week and c) whole-grain bread >5/week or white bread <1/day and white rice <1/week. Alcohol was replaced by wine. Overall, the questionnaire estimates the level of adherence to MD based on 9 items using a 0/1 score according to minimum thresholds for: olive oil, fruit, vegetables, fruit

and vegetables, legumes, fish and wine, and maximal thresholds for meat and a combination of a minima for either minimal (white bread and rice) or a maximum (whole bread) threshold for cereals; the total score ranges from 0 to 9 (Table 1).

3.1.2. Evidence on health-related outcomes

The study of Martinez-Gonzalez et al. [13] found that an increase of one point in the score was associated with a 18% (OR [95%CI]: 0.98 [0.86−0.98]) reduction in the risk of having had a myocardial infarction. However, from the inspection of the OR/Score curve it is evident that the discrimination power of the score is low, being the cardiovascular (CV) risk mostly concentrated in those with an extremely poor diet (score 0 and 2) with a substantially flat dose-response curve from score 3 to 9. The SMDQ has also been used to demonstrate that poor MD adherence is associated with functional gastrointestinal disorders in adults [16] and with lower levels of markers of fibrosis progression in subjects with non-alcoholic fatty liver disease (NAFLD), suggesting a protective role of MD adherence in NAFLD progression [17].

3.1.3. Comment

SMDQ is a simple and quick tool to evaluate the adherence to MD. However, it does not weight all the items as equally important, in fact, fruits and vegetables receive an additional point if both targets are achieved (assuming a synergism); whereas, the role of whole cereals is somewhat neglected: in fact, only whole bread is considered and a score of 1 can be obtained when its consumption is $>$ 5/week or, indirectly, when white bread and white rice are consumed $<$1/day and $<$1/week, respectively. Pasta of any type (white or whole) and whole-grain consumption other than bread are ignored. Wine is established to be the only protective alcohol-containing beverage with no upper threshold ($\geq$7/week), which is probably incorrect provided that alcohol consumption (of any type) between 3 and 10 drinks/week is associated with lower all-cause and cardiovascular death risk [18−20], while the risk increases both below and above this range.

Unfortunately, the thresholds were chosen based on the analysis of the dose-response curves, which are limited by the case-control nature of the study and the small sample size analyzed. Additionally, the questionnaire was developed to measure adherence to a cardio-protective diet rather than MD. With respect to the other questionnaires, as well as to the updated version of the MD pyramid and to data on chronic non-communicable diseases, the thresholds appear inadequate for vegetables and fruit (too low) and for meat (too high) (Fig. 1). In addition, nuts, an important healthy food category especially for cardiovascular disease (CVD) [21], are surprisingly not considered. Finally, the yes/no structure of the questionnaire implies no dose-response relationship between each food category and health-related outcomes and/or diet quality, which represents a flaw particularly for alcohol, vegetables and whole-grain.

3.2. 9-Items literature-based adherence score to mediterranean diet (MEDI-LITE/SOFI)

3.2.1. Description

The MEDI-LITE score has been developed by using data from meta-analyses of cohort studies investigating the association between adherence to the MD and health outcomes [22]**.** This score considers nine food groups (Table 1): fruit, vegetables, cereal grains, legumes, fish/fish products, meat/meat products, dairy products, olive oil and alcohol. The middle category of consumption is scored 1 and refers to the mean $\pm$ SD of the statistically weighted (per sample size) consumption of each item across the different cohort studies. Consumption below and above this interval is scored 0 and 2 for healthy and 2 and 0 for unhealthy food, respectively. For olive oil, 2 points are assigned for regular use, 1 point for frequent use and 0 points for occasional use. Finally, for alcohol intake (assessed as alcohol unit = 12 g of alcohol), 2 points are assigned to the middle category (1−2 alcohol units/day), 1 point to the lowest category (1 alcohol unit/day) and 0 points to $>$2 units/day. The final score is the sum of the points, and it ranges from 0 to 18 (lowest and highest adherence, respectively). The MEDI-LITE has been validated against the Mediterranean Diet Score (MDS) with a significant direct correlation ($r = 0.70$; $p < 0.0001$) in a cohort of 204 middle-aged Italian individuals [23].

3.2.3. Evidence on health-related outcomes

In the NutriNet-Santé cohort (n = 94 113 participants) a higher MEDI-LITE score was associated with a lower CVD risk (HR[95%CI]: 0.79 [0.67−0.93]) during a 6-year follow-up [24]. As for cardiometabolic risk factors, two cross-sectional studies demonstrated that higher MEDI-LITE scores were associated with a lower likelihood of being obese [25,26]. More in detail, in the study by Zappalà et al. in a large cohort of subjects (n = 1814), those in the highest quartile of the score were less likely to be obese (OR [95%CI]: 0.53 [0.32−0.89]) than individuals in the first quartile [25]. In line with these results, in a smaller cohort (n = 280), individuals with a MEDI-LITE score $\leq$9 had a significantly increased risk of abdominal obesity (OR [95% CI]: 3.21 [1.91−5.39]), and each one-point increase in the score led to a 28% reduction in the risk of being obese (OR [95%CI]: 0.72 [0.63−0.82]) [26].

3.2.3. Comment

The MEDI-LITE questionnaire is unique in not adopting optimal food consumption, but a consumption below or above the mean of different populations. Therefore, this approach does not provide an absolute estimate of adherence to MD, but a relative one, with respect to the average of the general population. It weights all items as

Table 1 Synopsis of the 8 questionnaires based on servings for the assessment of adherence to the Mediterranean Diet.

