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A systematic review, meta-analysis, and meta-regression of the impact of diurnal intermittent fasting during Ramadan on body weight in healthy subjects aged 16 years and above

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Abstract

Purpose Studies on the efect of Ramadan diurnal intermittent fasting (RDIF) on body weight have yielded conlicting results. Therefore, we conducted a systematic review and meta-analysis to estimate the efect size of body weight changes in healthy, non-athletic Muslims practicing Ramadan fasting, and to assess the efect of covariates such as age, sex, fasting time duration, season, and country, using subgroup analysis, and meta-regression. Covariate adjustments were performed to explain the variability of weight change in response to Ramadan fasting.

Methods CINAHL, Cochrane, EBSCOhost, EMBASE, Google Scholar, ProQuest Medical, PubMed/MEDLINE, ScienceDirect, Scopus, and Web of Science databases were searched from date of inception in 1950 to the end of August 2019.

Results Eighty-ive studies, conducted in 25 countries during 1982–2019, were identiied. RDIF yielded a signiicant, but small reduction in body weight (K = 85, number of subjects, N = 4176 (aged 16–80 years), Hedges' g =− 0.360, 95% conidence interval (CI) − 0.405 to − 0.315, I^2 = 45.6%), this efect size translates into diference in means of − 1.022 kg (95% CI − 1.164 kg to − 0.880 kg). Regression analysis for moderator covariates revealed that fasting time (min/day) is a signiicant (P < 0.05) moderator for weight change at the end of Ramadan, while age and sex are not. Variable efects for the season and country were found.

Conclusion RDIF may confer a signiicant small reduction in body weight in non-athletic healthy people aged 16 years and above, directly associated with fasting time and variably correlated with the season, and country.

Keywords Body weight · Caloric restriction · Diurnal intermittent fasting · Meta-analysis · Obesity · Ramadan · Systematic review

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Introduction

Obesity represents one of the causal factors for the most prevalent non-communicable diseases worldwide, with a concomitantly high economic and societal burden, respectively [1, 2]. The economic and health burden arises from the high cost of the medical management of obesity-related comorbidities, such as diabetes, cardiovascular diseases, and cancers [3]. Mounting evidence supports the notion that caloric restriction, weight-reducing diets or intermit-tent fasting, and physical exercise can reverse, or protect against, the adverse metabolic perturbations associated with obesity [4–6].

Ramadan is the ninth month of the Islamic lunar calendar, during which healthy adult Muslims refrain from consum-ing food and drink from dawn until sunset. During Rama-dan, and throughout the globe, the majority of practicing

Muslims have two main meals, one immediately after sunset (*suhoor*) and one just before dawn (*iftar*) [7]. During the night hours, from sunset to dawn, people are permitted to eat and drink freely, but they are not allowed to consume any food or drink after dawn [8]. Ramadan diurnal intermittent fasting (RDIF) represents a unique pattern of intermittent fasting that involves consistent diurnal abstinence from food and drink, for a fasting period of 12–18 h (depending on the season) over 29–30 days.

The impact of intermittent fasting and caloric restriction on body weight loss has been questioned, and several original research and review articles have been published in an attempt to answer this question during the last decade [5, 6, 9–16], with indings, however, bereft of uniformity. Given that Ramadan fasting is a form of intermittent fasting and time-restricted feeding pattern [17, 18] that is globally observed, its impact on body weight loss is of contemporary interest. Furthermore, in a recent meta-analysis on metabolic syndrome components (waist circumference, systolic blood pressure, fasting plasma/serum glucose, triglycerides, and high-density lipoprotein cholesterol) [19], bodyweight change was not investigated. Thus, the present systematic review and meta-analysis aimed to systematically summarize and analyze available scientiic evidence and to clarify the results of published literature about the efect of RDIF on body weight in healthy, non-athletic people observing Ramadan fasting. The current meta-analysis also investigates the impact of some contextual variables, speciically; the duration of the intermittent fasting period on the magnitude of weight loss. Findings of the current review will help to systematically and comprehensively test the efect size of body weight changes in healthy, non-athletic Muslims practicing fasting during Ramadan month, assess the generalizability of reported results, obtain a more stable estimate of the efect size of fasting during Ramadan on body weight change, and conduct subgroup analyses for associated confounding factors and to investigate diferences between diferent seasons and countries. Based on the nature of Ramadan fasting that involves consistent, frequent abstinence from food and drink, even water, we hypothesized that this systematic review and meta-analysis would show a signiicant body weight loss at the end of the fasting month.

Materials and methods

This meta-analysis used Meta-analysis Of Observational Studies in Epidemiology (MOOSE) as a guideline for reporting indings [20].

Database searches

Two authors (JS and MF) conducted an electronic search in ten databases: CINAHL, Cochrane, EBSCOhost, EMBASE, Google Scholar, ProQuest Medical, PubMed/MEDLINE, ScienceDirect, Scopus and Web of Science from database inception in 1950 to the end of August 2019. The search strategy included relevant keywords :"Islamic fasting" Or "Ramadan fasting" OR "Ramadan diurnal fasting" OR "Ramadan intermittent fasting" OR "Ramadan model of intermittent fasting" OR "Ramadan fast" OR "Intermittent prolonged fasting during Ramadan" OR "Recurrent circadian fasting" AND "body weight" OR "body composition" OR " body mass" OR "body mass index" OR "anthropometrics" OR "anthropometry". Reference lists of the obtained studies were hand searched, and authors were contacted to ind relevant articles and reviews and to make sure that all related publications were included in the current analysis.

Inclusion criteria

We included observational and intervention clinical studies that studied the efect of RDIF on body weight. Inclusion criteria for study selection were: (1) publication date between the inception of the database in 1950 to the end of August 2019; (2) original research articles published in the English language; (3) studies that reported numerical values (e.g., arithmetic mean with/without standard deviation, SD) for the body weight; (4) studies that assessed the efect of RDIF on healthy people as the target population in prospective observational studies or as healthy controls in case–control, semi-experimental, and experimental or interventional studies. As we were looking for studies that examined the efect of RDIF on body weight, we included studies that measured body mass in at least two stages: before Ramadan fasting month as the baseline (e.g., few days or 1–2 weeks before Ramadan month or the irst few days of Ramadan month), and post fasting (at least two weeks into the fasting month or after completion of the fasting month). It should be noted that Islamic laws pertaining to fasting specify that premenopausal women are exempt from fasting during menstruation days; therefore, these women are not expected to complete fasting for the whole month of Ramadan. A similar exemption applies to older people who may ind it hard to complete the entire Ramadan month and may miss some fasting days. AQ3

Exclusion criteria

The following exclusion criteria were applied on retrieved articles to eliminate factors that may incur potential methodological and quality issues: (1) studies that were exclusively conducted on fasting children and adolescents (less than 18 years old), (2) studies that included patients with diferent diseases or conditions who were observing RDIF including diabetes; (3) studies on the efect of RDIF on Muslim athletes who were observing Ramadan fasting; (4) lack of full text after contacting the respective authors; (5) studies that expressed changes in body weight using bar graphs and curves, without reporting exact numerical values; (6) studies on pregnant and/or lactating women who were observing Ramadan fasting; (7) studies that reported the post-Ramadan measurement after passing one month or longer, as mounting evidence supports that biochemical variables induced by RDIF disappear or return to the pre-fasting level after one month of Ramadan cessation [21–23]; (8) case reports, abstracts, review articles, editorials, and non-English-language articles; (9) unpublished, non-peer-reviewed data; all of which were excluded from the quantitative and qualitative analysis; and (10) studies that involved special dietary and physical activity plans during the fasting month. Articles were excluded from the current analysis if they met any of the aforementioned criteria. The low dia-gram of study selection is presented in Fig. 1.

Main outcomes and measures

The principal outcome of this review was to report the efect of RDIF as efect size changes in body weight. Two authors (JS and MF) independently screened the titles and abstracts of identiied studies and assessed the studies for eligibility. The screening was done by irst going through all titles and abstracts to exclude irrelevant publications. Two authors (JS and MF) performed the initial data extraction. Any conlicts in opinion regarding study eligibility were resolved through dialog with a third member (HJ) to reach consensus. To standardize data extraction, the review team collected data for study characteristics (e.g., title, country, year, sample size, participants' characteristics such as sex, age, or propor-tion of males); and the main indings for body weight before

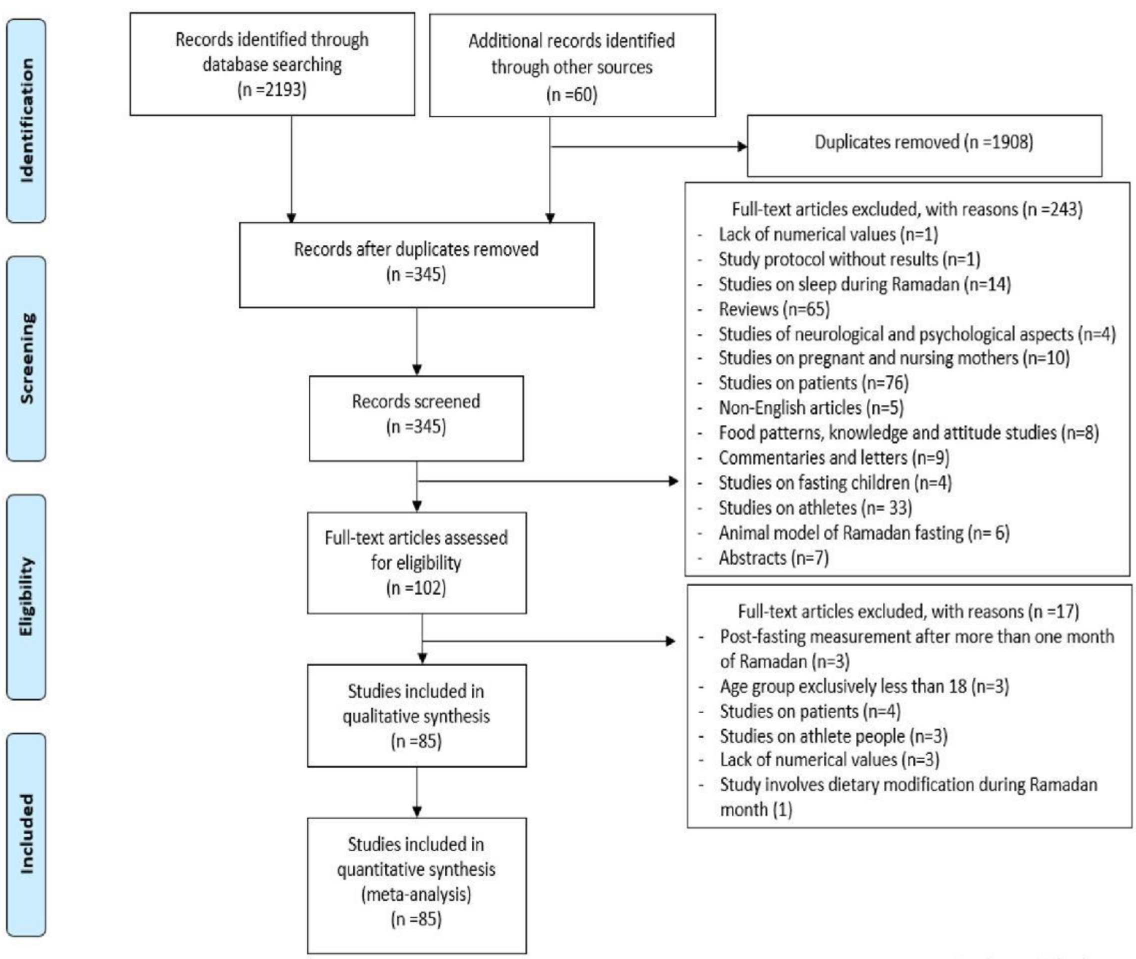

Fig. 1 Flowchart for the selection of publications included in the systematic review and meta-analysis

and at the end of Ramadan. Extracted data were entered into Microsoft Excel Sheet in preparation for analyses.

Estimating fasting time length and season

Ramadan month, as presented in the lunar calendar, was matched with the Gregorian calendar using a time and date website (https://www.timeanddate.com/holidays/us/ramadan-begins). The daily length of fasting during Ramadan month was calculated using the sunrise and sunset times reported for that month for the city/country of each included study (https://www.timeanddate.com/sun/@8469718). Time points for Ramadan fasting are the call to prayer (*Athan*) for *Fajr* (abstinence or *Imsak* time, end of pre-fasting mealtime or *suhoor*) and sunset or *Maghrib* (breakfast or *Iftar* meal-time) prayer times. The sunrise prayer time is declared by *Fajr Athan* to be about a mean of 80 min before the real sunrise time, as recorded in the Islamic calendar for prayer times. Therefore, the actual length of fasting time was calculated by adding 80 min to the time between the sunrise and sunset time points. Details of the pre-dawn *Fajr* and sunset *Maghreb* prayer time points on the Islamic calendar are available on the Islamic Finder website for Sharjah city, United Arab Emirates (UAE) (https://www.islamicinder.org/world/united-arab-emirates/292672/sharjah-prayer-times/). This showed that the length of fasting time for a speciic day (time between the *Fajr* and *Maghrib* prayer times) was 787 min (approximately 13 h), which was close to the length of fasting time calculated using the solar calendar (sunrise and sunset time points) for the month of Ramadan in Sharjah during the Islamic/Hijri year 1429 AH Georgian calendar year of 2008 in Sharjah city/UAE.

According to the meteorological deinition, the seasons begin on the irst day of the months that include the equinoxes and solstices: spring runs from March 1 to May 31; summer runs from June 1 to August 31; fall (autumn) runs from September 1 to November 30, and winter runs from December 1 to February 28. When the lunar month of Ramadan falls in two solar months, Ramadan is classiied according to the solar month with a signiicant number of days (e.g., Ramadan in 2009 started on the 22nd of August. Thus, Ramadan was classiied to run in autumn not summer). Start day for the month of Ramadan, with its corresponding solar day was taken from the website: https://www.timeanddate.com/holidays/us/ramadan-begins.

Data synthesis and statistical analyses

Combined means were computed when the study included subgroups (e.g., healthy body weight, overweight, obese) with diferent means and SD for each subgroup. See the supplementary ile (Supp. 1) for equations needed to recreating a mean from two or more groups [24]. *P* values for these combined subgroups means were calculated. All descriptive and inferential tests were performed using STATA software (Stata, M.P., 15.0. College Station, TX: StataCorp, 2017).

We performed a series of one group (pre-post) meta-analyses using pre- and post-means model, sample size, and P-values (paired groups). Hedges' *g* value was used for efect size measurement. An efect size of ≤ 0.2 was described as a small efect, an efect size around 0.5 as a medium efect, and an efect size around 0.8 was as a large efect. A Hedges' *g* value of one (1) indicates the two groups difer by one SD, a *g* value of two indicates they difer by two SDs, and so on. Standard deviations are equivalent to *z* scores (1 SD = 1 *z* score). In addition to Hedges' *g* values, forest plots were used to present the results graphically and to illustrate point estimates of the efect size and 95% conidence interval (CI). Random-efects modeling was used for all analyses. Using random-efects modeling, we, therefore, assume that there is not only one true efect size, rather, a distribution of true efect sizes. We, therefore, sought to estimate the mean of this distribution of true efect sizes. Sensitivity analyses were performed for body weight by removing one study at a time to determine if the pooled efect size was arbitrary or inluenced by one single study in all of the components.

Tau (τ^2) and I^2 statistics were used to assess the heterogeneity of the solicited studies within and between studies, respectively. Comprehensive Meta-Analysis version 3 [25] was used for all analyses. Leave-one-out sensitivity analyses were conducted by iteratively eliminating one study at a time to conirm any single study did not drive our meta-analysis indings. Moderator analysis was performed using: subgroup analysis for categorical variables (country, and season), and meta-regression for integer or decimal variables (age, the percentage of male subjects, and fasting time per day). Com-puting τ^2 and I^2 statistics were particularly vital to exam-ine heterogeneity due to explainable causes, for example, the timing of data collection before Ramadan month, and post fasting. Cochrane Handbook for Systematic Reviews of Interventions was used to interpret τ^2 and I^2 [26, 27]. For the I^2 a general guide to the interpretation of I^2 is as follows: 0–40%: might not be signiicant; 30–60%: may represent moderate heterogeneity; 50–90%: may represent substantial heterogeneity; 75–100%: considerable heterogeneity. For τ^2 because it represents the absolute value of the real variance (heterogeneity), the statistical signiicance was used.

The estimating algorithm for a random-efects meta-regression model was obtained using methods of moments [28]. The beta-coeicients and *P* values resulting from mod-eling were reported. Graphical plots are presented to aid the interpretation of the results visually. Funnel-plot based analysis was used to detect publication bias. Furthermore, the nonparametric trim and ill method was used to conirm indings [29]. Subgroup analysis for body weight change was performed to investigate diferences between countries. We

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Table 1 Characteristics and indings of the included studies on the efect of Ramadan diurnal intermittent fasting on body weight