	SMDQ	SOFI	MDS	MS	MSDPS	MDSS[c]	PyrMDS	erMEDAS	*PYRAMID*	*GBD*
Items	9	9	11	11	13	14	15	16		
SCORE per item	*0/1*	*0/1/2*	*0/1/2/3/4/5*	*0/1/2/3/4*	*0 to 10*	*0 or 1,2,3*	*0 to 1*	*0/1*		
Fruit (150 g)	≥7	<7/7−11/>11	never/≤1/≤2/≤3/≤4.5/>4.5	<7/<14/<21/<28/≥28	0−21	21-42 (3)	0-[21−42]	≥21	***14−28***	***9−14***
Vegetables (80 g)	≥7	<7/7−18/>18	never/≤1/≤2/≤3/≤4.5/>4.5	<7/<14/<21/<28/≥28	0−42	≥42 (3)	0−42	≥14	***≥28***	***25−38***
Fruit&vegetables	≥7	–	–	–	–	–		–		
Legumes (150 g)	≥2	<1/1−2/>2	never/≤1/≤2/≤3/≤4.5/>4.5	<3.5/<5.3/<10.5/≤14/>14	0−4	≥2 (1)	≥2	≥3	***≥2***	***2.8−3.3***
Nuts (30 g)	–	–	–			7-14 (2)	0-[7−14]	≥3	***7−14***	***3.7−5.8***
Potatoes (150 g)	–	–	never/≤1/≤2/≤3/≤4.5/>4.5	–	0−3	≤3 (1)	≥6 -≤3	–	**-**	**-**
Fish (150 g)	≥3	<1/1−2.5/>2.5	never/≤1/≤2/≤3/≤4.5/>4.5	0/<1/<2/<3/≥3	0−6	≥2 (1)	≥2	≥3	***≥2***	***1.7−2.4***
Cereals white (75 g)	<7 or >5[a]	–	–	–	–	–	–	≤10[b]	***≤3 (+potatoes)***	**-**
Cereals whole (75 g)		–	never/≤1/≤2/≤3/≤4.5/>4.5	<7/≤14/≤28/<49/≥49	0−56	–	–	≥5	***14−28***	***9−14***
Any Cereals		<7/7−11/>11	–	–	–	21-42 (3)	0-[21−42]	–	**-**	**-**
Wine	≥7	–	–	–	0-21/11	–	–	14-21/7-14	***moderate***	**-**
Wine and beer	–	>14/<7/7-14	>49or0/≤49/≤41/≤34/≤27/<21[e]	–	–	7-14 (1)	14(M)/7(W)	–	**-**	**-**
Olive oil	>7	Occ/freq/reg.	Never/rare/<1/1−3/3-5/7	<7/<14/<21/<28/≥28	no/mix/ only[d]	21 (3)	yes	EVO (cook.)	***14−21***	**-**
Butter/cream		–	–	–	–	–	–	<1	**-**	**-**
Red Meat (100 g)	<7	>11/7−11/<7	>4.5/≤4.5/≤3/≤2/≤1/never	≥6.5/≥4.5/≥2.5/≥1/<1	0−1	<2 (1)	≥4-<2	≤1	***≤2***	***1−2***
Processed meat (50 g)					–	–	≥2-≤1		***≤1***	***<1***
Poultry (150 g)			>4.5/≤4.5/≤3/≤2/≤1/never	0/<1/≤1.5or>3.5/≤2.5/≤3.5	0−4	2 (1)	0−2	Pref vs red	***1−2***	**-**
Dairy[f]	–	>11/7−11/<7	>4.5/≤4.5/≤3/≤2/≤1/never	<7or>28/22−28/-/7−13/14-21	0−14	14 (2)	0−14	–	***14−21***	***21−18***
Eggs (1 egg)	–	–	–	≥6.5/-/>4.5/-/<4.5	0−3	2-4 (1)	0-[2−4]	–	***2−4***	**-**
Sweets	–	–	–	≥7/5−6/3−4/1−2/<1	0−3	≤2 (1)	≥4-≤2	<3	***≤2***	**-**
Beverages carb/sweet	–	–	–	–	–	–	–	<1	**-**	***<1***
Sugar in coffe/tea	–	–	–	–	–	–	–	no	**-**	**-**
Herbs/spices	–	–	–	–	–	–	–	–	***daily***	**-**
Max score	9	18	55	44	100	24	15	16	***NA***	***NA***

The servings' frequency is expressed weekly for all items to facilitate comparisons. The last two columns show the dietary indications provided by the updated Mediterranean diet foundation expert group (PIRAMYD)[55] and the Global Burden of Disease (GBD) experts[27].

[a] Cereals consumption is scored 1 if [white bread <1/day and rice <1/week] or [whole bread >5/week].

[b] White bread and pasta/rice are divided in 2 items (bread ≤1/day = 1 and bread/rice/pasta ≤3/week = 1) but they were combined in this table for simplicity.

[c] The score for each goal is provided in brackets.

[d] No use of olive oil = 0, use of mixed oils = 5, exclusive use of olive oil = 10.

[e] Ethanol in grams was transformed in servings considering 1 serving = 12 g.

[f] Dairy identifies: milk (250 ml), yogurt (125 ml), cheese (50−100 g); GBD dairy values are approximated on the bases of the suggested optimal milk (350−520 ml/die) and calcium consumption (1−1.5/die).