Authors	Year	Country/continent	Study design	Sample size *n* (% male)	Mean age/age range (year)	BW before Ramadan (kg)	BW after Ramadan (kg)	Discussion	Quality assessment score
Fedail et al. [104]	1982	Sudan/Africa	Prospective observational[a]	24 (83.3)	30 (21–40)	69.5	67.7	There was a signiicant fall in body weight	4
Azizi and Rasouli [105]	1987	Iran/Asia	Prospective observational[a]	9 (100)	(23–54)	65.4	61.6	There was a signiicant reduction in body weight	3
Takruri [67]	1989	Jordan/Asia	Prospective observational[a]	137 (66)	(19–59)	67.64	65.54	The results showed a signiicant loss in body weight	4
El Ati et al. [106]	1995	Tunisia/Africa	Prospective observational[a]	16 (0)	(25–39)	59.3	58.9	No signiicant changes were observed in body weight	3
Adlouni et al. [107]	1997	Morocco/Africa	Prospective observational[a]	32 (100)	(25 -50)	69.61	67.83	The results showed a signiicant loss in body weight	3
Finch et al. [108]	1998	England/Europe	Prospective observational[a]	41 (37)	35.3 ± 1.8 (19–63)	71	70.7	There were no signii-cant changes in body weight over Ramadan	4
Maislos et al. [109]	1998	Israel/Asia	Prospective observational[a]	22 (64)	24 (20–45)	68	67	No signiicant changes were observed in body weight	4
Bilto [110]	1998	Jordan/Asia	Prospective observational[a]	74 (81)	(20–48)	72	70.8	The results showed a signiicant loss in body weight	4
Kayıkçıoglu [30]	1998	Turkey/Asia	Prospective observational[a]	32 (100)	22.3 ± 2.9	71.6	70.7	The results showed a signiicant loss in body weight	3
Akanji et al. [111]	2000	Kuwait/Asia	Prospective observational[a]	49	47.6 ± 10.8	81.8	81.5	There were no signii-cant changes in body weight over Ramadan	4
Ramadan [37]	2002	Kuwait/Asia	Prospective observational[a]	16 (100)	NR	80.16	79.1	There were no signii-cant changes in body weight over Ramadan	2
Afrasiabi et al. [112]	2003	Iran/Asia	Prospective observational[a]	16 (100)	NR	79.8	78.6	There were no signii-cant changes in body weight over Ramadan	2
Kassab et al. [113]	2003	Bahrain/Asia	Prospective observational[a]	44 (0)	(18–45)	79.25	78.6	There were no signii-cant changes in body weight over Ramadan	3
Fakhrzadeh et al. [114]	2003	Iran/Asia	Prospective observational[a]	91 (55)	19.9 ± 1.8	63.01	62.17	Fasting caused a sig-niicant reduction in weight in men	4

Table 1 (continued)

Authors	Year	Country/continent	Study design	Sample size *n* (% male)	Mean age/age range (year)	BW before Ramadan (kg)	BW after Ramadan (kg)	Discussion	Quality assessment score
Yucel et al. [39]	2004	Turkey/Asia	Prospective	38 (55)	32.5 ± 12.5 (20–45)	68.67	68.64	No statistically signiicant diference was found before and after Ramadan	4
Rahman et al. [115]	2004	Bangladesh/Asia	Prospective observational[a]	20 (100)	38.27 ± 4.07	64.05	62.07	Body weight decreased signiicantly during Ramadan compared with before Ramadan	3
Kassab et al. [116]	2004	Bahrain/Asia	Prospective observational[a]	46 (0)	22±2 (18–45)	80.8	80.1	There were no signiicant changes in body weight over Ramadan	4
Aksungar et al. [117]	2005	Turkey/Asia	Prospective observational[a]	24 (50)	(21–35)	72.69	72.58	There were no signiicant changes in body weight over Ramadan	4
Farshidfar et al. [118]	2006	Iran/Asia	Pre-experimental	21 (NR)	NR	58.77	57.94	Decrements in mean weight of cases at the end of Ramadan were statistically signiicant	2
Al-Numair [119]	2006	Saudi Arabia/Asia	Prospective observational[a]	45 (100)	(30 -45)	85.5	83.2	The results showed a signiicant loss in body weight	3
Ziaee V et al. [120]	2006	Iran/Asia	Cohort	81 (51)	22.7 ± 2.3 (20–35)	62.4	61.2	The results showed a signiicant loss in body weight	4
Dewanti et al. [121]	2006	Indonesia/Asia	Prospective observational[a]	37 (100)	39±10 (17–62)	64.5	63	The results showed a signiicant loss in body weight	3
Subhan et al. [97]	2006	Pakistan/Asia	Case–control longitudinal	46 (100)	24.2 ± 6.4 (16–41)	70.48	69.96	Body mass in Ramadan was signiicantly lower relative to pre-Ramadan	3
Salehi and Neghab [122]	2007	Iran/Asia	Prospective observational[a]	28 (100)	23.4 (20–26)	84.1	79.03	Fasting resulted in a signiicant decrease in the mean values of body weight	3
Al Hourani and Atoum [123]	2007	Jordan/Asia	Prospective observational[a]	57 (0)	21.6 ± 4.14 (18–29)	57.5	56.9	Body weight decreased signiicantly during Ramadan fasting	3

Table 1 (continued)

Authors	Year	Country/continent	Study design	Sample size *n* (% male)	Mean age/age range (year)	BW before Ramadan (kg)	BW after Ramadan (kg)	Discussion	Quality assessment score
Mansi [124]	2007	Jordan/Asia	Cohort	70 (NR)	21 ± 1.6	76.64	72.66	Body weight at the 4th week of Ramadan was signiicantly lower than pre-Ramadan values	2
Mansi and Amneh [124]	2007	Jordan/Asia	Prospective observational[a]	42 (100)	21.3 ± 1.6	76.64	72.66	Body weight was signiicantly lower than pre-Ramadan values	3
Moosavi et al. [125]	2007	Iran/Asia	Cohort	117 (66)	23.9 (26.2–29.6)	67.6	67.1	There was a signiicant diference between the pre- and post- Ramadan mean weights	4
Ibrahim et al. [126]	2008	UAE/Asia	Prospective observational[a]	14 (64)	(25–58)	70.5	69.1	There were no signiicant changes in body weight over Ramadan	4
Shariatpanahi et al. [127]	2008	Iran/Asia	Prospective observational[a]	55 (100)	34.1 ± 8.9 (34 -61)	80.69	78.73	The results showed a signiicant loss in body weight	3
Lamri-Senhadji et al. [42]	2009	Algeria/Africa	Prospective	46 (48)	24±3	61.87	61.39	There were no signiicant changes in body weight over Ramadan	4
Norouzy et al. [128]	2010	Iran/Asia	Prospective cohort	240 (66)	40 (18–70)	71.81	70.72	Ramadan fasting caused a signiicant reduction in body weight	4
Pathan and Patil [129]	2010	India/Asia	Prospective observational[a]	39 (100)	(25 -35)	61.9	60.56	The results showed a signiicant loss in body weight	3
Abedelmalek et al. [43]	2011	Tunisia/Africa	Case–control	9 (100)	22.1 ± 0.2	74	71.5	The body mass was signiicantly lower in the fourth week of Ramadan	3
Assadi et al. [59]	2011	Iran/Asia	Prospective observational[a]	58 (100)	40.7 ± 7.1	78.61	77.24	The results showed a signiicant loss in body weight	3
Ünalacak et al. [130]	2011	Turkey/Asia	Cross-sectional	20 (100)	27.4 ± 5.2	77.55	75.5	Signiicant weight reduction was observed in the study group	3

Table 1 (continued)

Authors	Year	Country/continent	Study design	Sample size *n* (% male)	Mean age/age range (year)	BW before Ramadan (kg)	BW after Ramadan (kg)	Discussion	Quality assessment score
Faris et al.[90] a	2012	Jordan/Asia	Cross-sectional	50 (42)	32.7 ± 9.5 (18–51)	71.82	70.58	Body weight was signiicantly lower during Ramadan as compared with before Ramadan	4
Faris et al. [131] b	2012	Jordan/Asia	Cross-sectional	50 (42)	32.7 ± 9.5 (18–51)	72.5	71.7	The results showed a signiicant loss in body weight	4
Khattak et al. [78]	2012	Malaysia/Asia	Prospective observational[a]	20 (50)	NR	80.88	69.43	Weight was signiicantly reduced in obese individuals on day 21 of Ramadan	2
Shehab et al. [132]	2012	UAE/Asia	Prospective observational[a]	60 (60)	43.2 ± 9.4	78.58	77.63	The results showed a signiicant loss in body weight	4
Agoumi et al. [133]	2013	Spain/Europe	Cohort	55 (40)	(18–70)	77.45	76.67	Body weight decreased due to fasting in Ramadan	4
Develioglu et al. [45]	2013	Turkey/Asia	Prospective observational[a]	35 (100)	35.86 ± 11.07 (20–59)	77.17	75.97	Body weight decreased signiicantly during Ramadan fasting compared with before fasting	3
Haouari-Oukerro et al. [134]	2013	Tunisia/Africa	Prospective observational[a]	38 (100)	20.8 ± 1 (18–23)	70	68.7	There were no signiicant changes in body weight over Ramadan	3
Hosseini et al. [135]	2013	Iran/Asia	Semi-experimental	11 (0)	(20–45)	71.1	69.9	The results showed a signiicant decline in body weight at the end of Ramadan	3
Norouzy et al. [36]	2013	Iran/Asia	Prospective observational	240 (66)	40.1 ± 0.7 (18–70)	71.81	70.72	There was a signiicant reduction in body weight in almost all subjects	4
Rohin et al. [136]	2013	Malaysia/Asia	Prospective observational[a]	46 (30)	33.04 ± 4.57 (25–40)	66.16	64.81	There was a signiicant reduction in body weight	4
Sayedda et al. [137]	2013	India/Asia	Prospective observational[a]	20 (100)	24.65 ± 4.38 (19–32)	71.1	68.92	Body weight was found to be signiicantly decreased	3

Table 1 (continued)

Authors	Year	Country/continent	Study design	Sample size *n* (% male)	Mean age/age range (year)	BW before Ramadan (kg)	BW after Ramadan (kg)	Discussion	Quality assessment score
Alzoghaibi et al. [44]	2014	Saudi Arabia/Asia	Prospective observational[a]	8 (100)	26.6 ± 4.9 (25–35)	69.1	66.3	There were no signiicant changes in body weight over Ramadan	3
Cansel et al. [138]	2014	Turkey/Asia	Prospective cohort	40 (60)	29.3 ± 5.9 (19–40)	61.8	62.3	There were no signiicant changes in body weight over Ramadan	4
Celik et al. [139]	2014	Turkey/Asia	Prospective observational[a]	42 (100)	35 ± 8.9	80.4	78.8	Ramadan fasting in healthy adult men was associated with signiicant decreases in body weight	3
Feizollahzadeh et al. [74]	2014	Iran/Asia	Prospective observational[a]	70 (100)	47.88 (30–70)	79.77	77.93	There was a signiicant reduction in body weight	3
Hassan and Isawumi [140]	2014	Nigeria/Africa	Prospective observational[a]	60 (60)	42.3 ± 16.7	65.92	65.29	There were no signiicant changes in body weight over Ramadan	4
McNeil et al. [141]	2014	Canada/ North America	Prospective observational[a]	20 (100)	(20–35)	90.35	88.55	No signiicant diference in body weight was noted	3
Salahuddin and Javed [142]	2014	India/Asia	Case–control	30 (NR)	(35–65)	60.47	58.52	There were no signiicant changes in body weight over Ramadan	2
Begum et al. [143]	2015	Bangladesh/Asia	Prospective	60 (100)	(24–28)	61.51	58.97	Mean body weight signiicantly decreased	3
Gnanou et al. [144]	2015	Malaysia/Asia	Prospective observational[a]	20 (100)	(19–23)	63.07	61.55	Subjects experienced a signiicant decrease in body weight	3
Hosseini and Hejazi [145]	2015	Iran/Asia	Quasi-experimental	25 (52)	NR	69.3	68.79	The results showed a signiicant decline in body weight	2
López-Bueno et al. [146]	2015	Spain/Europe	Longitudinal	62 (0)	33.6 ± 12.7 (18–61)	67.2	66.1	There was a signiicant reduction in total body weight values	3
Sijavand et al. [62]	2015	Iran/Asia	Prospective observational[a]	89 (57)	34.97 (20–50)	77.59	76.62	A week after Ramadan, body weight decreased compared to a week before Ramadan	4

Table 1 (continued)

Authors	Year	Country/continent	Study design	Sample size *n* (% male)	Mean age/age range (year)	BW before Ramadan (kg)	BW after Ramadan (kg)	Discussion	Quality assessment score
Suriani et al. [147]	2015	Malaysia/Asia	Prospective observational[a]	84 (0)	39.8 ± 10.3	78.76	77	The results showed a signiicant decline in body weight	3
Talib et al. [148]	2015	Qatar/Asia	Cohort	45 (100)	37 ± 7.2 (27–56)	94.67	94	The results showed a signiicant decline in body weight	3
BaHammam et al. [149]	2016	Saudi Arabia/Asia	Prospective observational[a]	80 (100)	26.6 ± 4.9 (20–35)	67.5	66.3	The results showed a signiicant decline in body weight	3
Ganjali et al. [150]	2016	Iran/Asia	Quasi-experimental	45 (58)	37.6 ± 6.9 (25 -58)	81.47	79.62	The results showed a signiicant decline in body weight	4
Syam et al. [38]	2016	Indonesia/Asia	Longitudinal	43 (16)	34.19 ± 11.25	59.82	58.95	By the 28th day of Ramadan, it was found that the body weight had decreased signii-cantly	4
Nugraha et al. [151]	2017	Germany/Europe	Prospective observational[a]	25 (100)	26.12 ± 0.98	77.82	76.04	Participants experienced a signiicant loss in body weight	3
AbdulKareem et al. [152]	2017	Iraq/Asia	Case–control	12 (25)	37.5 ± 10.81 (24–57)	67.2	66.1	Healthy subjects showed a signiicant decrease in the body weight	4
Alsubheen et al. [80]	2017	Canada/North America	Prospective observational[a]	9 (100)	32.2 ± 7.8	82.9	80.8	Signiicant reduction in body weight was observed at the end of Ramadan	3
Bakki et al. [153]	2017	Nigeria/Africa	Cross-sectional	75 (62.6)	25±2 (18–30)	59.1	56.8	No signiicant diference in body weight was noted	4
Khan et al. [154]	2017	Pakistan/Asia	Prospective observational[a]	35 (51)	21.66 ± 0.68 (21 -23)	60.49	60.46	No signiicant diference in body weight was noted	4
Kiyani et al. [155]	2017	Pakistan/Asia	Prospective observational[a]	80 (62.5)	20.5 (18–24)	62.7	62.3	No signiicant diference in body weight was noted	4
Latiri et al. [156]	2017	Tunisia/Africa	Prospective observational[a]	29 (100)	27±1 (20–40)	81.6	81.2	There was no statisti-cally signiicant efect of Ramadan fasting on body weight	3

Table 1 (continued)

Authors	Year	Country/continent	Study design	Sample size *n* (% male)	Mean age/age range (year)	BW before Ramadan (kg)	BW after Ramadan (kg)	Discussion	Quality assessment score
Malekmakan et al. [60]	2017	Iran/Asia	Semi-experimental	93 (52.7)	37.2 ± 7.9 (25–57)	71.6	70.4	The results showed a signiicant decline in body weight	4
Mohammadzade et al. [49]	2017	Iran/Asia	Prospective observational	30 (100)	29.44 ± 7.4 (20–35)	82.73	80.43	The results showed a signiicant decline in body weight	3
Norouzy et al. [61]	2017	Iran/Asia	Prospective observational	12 (50)	54.6 ± 4	67.4	67.5	There was no statistically signiicant efect of Ramadan fasting on body weight	4
Ongsara et al. [157]	2017	Thailand/Asia	Prospective observational	65 (32)	20.82 ± 1.14 (19–24)	55.7	55.1	There was no statistically signiicant efect of Ramadan fasting on body weight	4
Pallayova et al. [54]	2017	Qatar/Asia	Prospective observational	18 (28)	24 (21–27)	64.6	62.2	There was no statistically signiicant efect of Ramadan fasting on body weight	4
Roy and Bandyopadhyay [158]	2017	India/Asia	Prospective observational[a]	36 (100)	22.73 ± 1.56 (20–25)	57.5	55.53	A slight but statistically insigniicant decrease in body weight following the month of Ramadan fasting	3
Al-Barha and Aljaloud [35]	2018	Saudi Arabia/Asia	Quasi-experimental before/after design	44 (100)	27.7 ± 5.8 (18–39)	70	69.6	There was no statistically signiicant efect of Ramadan fasting on body weight	3
Nachvak et al. [21]	2018	Iran/Asia	Observational	152 (100)	39.35 ± 10.7 (21–63)	76.33	74.22	The results showed a signiicant decline in body weight	3
Prasetya and Sepwarobol [55]	2018	Thailand/Asia	Prospective observational[a]	27 (100)	24.3 ± 3.7 (19–40)	65.33	64.23	Results demonstrate reductions in body weight	3
Faris et al. [40]	2019	UAE/Asia	Prospective	57 (61)	36.2 ± 12.5	89.4	88.2	A signiicant decrease in body weight was observed	4
Haghighi et al. [159]	2019	Iran/Asia	Semi-experimental	25 (0)	(21–51)	67.62	67.29	There was no statistically signiicant efect of Ramadan fasting on body weight	3

Table 1 (continued)

Authors	Year	Country/continent	Study design	Sample size (% male)	Mean age/age range (year)	BW before Ramadan (kg)	BW after Ramadan (kg)	Discussion	Quality assessment score
Jarrar et al. [160]	2019	UAE/Asia	Randomized, controlled,	36 (14)		60.5	59.9	A significant decrease	4
Rahbar et al. [161]	2019	Iran/Asia	Prospective single-blinded, parallel	34 (100)	35 ± 11 21. ± 1.95 (18–47)	6274.	9373.	A significant decrease in body weight was observed	3
Alam et al. [57]	2019	Pakistan/Asia	Open-label longitudinal observational[a] follow-up	78 (100)	(16–64) (20–85)	567.	763.	A significant reduction in body weight was observed in participants during Ramadan fasting in body weight was observed in participants at the end of the Ramadan month	3

[a] Not reported by study authors, body weight, BW not reported

achieved this subgroup analysis if three or more studies were available from any given country.

Critical appraisal of studies (quality assessment)

Two reviewers (MF and HJ) independently assessed the methodological quality of studies using a pre-designed standardized checklist consisting of six items in terms of sample size and sampling technique, standardization of data collection, appropriateness of statistical analyses, quality of reporting results, and generalizability. The appraisal scores range between zero and six, with scores of 0–2 corresponds to low quality, 3–4 medium quality, and 5–6 high quality. The inal quality score was set for each study by consensus after discussion [19]. (See Supp. 2).

Results

Of 2253 initially retrieved studies, eighty-ive studies on the efects of RDIF on body weight met the inclusion criteria and were subjected to meta-analysis; the stages of evaluation and exclusion of the identiied studies are presented in Fig. 1. The eighty-ive studies included a total of 4176 participants. Details of study sample size, sex, study design, age, and signiicant indings related to body weight are found in Table 1. All included studies used a pre-post model to report changes in body weight. Approximately 70.7% of participants were male, and the median age was 30.0 years (range of 16–80 years). The mean fasting length during Ramadan for all included studies was 837 min, with a SD of 91; range between 667 and 1070 min per day.