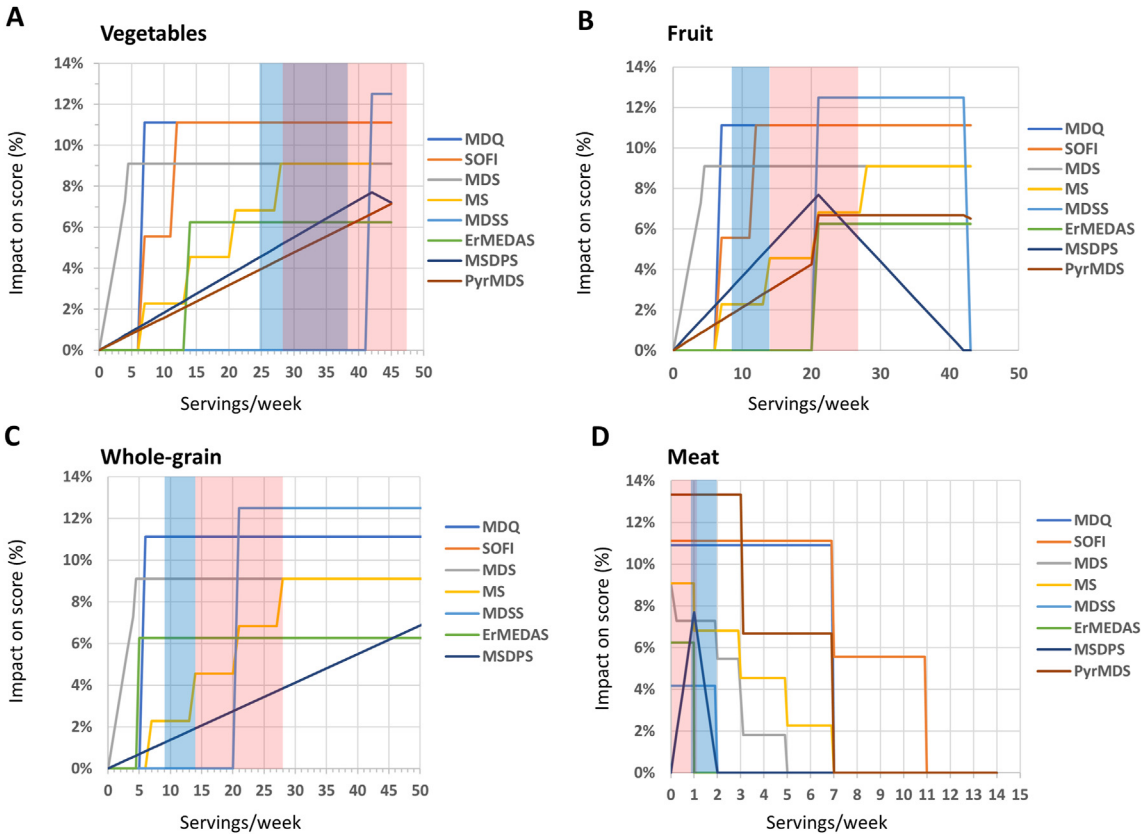

Figure 1 Comparison of the impact of the number of servings of vegetables, fruit, whole-grain and meat on the total score for each questionnaire. The figure shows the relative impact of the number of weekly servings on the total score of each questionnaire for the following food items: A) vegetables; B) fruit; C) whole-grain and D) meat. For example: a weekly intake of 30 servings of vegetables (A) contributes for a total of 0% to the maximal MDSS score, 4.5% for the PyrMDS score, 5.5% for the MSDPS score, 6% for the ErMEDAS score, 9% for the MS and MDS scores and 11% for the SOFI and MDQ scores.
The shaded blue and red boxes indicate the range of recommended servings per week based on the Global Burden of Disease (GBD) and the updated Mediterranean diet Pyramid recommendations, respectively.

equally important, and despite the 3 scoring levels (0/1/2) it assumes a very steep dose-response relationship for both healthy and unhealthy food on MD adherence, and therefore on health outcomes prevention, with scores of individual items changing abruptly for small differences in the number of servings (Fig. 1).

For example, cereals are scored 0, 1 or 2 on the bases of the thresholds: <1/day, 1–1.5/day and >1.5/day. The same applies to fruit, vegetables and meat with thresholds and relative weights that are very close to the SMDQ (Fig. 1), which we already commented as somewhat inappropriate (too low). The scoring of alcohol is correctly assumed to be U-shaped, with an optimal consumption of 1–2 servings/day, that, both in terms of coronary events and all-cause death prevention, appears adequate [19,20]. Dairy products are considered unhealthy food with an optimal intake of <1/day, which is in contrast with the Global Burden of Disease (GBD) data [27], the updated MD pyramid [28] and a number of ecological studies [29,30] recommending a higher intake. Furthermore, it does not distinguish between whole and white cereals and completely neglects nuts, which are two extremely important components of the MD [27,28].

3.3. 11-Items Mediterranean Diet Score (MDS)

3.3.1. Description

The Mediterranean Diet Score (MDS) was proposed in 2006 by a group of researchers from Athens [31], who updated a previous version of the score by adding olive oil consumption [32]. The MDS was developed following the recommendations of the Greek Ministry of Health [31]. The score is based on 11 items, including 9 food items (non-refined cereals, potatoes, fruits, vegetables, legumes, fish, read meat and products, poultry, full fat dairy products) plus olive oil and alcoholic beverages. Food frequency consumption is measured in monthly servings with the following 6 intervals for all items: never, 1–4, 5–8, 9–12, 13–18, >18/month, that generate a score 0 to 5 if the food is considered healthy and an opposite score if unhealthy (red meat, poultry, dairy products). Olive oil use is evaluated on the number of times that is used per week and is scored 0–5 according to the following frequency: never, rare, <1, 1–3, 3–5. Alcohol is evaluated as grams of ethanol/day and a score of 5-0 is given to the following consumption values: <36, 36, 48, 60, 72, >84 or 0. The maximum total score is 55.