Critical appraisal of studies or quality assessment revealed that 78 studies (91.8%) were of medium-quality, and the remaining seven studies (8.2%) were of low-quality studies (Table 1). The mean quality score was 3.4, with a SD of 0.7.

A meta-analysis of body weight

Characteristics of the selected studies regarding the number of studies (K), the number of subjects (N), the mean age of study subjects, percent of male subjects, fasting time expressed in minutes per day are summarized in Table 2. Visual inspection of the precision plots indicated no bias in any of the selected studies (Fig. 2). Meta-analytic pooling for the body weight was performed and results were expressed as K, N, Hedges' g value, 95% CI and I^2, and found to be: ($K = 85$, $N = 4176$, -0.360, 95% CI -0.405 to -0.315, $I^2 = 45.6\%$) (Fig. 3), this efect size translates to diference in means of -1.022 kg (95% CI -1.164 to -0.880 kg). The results of sensitivity analyses revealed that the pooled efect size was robust and was not inluenced by one single study.

Table 2 Moderators and statistical values for the three moderators for the effect of Ramadan diurnal intermittent fasting on weight change at the

Number[a]	N[b]	I^2[c]	τ^2[d]	Mean age (year)	Overall % male	Fasting time (minute/day)	Overall Hedges' g (95%CI)	Moderators: age	Moderators: Sex (%male)	Moderators: Fasting time/day
[illegible]	[illegible]	[illegible]	[illegible]	30. ± 7.13	70.	837. ± 87.69	78%48 … 0.315)	[illegible]	[illegible]	[illegible]

a studies

b participant

c I^2 percentage of variation across studies due to heterogeneity rather than chance [162]

d denotes the number of K denotes the number of N

τ^2 In random-effects meta-analysis, the extent of variation among the effects observed in different studies (between-study variance) is referred to as tau-squared [163]

e CI, confidence interval

Moderator analysis for body weight

Moderator analysis was performed for body weight (Table 2). Results indicated that age (β = 0.0009, P = 0.66) and sex (β = − 0.0002, P = 0.70, as %male) of the fasting people were not signiicant moderators for changes in body weight (Figs. 4, 5), respectively. However, fasting time (min/ day) was a signiicant moderator in explaining variation in body weight change (β =− 0.0003, P = 0.049) (Fig. 6), suggesting that the longer the fasting time duration during Ramadan, the more substantial the reduction in body weight change at the end of Ramadan.

Subgroup analysis was performed to investigate differences in body weight between countries (Fig. 7). Results of this analysis revealed that nine countries (Iran, Jordan, Turkey, India, Malaysia, Pakistan, Saudi Arabia, Tunisia, and UAE) contributed three or more studies, independently, in measuring body weight change during RDIF (Table 3). The greatest reduction was observed in Malaysia (Hedges' g value, 95%CI) (− 0.519,− 0.696 to − 0.341), followed by India (− 0.486, − 0.713 to − 0.259), UAE (− 0.449, − 0.603 to − 0.294), Tunisia (− 0.424, − 0.842 to − 0.006), Iran (− 0.374, − 0.430 to − 0.264), Pakistan (− 0.347, − 0.476 to − 0.218), Turkey (− 0.325, − 0.560 to − 0.090), Jordan (− 0.291,− 0.381 to − 0.200), and Saudi Arabia (− 0.148, − 0.294 to − 0.002) (Fig. 7).

Subgroup analysis for the season during which the Ramadan study fell revealed that the most considerable reduction in body weight was reported in summer (− 0.376, 95%CI − 0.437 to − 0.314), followed by fall (autumn) (− 0.341, 95%CI − 0.419 to − 0.263), spring (− 0.329, 95% CI − 0.562 to − 0.095) and, inally, winter (− 0.298, 95%CI − 0.419 to − 0.177) (Fig. 8).

Discussion

This systematic review and meta-analysis highlighted the efect of RDIF on body weight and demonstrated that RDIF incurs a signiicant, but small, reduction. Further, the present study shows the impact of variable moderators, such as age, sex, and, for the irst time, the efect of fasting time duration, season, and country on body weight change at the end of the fasting month.

Ramadan diurnal intermittent fasting (RDIF) may be one of the most extensively studied types of religious fasting [30, 31], with a vast number of original research, system-atic reviews and meta-analyses demonstrating that RDIF is associated with variable changes in body weight [32–34], body composition [33, 35–37] and fat mass [38, 39], with an emphasis on visceral fat [40], serum lipids [34, 41, 42], immunomodulatory responses [43–47], and inlammatory and oxidative stress changes [46, 48–53]. Furthermore, some

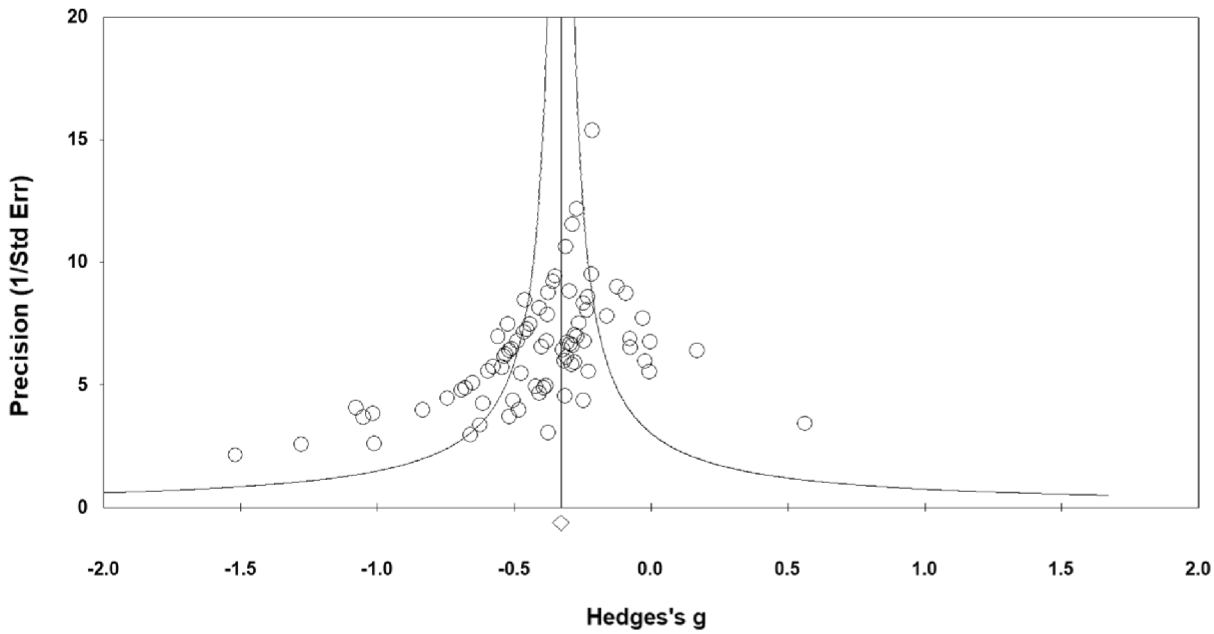


Fig. 2 Precision plot for studies included in the meta-analysis of body weight change induced by Ramadan fasting

work has reported that RDIF afects cardiometabolic risk factors, including insulin sensitivity [54, 55], and glucose homeostasis [56], and blood pressure [57–62] in an inconsistent manner.

Azizi [7] reported that RDIF yielded changes in body weight that varied between individuals, ranging from weight gain to weight loss, depending on total caloric intake during the fasting night hours in comparison to the pre-fasting intakes [7]. However, caloric intake before and during Ramadan month was not analyzed in the current meta-analysis, which therefore warrants further research and analysis, as it represents a conceivably inluential factor on body weight change at the end of the fasting month. In their systematic review and meta-analysis, of data from thirty-ive studies, including 1234 subjects, Sadeghirad and colleagues [32] revealed that body weight change induced by RDIF was mostly reversed after Ramadan, gradually returning to pre-Ramadan status [32], indicating that body weight loss caused by Ramadan fasting is transient and elicits only a short-term efect. The same inding was reported by Fernando and colleagues [33] in their systematic review and meta-analysis on seventy studies, which included 2947 subjects; moreover, the authors also found that overweight or obese fasting people exhibited a more pronounced reduction in body weight and body fat than healthy-weight people. However, the latter meta-analysis has been criticized because the authors included studies on physical activity during Ramadan month in their analysis [63–66], and many of the collected articles were not included in the inal analysis (e.g., the Takruri study [67]). Further, neither of the aforementioned meta-analyses examined the relationship between body weight changes and moderator confounding factors, such as age, sex, fasting time, season, and country of study, which may conceivably impact body weight changes at the end of the fasting month.

The importance of body weight is based on the fact it represents a predisposing factor and associated risk of CVD and type 2 diabetes, in addition to other harmful metabolic abnormalities, such as nonalcoholic fatty liver disease [68]. Increased body weight is usually accompanied by increased central obesity and diferent metabolic disorders in non-athletic people, such as insulin resistance, hypertension, and dyslipidemia. Therefore, dietary strategies and interventions that aid in alleviating and treating obesity and lowering body weight are of growing, contemporary importance. Given that RDIF is associated with body weight loss [32] and the alleviation of inlammatory and oxidative stress states [46], RDIF could viably represent a short-term pre-ventive measure against metabolic syndrome in healthy people.