3.3.2. Evidence on health-related outcomes

The MDS was used in the ATTICA study, involving 3042 participants without CVD. The study has provided robust evidence that a high MD adherence is associated cross sectionally with lower BMI, blood pressure, lipids and liver steatosis [31]. The 10-year follow up of the ATTICA shows that adherence to the MD is associated with a reduction in CV events (RR [95%CI] reduction: 4 [7−0]% for each additional point in the MDS) [33], with lower incidence of diabetes in subjects with prediabetes (OR [95%CI]: 0.13 [0.03−0.63] for a MDS score >35 *vs* a score <25) [34], and with lower prevalence of NAFLD (OR [95% CI]: 0.85 [0.80−0.91] for each additional point in the MDS) [35]. In a US population (n = 3790; >65 yrs), individuals with the highest adherence to MD, estimated with the use of the MDS, had a significantly slower cognitive decline in comparison with subjects with the lowest adherence [36]. In an analysis conducted on 130 countries with populations over 1 million each, the MDS score was positively associated with healthy-life expectancy ($\beta = 0.88$, $p = 0.011$) after controlling for a substantial set of covariates [37].

3.3.3. Comment

MDS weighs all the items as equally important, assumes a linear dose-response relationship of both "good" and "bad" food. Additionally, it is somewhat permissive with alcohol, grading the optimal consumption as <3 serving/die (score = 5), a score of 0 is given for more than 7 serving/die or no consumption, with intermediate points between 3 and 7 servings/die. This score is unique in under evaluating the optimal consumption of fruit, vegetables and non-refined cereals (with maximal points given for a consumption superior to 4.5/week) *vs* most of the other scores that indicate 4 to 10-fold higher frequency values (Fig. 1). In addition, it is particularly strict on the intake of red/white meat and dairy products, indicating an optimal consumption of 0/week each. This is in conflict with the updated MD pyramid [28], particularly for dairy products, given the solid evidence showing no harm for the moderate consumption of these products [30]. Surprisingly, nuts, which are an important component of MD, are not included in the score.

In addition, in the ATTICA study, the frequency distribution of the score showed a limited interindividual variability with 90% of the individuals falling between 25 and 30, which, although partially explained by the fact that the subjects were sampled from the same region, raises concerns on its discrimination power.

3.4. 11-Items mediterranean score (MS)

3.4.1. Description

The Mediterranean score (MS) was proposed by a Canadian research group in 2003 in the setting of a small clinical trial that evaluated the effect of increasing adherence to MD on plasma lipids and body weight [38]. The score was built on the basis of a 91-item FFQ, adopting an accurate definition of the portion size for each food. The score includes 11 food items: grains, fruits, vegetables, legumes/nuts/seeds, olive oil and milk/dairy products (daily frequency); and fish, poultry, eggs, sweets and red/processed meat (weekly frequency). Apart from dairy and poultry, all the other items are scored from 0 to 4 in direct or inverse proportion to their daily or weekly frequency (Table 1). Given the optimal consumption (score 4) of dairy products of 2−3/day and of 3/week for poultry, the score declines in a non-symmetric fashion both above and below the respective intervals (Table 1); the maximum score is 44. A rather accurate definition of the portions' size for each item is used and data were retrieved from a 91-items FFQ.

3.4.2. Evidence on health-related outcomes

The 12-week dietary intervention of the Canadian trial increased the MS score from an average of 21.1 ± 3.6 points to 28.6 ± 4.4 and was associated with minor improvements in BMI and apolipoprotein B levels [38]. Other intervention trials, performed by the same research group, confirmed small positive effects on several cardiovascular risk factors (weight, LDL-cholesterol, oxidized-LDL, inflammation) in response to an increase of 5-4 points in MD adherence, which were slightly more pronounced in men compared to women [38−45]. We could not find studies on MS and hard cardiovascular outcomes.

3.4.3. Comment

MS weighs all the food items as equally important and assumes a linear dose-response relationship for both "good" and "bad" food, with the only exception of poultry and dairy products (bell-shaped curves), with an unclear rationale. Among the questionnaires evaluated in this review, this is the only one that completely neglects the consumption of wine, or any other alcoholic beverage, and joins legumes, nuts and seeds in one single item. In terms of optimal serving frequency, this score is probably the most congruent with the updated MD pyramid [28] (Table 1 and Fig. 1). Unfortunately, the servings are only considered as integers and some rounding is necessary to univocally calculate the score, thus we adopted the mid-point between integers of the intervals for calculations.

3.5. 13-Items mediterranean style dietary pattern score (MSDPS)

3.5.1. Description

This score was developed in 2009 by a research group in Boston with the aim of overcoming the limitation of other indices that do not systematically consider the overconsumption of food items, which can be a problem, particularly in the US [46]. The score components are 13: whole cereals, fruit, vegetables, dairy, wine, fish, poultry, olives/legumes/nuts, potatoes, eggs, sweets, meat and olive oil. Except for olive oil, to each component is assigned a wide range of points oscillating between 0 and 10 in relation to how close the consumption is the optimal, defined according to the suggestions of the 1994 version of the MD pyramid for adults [47]. The score is weighted

negatively whenever the number of servings exceeds the optimal range in percent terms. When the consumption is exceeded by >100% the assigned score is 0. Olive oil is assigned a 10-points score if it is consumed exclusively, 5 if it is consumed with other oils and 0 if it is not consumed at all. The score also establishes a penalty depending on the percentage of energy provided by the consumption of food other than that of the items included in the score.

3.5.2. Evidence on health-related outcomes

The MSDPS was applied to dietary data collected during the 7th examination of the Framingham.

Offspring Cohort [46]. The quintiles of MSDPS were significantly and positively associated with the dietary intakes of fibers, n-3 polyunsaturated fatty acids (PUFA), antioxidant vitamins, calcium, magnesium and potassium. While the associations with added sugars, glycemic index, saturated fatty acids, *trans*-fat acids, n-6 PUFA: n-3 PUFA ratio were inverse.

Besides this cross-sectional analysis, the score has not been extensively tested. Two observational studies in the Framingham Offspring Cohort (mean age: 60 years) have shown that the 7-year incidence of metabolic syndrome was 30% in the highest MSDPS quintile vs 38% in the lowest quintile [48] and that a higher MSDPS is associated with maintenance of physical performance after 11 years [49]. Case-control studies have described that patients with colon [50], esophageal squamous cell [51] and prostate [52] cancer have a low adherence to MD assessed by the MSDPS.

3.5.3. Comment

By adopting a two-sided penalty on all the individual items, the MSDPS implies a bell-shaped relationship between the consumption of all food categories and MD adherence or health outcomes, an assumption that is neither rational nor evidence based. Paradoxically, an overconsumption of legumes and nuts or fruit has an equal weight of an overconsumption of meat. Wine is the only fermented beverage considered with different optimal ranges for men (0–21/week) and women (0–11/week). This is arbitrary since, for all-cause and cardiovascular mortality, alcohol appears protective regardless of the type of drink, and in both sexes with an upper threshold of 10/week [19,20]. Compared to the other scores (Fig. 1) and in absolute terms, the optimal consumption of vegetables and whole-grain (8/day = 56/week for both) appears extremely high with respect to common feeding behavior and is not justified by evidence, which is in favor of a flat dose-response curve beyond 4/5 servings/day for the sum of vegetables and fruit for all-cause, cardiovascular and cancer mortality [53]. On the other hand, the MSDPS questionnaire is too strict with respect to meat intake, calculating a maximum score for the consumption of 1/week and 0 either for 0 or ≥2/week (Fig. 1). In addition, processed meat is not specifically considered and it is probably included in the generic item of meat. Also, the optimal consumption of fish (>6/week) appears somewhat overzealous. Due to these shortcomings, MSDPS is probably the questionnaire that less closely follows the most updated MD pyramid and GBD indications among those evaluated [27,28]. Last, but not least, the correction for the proportion of calories from food not included in the list, makes this score inadequate for clinical use requiring a full FFQ, or at least a transformation of this 13 items-servings in calories and an independent estimate of total energy consumption.

3.6. 14-Items mediterranean diet serving score (MDSS)

3.6.1. Description

This score has been proposed in 2015 by a Spanish research group [54], on the basis of a FFQ administered to a cohort of women, with the intention of reflecting more closely the 2011 updated version of the MD pyramid [55]. The items considered are 14: fruit, vegetables, cereals (bread, rice and pasta), potatoes, olive oil, nuts, dairy products (milk, yogurt, cheese and ice-cream), legumes, eggs, fish, white meat, red meat, sweets (sugar, candies, pastries, sweetened beverages and soft drinks) and fermented beverages (wine and beer). A maximal score of 1, 2 or 3 is given for different items when the optimal consumption frequency is achieved, otherwise the score is 0. For fermented beverages the optimal frequency is of 2 glasses/day for men and 1 glass/day for women (Table 1). The total score is 24 and the best cut-off point for discriminating adherence to MD was 14. This score has been validated in a sample of Croatian students against the Mediterranean Diet Adherence Screener (MEDAS) [56].

3.6.2. Evidence on health-related outcomes

In a small sample (n = 349) of healthy Italian subjects the MDSS score was positively correlated to increased levels of HDL cholesterol and vitamin C, and negatively correlated with uric acid levels, triglycerides and smoking [57]. In the Croatian cohort of healthy subjects previously mentioned, it was correlated with age, and also with self-assessed health status and well-being [56]; The MDSS score has also been associated with a better nutritional status in kidney transplant recipients [58]. We could not find studies on health-related hard outcomes.

3.6.3. Comment

Among the scores evaluated in this review, MDSS is the only one that establishes a clear hierarchy among the single food items (3 = fruit, vegetables, cereals and olive oil; 2 = nuts and dairy; 1 = legumes, potatoes, fish, red and white meat, sweets and alcohol). This decision was made on the assumption that food to be eaten at each meal weighs more (score 3) than food to be eaten daily (score 2) or weekly (score 1), which appears extremely reasonable in terms of formally assessing adherence according to the MD pyramid. However, when the score is used to assess the impact of the diet on the risk of non-

communicable disease, this hierarchy among food groups might produce some distortion, being not fully evidence-based. Some food items have lower thresholds (vegetables, legumes and fish), others upper thresholds (potatoes, red meat and sweets), implying no graded dose-response. While for other foods (fruit, cereals, olive oil, nuts, dairy, eggs, white meat, alcohol) the consumption below or above the suggested optimal interval is scored zero (assuming a squared bell-shaped dose-response curve as indicated in Fig. 1 for fruit). While this assumption appears reasonable for alcohol, for the other food items it is not. There are other shortcomings: ≥2 servings of vegetables at each meal, including breakfast, is too high (Fig. 1) as an optimal target (it was in fact achieved by only 11.4% of the subjects); no distinction is made between refined and whole cereals; the optimal frequency of dairy products is lower than that recommended by recent expert consensuses [27,28] and the literature on cardiovascular outcomes [30]. Interestingly, the paper presenting the score [54] provides a clear comparison between subjects of the two extreme tertiles whose differences are concentrated only in 3 food items: sweets, red meat and white meat. This raises doubts regarding the ability of this score to discriminate between different dietary patterns in terms of MD and more in general of healthy dietary habits.

3.7. 15-Items Pyramid based Mediterranean Diet Score (PyrMDS)

3.7.1. Description

This score was developed by a UK based research group in 2016 [59] with the aim of adopting the indications of the 2011 version of the MD pyramid [55]. It consists of 15 items and, like the MSDPS, adopts the strategy of introducing different and continuous weights for both under and overconsumption, but in a different way for each food item. The optimal food frequency for each item is established according to the 2011 version of the MD pyramid [55] and is scored 1. Suboptimal consumption of legumes and vegetables (high frequency healthy foods) is scored with values from 0 to 0.99 in proportion to the servings (actual/optimal). The same applies to food to be consumed moderately (fruits, nuts, cereals, dairy, white meat, eggs) for which overconsumption (double the mid-point value of the recommended intake) is penalized with a score of 0.5; a consumption between the recommended level and the penalty point is scored in a proportional manner. The overconsumption of low frequency food (red and processed meat, potatoes, sweets) is penalized similarly to the moderate-consumption food. For alcohol, overconsumption is scored 0, while no consumption is scored 0.5.