The small reduction in body weight reported in this meta-analysis might help in explaining the slight decline reported in the inlammatory and oxidative stress markers accompanied by RDIF, as indicated in a previous meta-analysis [46]. It is well documented that a reduction in body weight is associated with the amelioration of inlammation and oxidative stress levels in overweight and obese peo-ple [69, 70]. Further, the presence of metabolic syndrome, for which increased body weight expressed by high BMI

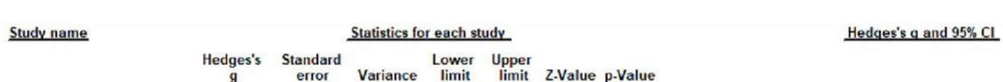


Fig. 3 Hedges'*g* value with 95%, CI revealed signiicant small (− 0.360) reduction in body weight was induced by Ramadan fasting. Heteroge-neity statistics: 95% CI − 0.405 to − 0.315, I^2 = 45.6%. Hedges' *g* value is considered small when value = 0.2, medium = 0.5, large = 0.8

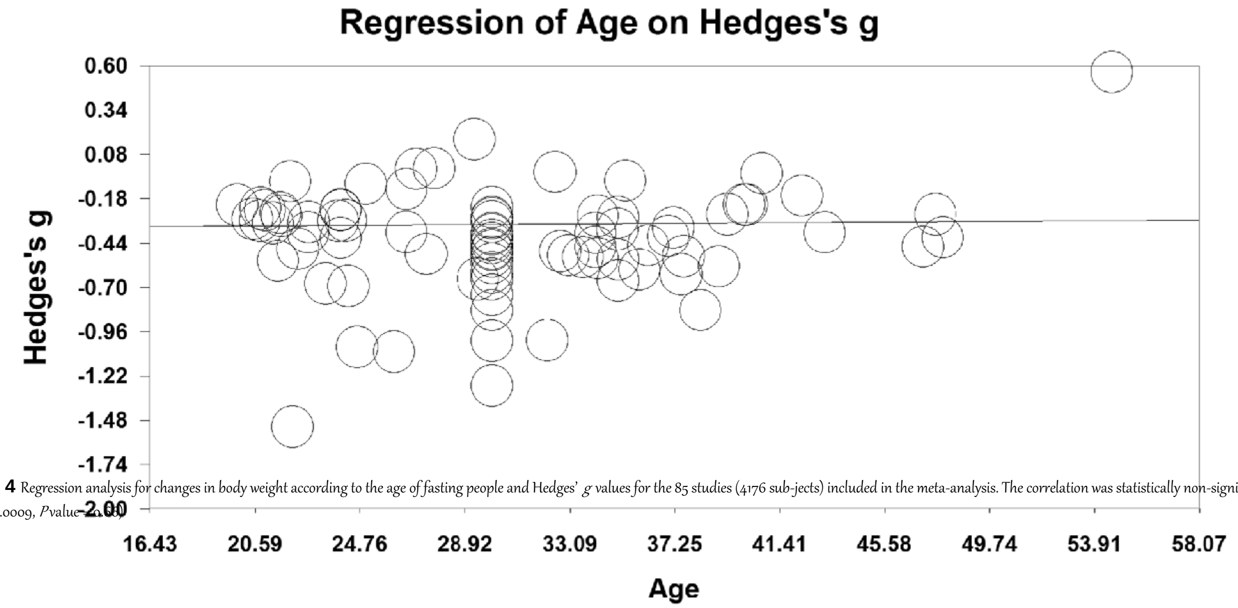


Fig. 4 Regression analysis for changes in body weight according to the age of fasting people and Hedges' *g* values for the 85 studies (4176 sub-jects) included in the meta-analysis. The correlation was statistically non-signiicant (β = 0.0009, *P*value = 0.66)

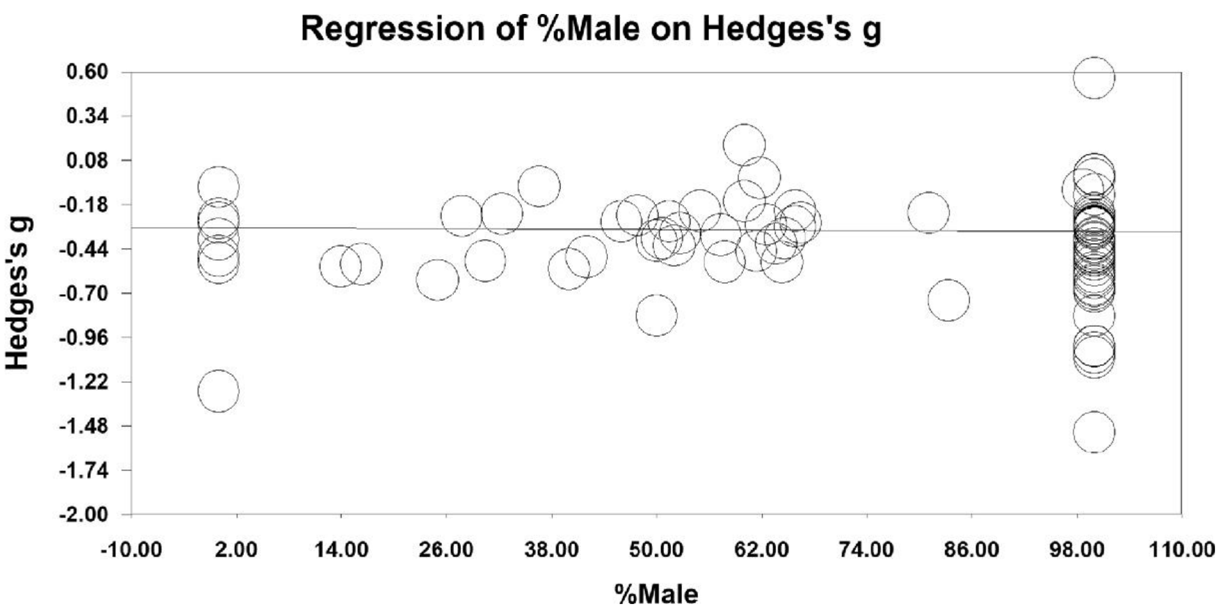


Fig. 5 Regression analysis for changes in body weight according to the sex of fasting subjects and Hedges' *g* values for the 85 studies (4176 sub-jects) included in the meta-analysis. The correlation was statistically non-signiicant (β = − 0.0002, *P*value = 0.71)

represents the irst indicator, was found to be associated with lower plasma adiponectin levels [71]; indicating adipose tissue dysfunction and a 2–4 times increased risk of both the development of type 2 diabetes [72] and cardiovascular disease [73]. Moreover, several reports have indicated that RDIF is associated with variable incremental levels in adiponectin in fasting people [50, 74–76]. Recently, it was reported that RDIF is associated with a signiicant reduction in the visceral fat surface area, as measured by magnetic resonance imaging, in 57 overweight and obese subjects, concomitant with substantial reductions in the pro-inlammatory cytokines IL-6, and TNF-α, and a signiicant increase in the anti-inflammatory cytokine IL-10 [40]. The same samples revealed that RDIF was associated with enhanced expression of the anti-oxidant genes nuclear factor erythroid 2 related factor 2, superoxide dismutase 2, and mitochondrial transcription factor A [72]. Furthermore, Fernando and colleagues, in their systematic review and meta-analysis on the efect of RDIF on body fatness, found a signiicant reduction in fat percentage between pre-Ramadan and post-Ramadan in people with overweight or obesity (− 1.46, 95% CI − 2.57 to − 0.35%, P = 0.010), rather than in normal-weight fasting subjects [33]; implying that RDIF elicits a pronounced protective efect against the development of metabolic syndrome in overweight/obese subjects, for which increased body fatness is the core etiopathological condition [77].

Given that Ramadan fasting represents a form of time-restricted feeding (TRF), as reported by Patterson and Sears [18]; indings of the current review are consistent with other research on human and animal intermittent energy restriction and TRF, for which a growing evidence base is demonstrating its beneits on glucose and lipid homeostasis in the short-to-medium term, even in the absence of signiicant total daily caloric restriction (reduction in 25–40% of total daily caloric intake). During Ramadan, the vast majority of published research has revealed a lack of signiicant changes in total daily caloric intake in comparison with the pre-fasting caloric intake [78–80]. One of the mechanisms conceivably explaining how TRF, including RDIF, may improve body weight regulation is related to the extended fasting duration [81]. It has been reported that extended fasting duration can trigger the mobilization of free fatty acids, increase the production of ketones, and increase fat oxidation [82]. Besides, evidence from rodent-based models suggests that reducing the daily eating duration can elicit beneicial efects on body weight, body composition, and metabolism [83, 84]. Furthermore, such beneicial efects appear to be attainable even without a reduction in daily energy intake [83, 84].

Total energy expenditure (TEE) and resting metabolic rate (RMR) play a fundamental role in determining body weight changes [85]. In the context of RDIF, few studies have investigated the impact of RDIF on RMR and TEE without reporting signiicant changes [86, 87].

Variable changes in body compartments have been reported in fasting people during the month of Ramadan, which includes body water [88], fat-free mass [36], body fat mass [38, 64, 89, 90] including visceral fat [40]. These variable changes in body composition associated with Ramadan fasting are supposed to be afected by variable factors and to be determined by cultural, seasonal, geographical, and social [91] as well as the gut microbiome, genetic, and epigenetic factors [92].