3.7.2. Evidence on health-related outcomes

This score has been validated with respect to the incidence of CVD in the EPIC-Norfolk study, a cohort of 23 902 cases followed for 10 years [59]. A high adherence to MD, estimated with the score was associated with a linear reduction in CVD incidence, with a 5% reduction of the risk of incident CVD (HR [95%CI]: 0.95 [0.92−0.97] for each SD reduction in the score), and of 9% for CVD mortality (HR [95%CI]: 0.91 [0.87−0.96] for each SD reduction). It also has been shown to be superior to Australian Dietary Guidelines Index in predicting both cardiovascular outcomes and all-cause mortality in an Australian cohort of elderlies with different ethnic background [60].

3.7.3. Comment

This is probably one of the most accurate score/questionnaire among the ones evaluated, given that it closely follows the indications of the updated version of the MD pyramid [55] and also fits with the GBD evidence [27]. It also takes into consideration how close the consumption of the individual foods is to their optimal level, but with a hierarchical approach, since it only penalizes the overconsumption of foods to be eaten with moderation or rarely. The score also groups together wine and other fermented beverages [19], and acknowledges the substantial neutrality of dairy products [30]. It also differentiates between processed meat and red meat and poultry [61]. Overall, the score is easy to use being based on daily or weekly servings and is supported by solid evidence on hard outcomes.

Its major defects are: a) does not distinguish between whole-grain and refined cereals; b) is slightly overzealous with vegetables and permissive with meat (Fig. 1); c) underestimates the optimal consumption of legumes, which according to the GBD initiative [27] should be 3.5−4.9/week and not 2/week, while also penalizing overconsumption and d) the translation of the individual food frequencies in the respective scores requires a rather complex algorithm.

3.8. 16-Items Mediterranean Diet Adherence Screener (MEDAS) and 16-Items Energy restricted MEDAS (erMEDAS).

3.8.1. Description

The 14-items yes/no Mediterranean Diet Adherence Screener (MEDAS) questionnaire was developed by the PREDIMED investigators in 2011 [62]. Although it is stated that it re-elaborates the 9-items yes/no SMDQ questionnaire, its structure is rather different both for the items and the optimal thresholds. It contains 2 qualitative questions related to dietary habits ("Is olive oil the principal source of fat for cooking?", "Do you prefer white vs red/processed meat?") and 4 additional items are included (animal fat for cooking and dressing, carbonated and sweetened beverages, cakes and commercial pastries, and sofrito) in addition to olive oil, fruit, vegetables, meat, legumes and wine, while cereals are dropped. Minimal and maximal optimal frequencies for each quantitative item are defined either per day or per week, on somewhat unclear bases.

The MEDAS score has been validated against a 3-day FFQ in 7 European countries [63] and moderate correlations (r = 0.50−0.60) were observed in Portugal, Italy and Spain and a strong correlation in Greece (r = 0.90). In the same countries the majority of items exhibited a fair or moderate agreement with the exception of red meat and sofrito, for which agreement was poor. The questionnaire has been

translated and validated in UK [64] and also adapted and validated in Israel [65]. When tested with a validated full length FFQ in 7146 participants of the PREDIMED trial, the MEDAS score showed a moderate correlation (r = 0.52), with 48% of individuals grouped in the same score tertile, while only 9% grouped in opposite tertiles [62]. The MEDAS score was positively associated with nutrients and food intake considered healthy (vitamin C, β-carotene, folic acid, dietary fiber, unsaturated fat, vegetables, fruits, whole-grain cereals, nuts and fish) and was negatively associated with intake of sodium, saturated fat, sweetened beverages and refined cereals. In 2021 the PREDIMED investigators have proposed the 16-items energy-restricted MEDAS (erMEDAS), which was meant to capture moderation in food consumption [66]. Five additional questions were included in the score, regarding the addition of sugar to beverages (y/n), the consumption of white bread per day (≤1), of whole-grain bread/pasta/rice per week (≥5) and of refined bread/pasta/rice per week (<3). Optimal wine consumption per week, was differentiated between men (14/21) and women (7/14), while the amount of olive oil per day and the use of sofrito were both eliminated. Adherence to MD was defined poor for a 1-5score, moderate for 6–8 and high for a score ≥9.

3.8.2. Evidence on health-related outcomes

The PREDIMED-Reus trial evaluating the effects of MD versus a low-fat diet on the incidence of T2D in 418 non-diabetic subjects, demonstrated that the implementation of MD was associated with a 50% reduction (RR [95%CI]: 0.48 [0.27–0.86]) in T2D incidence, with a higher reduction in individuals with moderate fasting hyperglycemia (RR [95%CI]: 0.32 [0.11–0.98]). Notably, the difference in MEDAS score between the low-fat diet and MD was rather small (8.4 vs 7.9) [67].

In the PREDIMED cohort at 5-year follow-up, a 2-point transition in MEDAS score in obese subjects was associated with a 14% lower likelihood to develop unhealthy obesity (defined as ≥2 metabolic syndrome criteria) and a 16% reduction in the regression from unhealthy to healthy obesity (0–2 metabolic syndrome criteria), while healthy non obese subjects had a 20% reduction in the risk of developing obesity [68].