The findings of the current meta-analysis are con-cordant with that of Sadeghirad and colleagues [32] who reported that RDIF resulted in a small signiicant weight loss (− 1.24 kg, 95%CI − 1.60 to − 0.88 kg), with sub-stantial reductions in body weight for both men (− 1.5 kg) and women (− 0.92 kg), respectively. The lack of difer-ence in the signiicance of body weight loss for both sexes is in agreement with our inding that sex did not work as a

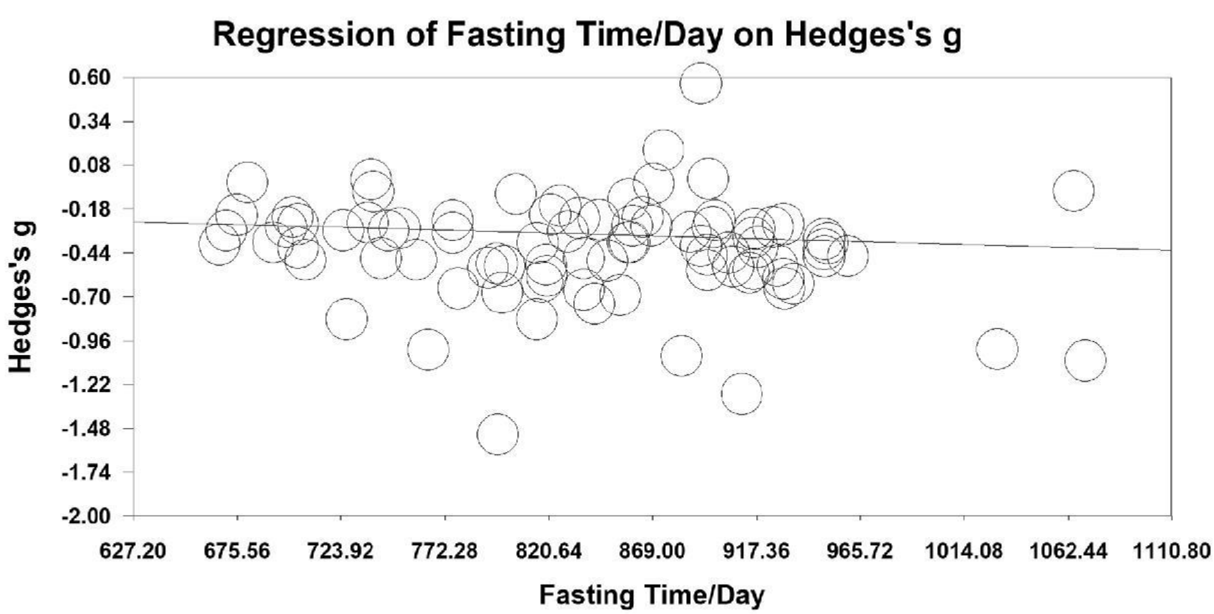
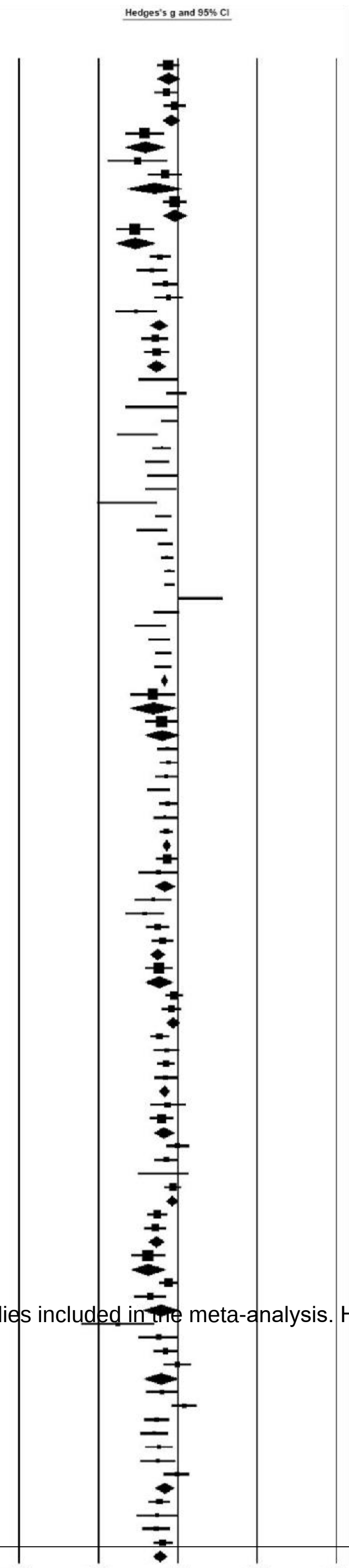


Fig. 6 Regression analysis for changes in body weight according to fasting minutes/day of fasting subjects and Hedges' g values for the 85 stud-ies (4176 subjects) included in the meta-analysis. The correlation was statistically signiicant (β = − 0.0003, P value = 0.049)