Another observational study has exploited the MEDAS questionnaire (SUN study), this cohort consisted of 20 155 university graduates from 5 Spanish Universities of whom 9 109, free of cancer, T2D and CVD at baseline, were followed for 6.2 years [69], exploring an aggregated outcome (T2D, CVD and all-cause mortality). An increase of 3 points in the MEDAS score was associated with a risk reduction of the composite endpoint of 25% (HR [95%CI] = 0.75 [0.58–0.97]), that was independent of sex, BMI, total energy intake, smoking and physical activity [70]. The individual outcomes could not be evaluated due to the low number of events, which was expected for the relatively young mean age of the population (38 years).

In addition, in a large (n = 20 338) Iranian cohort of patients with T2D attending tertiary care academic clinics followed for the subsequent 2 to 11 visits, a MEDAS score ≥7 was associated with a lower risk of CVD (OR [95%CI]: 0.61 [0.57–0.89]), symptomatic neuropathy (OR [95%CI]: 0.68 [0.64–0.72]), nephropathy (OR [95%CI]: 0.88 [0.80–0.96]) and retinopathy (OR [95%CI]: 0.68 [0.61–0.71]), after adjusting for age, sex, and other relevant cardiovascular risk factors [71].

3.8.3. Comment

Despite its wide use this tool has several limitations. By considering all the individual items as equally important and using optimal upper and lower thresholds and a 0/1 score, it ignores how close the individual diet is to the optimal threshold and assumes that the effect of each food has no dose-response relationship with major health outcomes. This is the only score separately evaluating the consumption of butter, margarine and cream, which are considered unhealthy foods (<1 serving/day), while no other dairy product is considered. It is particularly accurate in the evaluation of simple sugars consumption by considering carbonated and sweetened beverages, and sugar (in tea and coffee), in addition to sweets and pastries. However, not all these can be considered pillars of the MD and the score also neglects that carbonated beverages can be unsweetened. Optimal alcohol consumption is considered only for wine and in erMEDAS is different for males (14–21/week) and females (7–14/week), whilst, surprisingly, it has no upper threshold in MEDAS (≥7/week). For both cardiovascular and all-cause mortality there is no evidence of clear sex differences and the optimal alcohol consumption is between 3 and 14 drinks/week [19,20]. Optimal consumption of cereals (neglected in MEDAS) in erMEDAS is differentiated in 3 items: white bread (≤1/day), whole-grain bread/pasta/rice (≥5/week) and refined bread/pasta/rice (<3/week) with some overlap and possible confusion. Additionally, the threshold for red and processed meat (with no distinction between the two) is very low (≤1/week) and white meat is only considered a subjective preference.

Finally, the ability of erMEDAS to capture the moderation in calories intake is rather limited since for several items (nuts, legumes, fish and whole cereals) there is no upper limit, and the extent of the excess number of servings of unhealthy food (pastries, sugar, beverages) is not considered.

4. Discussion

The wide heterogeneity of the scoring systems and of the selected food items among the questionnaires have important consequences. We compared the dietary habits of 4 imaginary subjects with realistic servings' frequencies expected to differ in the degree of adherence to MD (Fig. 2). The tendency to sense large differences in dietary habits is present with all scores, yielding progressively lower values while adherence declines (Fig. 2 from A to D). However, in absolute terms, the results are not consistent. The estimated adherence differs to a large extent depending on the score used, with three questionnaires (MS, MSDPS and MDSS) generating relatively lower values

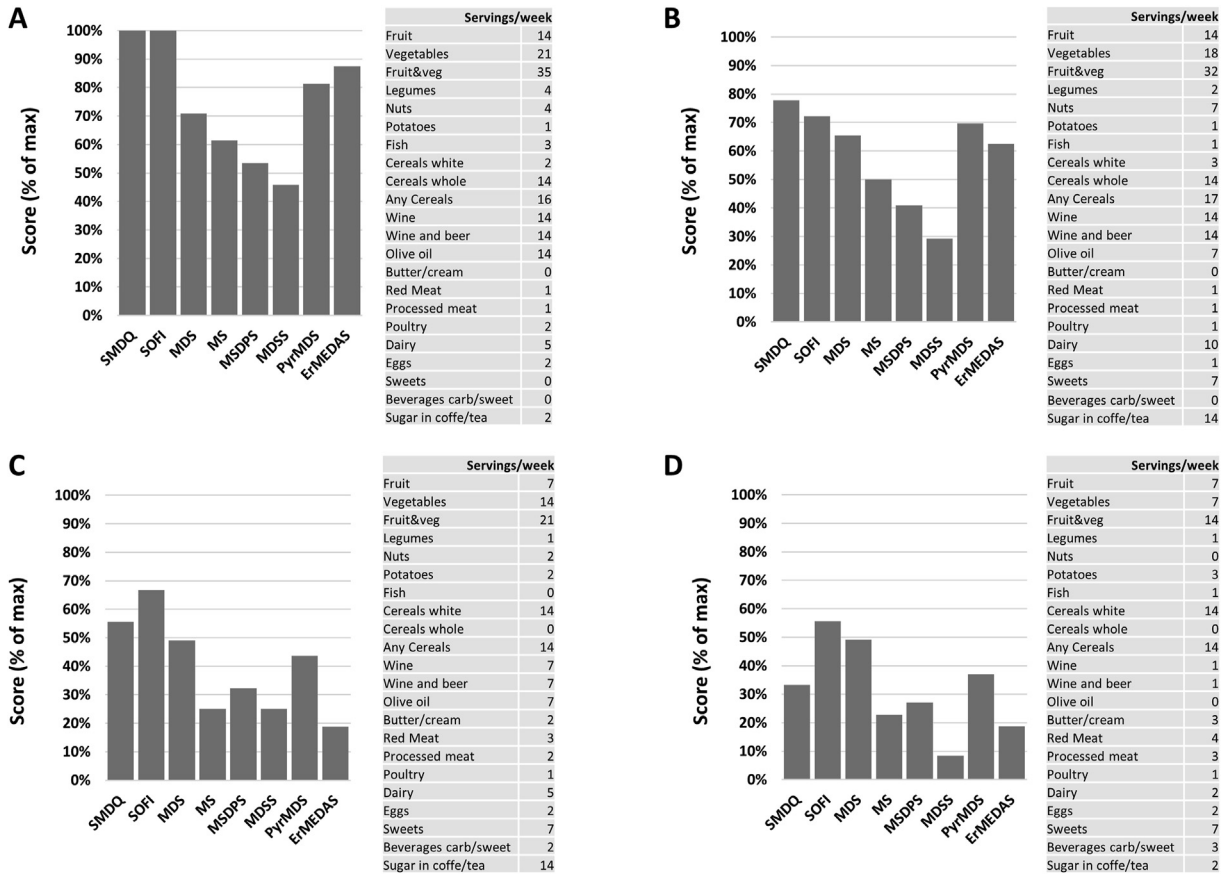

Figure 2 Comparison of the questionnaires' performance in estimating the adherence to the Mediterranean Diet of four imaginary subjects. The figure compares the adherence to the Mediterranean Diet of four imaginary subjects with decreasing MD adherence (from A to D). The adherence of every subject is calculated for each questionnaire based on realistic food servings per week (reported in the grey columns), and it is expressed as the ratio between the calculated score and the maximal score for each questionnaire.

with respect to the others. It is surprising that for the same individual both SMDQ and SOFI yield a 100% score, while MS, MSDPS and MDSS estimate an adherence between 45 and 60% (Fig. 2A). Apart from this trend, that is consistent across the 4 putative subjects, the large variability among all the scores makes an objective quantification of the adherence to MD impossible.

Even in relative terms, the different scores are not homogeneous. When the gradients from diet A to B, C and D were calculated either in absolute (-17 ± 8, -19 ± 13, $-8 \pm 8\%$) or percent (-22 ± 9, -25 ± 15, -11 ± 12) they resulted extremely variable with coefficients of variance ranging from 40 to 100%. The least sensitive indices were MDS and MSDPS with absolute gradients of -5, -16 and 0% and -13, -9 and -5%, respectively.

In general, the diet must be considered a therapy, in fact, the term "medical nutritional therapy" has been adopted in the most recent American Diabetes Association guidelines. As any other medical therapy, it requires robust criteria for diagnosis and also for monitoring. We are convinced that adherence to MD improves the health status of any individual and deviations from its pattern should be detected and selectively corrected through specific educational interventions. The major problem is that adherence to MD is difficult to measure. All the simple questionnaires (those based on servings) not only show defects and limitations inherent to the modelling assumptions, but also differ dramatically from each other (Table 1) in the single items considered and even in the optimal consumption thresholds. Therefore, they produce profoundly different estimates of adherence to MD (Fig. 2).

In this regard, a crucial aspect that differentiates the questionnaires included in this review is the assumption adopted to score the consumption of each item. Some questionnaires adopt a single threshold neglecting both how close is the frequency to the ideal target and over-consumption (MDSS, MDQ, SOFI, MDS, erMEDAS) while others set an optimal consumption range for each item and adopt a gradual variation in the attributed points proportionally to the degree of both under- or over-consumption of different foods (MS, MSDPS and PyrMDS). The latter approach is certainly more accurate in detecting the deviations from the pattern, provided that also that over-consumption of some healthy food (*e.g.* fruits, cereals, dairy, nuts) is not advisable since it might limit the consumption of the other healthy food or produce a calorie excess. Among the 3 gradual questionnaires, the PyrMDS is the only one that adopts an unique graded-scoring system that

is different for specific food groups: a threshold for overconsumption of unhealthy food (red and processed meat, sweets), a bell shaped curve for alcohol, a partial decline of the score for overconsumption of fruits, nuts, cereals, dairy, white meat and egg and no negative effect of overconsumption of vegetables, legumes and fish. These assumptions are all rational and somewhat supported by ecological studies. In addition, PyrMDS closely follows both latest recommendation of the MD pyramid and, to a large extent, the GBD evidence, and has been validated in large cohorts of non-mediterranean countries in terms of hard outcomes [59]. On the basis of these considerations, we consider the PyrMDS questionnaire the most accurate and reliable tool to estimate MD adherence in clinical practice.

An additional issue, often overlooked when addressing the adherence to MD, is that individual countries show dietary differences due to their unique cultural and culinary traditions. Thus, even neighboring Mediterranean countries, although broadly following the principles of MD, can have unique recipes and different preparations. Even so, a recent study found that several southern Mediterranean nations show a similar adherence to MD despite the expected differences in dietary habits [72]. Therefore, even if dietary patterns in Mediterranean nations might vary, this does not significantly affect the estimates of MD adherence, also because it is based on food items that are largely available and consumed worldwide and not on food preparation.

5. Conclusions

It is possible to reliably detect the MD adherence in any subject in a clinical setting through a simplified questionnaire. As a study group, we suggest the use of the PyrMDS score which, among the 8 questionnaires evaluated, is the one with less defects and a with solid literature in support of the hard health-related outcomes. Information on consumption of whole, rather than any, cereals should be adopted, and the optimal range of legumes servings should be revised to 3.5–4.9 rather than 2 to make it more up to date. To promote and facilitate its use we have developed an open web-based tool (www.siditalia.it/divulgazione/alimentazione-e-diabete) to provide the estimate of adherence to the MD based on the PyrMDS questionnaire that does not require calculations, and offers a direct graphical assessment of adherence to each single item, in order to improve communications with the patients.

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Declaration of competing interest

The authors have nothing to disclose.

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