Group by Country	Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Algeria	Lamri-Senhadji et al 2009	-0.243	0.147	0.022	-0.532	0.045	-1.654	0.098
Algeria		-0.243	0.147	0.022	-0.532	0.045	-1.654	0.098
Bahrain	Kassab et al 2003	-0.286	0.151	0.023	-0.582	0.010	-1.892	0.058
Bahrain	Kassab et al 2004	-0.077	0.146	0.021	-0.361	0.208	-0.527	0.598
Bahrain		-0.177	0.105	0.011	-0.382	0.028	-1.691	0.091
Bangladesh	Rahman et al 2004	-0.834	0.252	0.063	-1.327	-0.340	-3.309	0.001
Bangladesh		-0.834	0.252	0.063	-1.327	-0.340	-3.309	0.001
Canada	Alsubheen et al 2017	-1.010	0.384	0.147	-1.763	-0.258	-2.632	0.008
Canada	McNeil et al 2014	-0.314	0.220	0.049	-0.746	0.118	-1.426	0.154
Canada		-0.591	0.341	0.116	-1.259	0.077	-1.734	0.083
England	Finch et al 1998	-0.074	0.153	0.024	-0.375	0.226	-0.485	0.628
England		-0.074	0.153	0.024	-0.375	0.226	-0.485	0.628
Germany	Nugraha et al 2017	-1.078	0.246	0.061	-1.561	-0.596	-4.373	0.000
Germany		-1.078	0.246	0.061	-1.561	-0.596	-4.373	0.000
India	Begum et al 2016	-0.441	0.134	0.018	-0.703	-0.179	-3.302	0.001
India	Pathan and Patil 2010	-0.651	0.197	0.039	-1.036	-0.266	-3.309	0.001
India	Roy and Bandyopadhyay 2017	-0.317	0.167	0.028	-0.646	0.011	-1.896	0.058
India	Salahuddin and Javed 2014	-0.228	0.180	0.032	-0.581	0.125	-1.265	0.206
India	Sayedda et al 2013	-1.051	0.271	0.074	-1.583	-0.519	-3.872	0.000
India		-0.486	0.116	0.013	-0.713	-0.259	-4.197	0.000
Indonesia	Dewanti et al 2006	-0.577	0.174	0.030	-0.918	-0.235	-3.307	0.001
Indonesia	Syam et al 2016	-0.530	0.160	0.026	-0.844	-0.216	-3.305	0.001
Indonesia		-0.551	0.118	0.014	-0.782	-0.320	-4.671	0.000
Iran	Afrasiabi et al 2003	-0.483	0.252	0.064	-0.977	0.012	-1.914	0.056
Iran	Assadi et al 2011	-0.029	0.130	0.017	-0.283	0.225	-0.226	0.821
Iran	Azizi and Rasouli 1987	-0.659	0.339	0.115	-1.323	0.005	-1.945	0.052
Iran	Fakhrzadeh et al 2003	-0.217	0.105	0.011	-0.423	-0.010	-2.060	0.039
Iran	Farshidfar et al 2006	-1.016	0.262	0.069	-1.529	-0.502	-3.877	0.000
Iran	Feizollahzadeh et al 2014	-0.406	0.123	0.015	-0.648	-0.165	-3.301	0.001
Iran	Ganjali et al 2016	-0.517	0.156	0.024	-0.823	-0.210	-3.305	0.001
Iran	Haghighi et al 2019	-0.382	0.201	0.040	-0.776	0.012	-1.901	0.057
Iran	Hosseini and Hejazi 2015	-0.421	0.203	0.041	-0.818	-0.023	-2.076	0.038
Iran	Hosseini et al 2013	-1.277	0.389	0.152	-2.040	-0.514	-3.279	0.001
Iran	Malekmakan et al 2017	-0.350	0.106	0.011	-0.557	-0.142	-3.299	0.001
Iran	Mohammadzade et al 2017	-0.651	0.197	0.039	-1.036	-0.266	-3.309	0.001
Iran	Moosavi et al 2007	-0.310	0.094	0.009	-0.494	-0.126	-3.297	0.001
Iran	Nachvak et al 2018	-0.271	0.082	0.007	-0.432	-0.110	-3.296	0.001
Iran	Norouzy et al 2010	-0.214	0.066	0.004	-0.342	-0.087	-3.294	0.001
Iran	Norouzy et al 2013	-0.214	0.065	0.004	-0.342	-0.087	-3.294	0.001
Iran	Norouzy et al 2017	0.563	0.292	0.085	-0.010	1.135	1.927	0.054
Iran	Rahbar et al 2019	-0.289	0.171	0.029	-0.624	0.047	-1.688	0.091
Iran	Salehi and Neghab 2007	-0.678	0.205	0.042	-1.079	-0.276	-3.309	0.001
Iran	Shariatpanahi et al 2007	-0.463	0.140	0.020	-0.737	-0.188	-3.303	0.001
Iran	Sijavandi et al 2015	-0.358	0.108	0.012	-0.570	-0.145	-3.299	0.001
Iran	Ziaee et al 2006	-0.376	0.114	0.013	-0.599	-0.153	-3.300	0.001
Iran		-0.347	0.042	0.002	-0.430	-0.264	-8.171	0.000
Iraq	AbdulKareem et al 2017	-0.625	0.297	0.088	-1.208	-0.042	-2.103	0.035
Iraq		-0.625	0.297	0.088	-1.208	-0.042	-2.103	0.035
Israel	Maislos et al 1998	-0.409	0.215	0.046	-0.829	0.012	-1.904	0.057
Israel		-0.409	0.215	0.046	-0.829	0.012	-1.904	0.057
Jordan	Al- Hourani and Atoum 2007	-0.262	0.133	0.018	-0.522	-0.001	-1.969	0.049
Jordan	Bilto 1998	-0.229	0.117	0.014	-0.458	-0.001	-1.967	0.049
Jordan	Faris et al 2012a	-0.280	0.142	0.020	-0.558	-0.001	-1.970	0.049
Jordan	Faris et al 2012b	-0.487	0.148	0.022	-0.777	-0.198	-3.304	0.001
Jordan	Mansi 2007	-0.247	0.120	0.014	-0.483	-0.012	-2.061	0.039
Jordan	Mansi and Amneh 2007	-0.321	0.155	0.024	-0.626	-0.017	-2.067	0.039
Jordan	Takruri 1989	-0.286	0.087	0.008	-0.456	-0.116	-3.298	0.001
Jordan		-0.291	0.046	0.002	-0.381	-0.200	-6.296	0.000
Kuwait	Akanji et al 2000	-0.271	0.143	0.021	-0.552	0.010	-1.891	0.059
Kuwait	Ramadan 2002	-0.483	0.252	0.064	-0.977	0.012	-1.914	0.056
Kuwait		-0.323	0.126	0.016	-0.567	-0.078	-2.580	0.010
Malaysia	Gnanou et al 2015	-0.614	0.236	0.056	-1.076	-0.152	-2.607	0.009
Malaysia	Khattak et al 2012	-0.834	0.252	0.063	-1.327	-0.340	-3.309	0.001
Malaysia	Rohin et al 2013	-0.510	0.154	0.024	-0.813	-0.208	-3.306	0.001
Malaysia	Suriani et al 2015	-0.381	0.147	0.022	-0.670	-0.093	-2.589	0.010
Malaysia		-0.519	0.091	0.008	-0.696	-0.341	-5.726	0.000
Morocco	Adlouni et al 1997	-0.473	0.182	0.033	-0.831	-0.116	-2.596	0.009
Morocco		-0.473	0.182	0.033	-0.831	-0.116	-2.596	0.009
Nigeria	Bakki et al 2017	-0.092	0.115	0.013	-0.316	0.133	-0.800	0.423
Nigeria	Hassan and Isawumi 2014	-0.160	0.128	0.016	-0.412	0.091	-1.248	0.212
Nigeria		-0.122	0.085	0.007	-0.289	0.045	-1.428	0.153
Pakistan	Alam et al 2019	-0.460	0.118	0.014	-0.691	-0.229	-3.899	0.000
Pakistan	Khan et al 2017	-0.279	0.169	0.028	-0.610	0.051	-1.667	0.097
Pakistan	Kiyani et al 2017	-0.297	0.113	0.013	-0.518	-0.075	-2.620	0.009
Pakistan	Subhan et al 2006	-0.307	0.148	0.022	-0.598	-0.016	-2.065	0.039
Pakistan		-0.347	0.066	0.004	-0.476	-0.218	-5.266	0.000
Qatar	Pallayova et al 2017	-0.246	0.229	0.052	-0.694	0.203	-1.075	0.283
Qatar	Talib et al 2015	-0.400	0.152	0.023	-0.699	-0.102	-2.626	0.009
Qatar		-0.353	0.127	0.016	-0.602	-0.104	-2.781	0.005
Saudi Arabia	AL-barha and Aljaloud 2018	-0.002	0.148	0.022	-0.292	0.288	-0.013	0.990
Saudi Arabia	Al-Numair 2006	-0.295	0.150	0.022	-0.589	-0.002	-1.971	0.049
Saudi Arabia	Alzoghaibi et al 2014	-0.376	0.328	0.108	-1.018	0.267	-1.145	0.252
Saudi Arabia	Bahammam et al 2016	-0.123	0.111	0.012	-0.341	0.095	-1.104	0.269
Saudi Arabia		-0.148	0.074	0.006	-0.294	-0.002	-1.986	0.047
Spain	López-Bueno et al 2015	-0.522	0.134	0.018	-0.785	-0.260	-3.900	0.000
Spain	Agoumi et al 2013	-0.559	0.143	0.021	-0.839	-0.278	-3.900	0.000
Spain		-0.539	0.098	0.010	-0.731	-0.348	-5.513	0.000
Sudan	Fedail et al 1982	-0.744	0.225	0.050	-1.184	-0.303	-3.310	0.001
Sudan		-0.744	0.225	0.050	-1.184	-0.303	-3.310	0.001
Thailand	Ongsara et al 2017	-0.236	0.124	0.015	-0.478	0.009	-1.888	0.059
Thailand	Prasetya and Sapwarobol 2018	-0.693	0.209	0.044	-1.103	-0.282	-3.309	0.001
Thailand		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Tunisia	Abedelmalek et al 2011	[illegible]	[illegible]	0.219	-2.434	[illegible]	-3.246	0.001
Tunisia	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-1.914	0.056
Tunisia	Haouari-Oukerro et al 2013	-0.308	0.163	[illegible]	-0.627	0.011	-1.894	0.058
Tunisia	Latiri et al 2017	-0.006	0.181	0.033	-0.359	0.350	-0.026	0.980
Tunisia		-0.424	0.213	0.045	-0.842	-0.006	-1.987	0.047
Turkey	Aksungar et al 2005	-0.390	0.205	0.042	-0.793	0.012	-1.902	0.057
Turkey	Cansel et al 2014	0.170	0.156	0.024	-0.137	0.478	1.085	0.278
Turkey	Celik et al 2014	-0.537	0.162	0.026	-0.855	-0.219	-3.306	0.001
Turkey	Develioglu et al 2013	-0.595	0.180	0.032	-0.948	-0.242	-3.307	0.001
Turkey	Kaykcoglu et al 1998	-0.473	0.182	0.033	-0.831	-0.116	-2.596	0.009
Turkey	Unalacak et al 2011	-0.504	0.229	0.052	-0.952	-0.055	-2.199	0.028
Turkey	Yucel et al 2004	-0.023	0.168	0.028	-0.351	0.306	-0.134	0.893
Turkey		-0.325	0.120	0.014	-0.560	-0.090	-2.707	0.007
UAE	Faris et al 2019	-0.454	0.137	0.019	-0.723	-0.184	-3.303	0.001
UAE	Ibrahim et al 2008	-0.518	0.270	0.073	-1.047	0.011	-1.920	0.055
UAE	Jarrar et al 2019	-0.545	0.175	0.031	-0.888	-0.201	-3.108	0.002
UAE	Shehab et al 2012	-0.378	0.127	0.016	-0.627	-0.129	-2.978	0.003
UAE		-0.449	0.079	0.006	-0.603	-0.294	-5.696	0.000

Fig. 7 Hedges' *g* values for reductions in body weight for 25 countries-studies included in the meta-analysis. Hedges' *g* value is considered small when value = 0.2, medium = 0.5, large = 0.8.

Table 3 Characteristics of studies included in body weight change during Ramadan reviewed and analyzed as per the country included with three or more studies

Component	Country	K^a	N^b	I^{2c} (%)	Hedges' g (95%CI)[d]
Body weight change	Iran	22	1542	53.1	− 0.305 (− 0.356 to − 0.254)
	Jordan	7	480	0.001	− 0.291 (− 0.434 to − 0.268)
	Turkey	7	227	67.6	− 0.301 (− 0.381 to − 0.200)
	India	5	176	50.6	− 0.291 (− 0.612 to − 0.304)
	Malaysia	4	134	0.001	− 0.291 (− 0.696 to − 0.341)
	Pakistan	4	239	0.001	− 0.291 (− 0.381 to − 0.002)
	Saudi Arabia	4	177	0.001	− 0.148 (− 0.296 to − 0.200)
	Tunisia	4	92	69.9	− 0.297 (− 0.505 to − 0.089)
	UAE	4	172	0.001	− 0.449 (− 0.603 to − 0.294)

[a] *K*: denotes the number of studies

[b] *N*: denotes the number of participants

[c] I^2 statistic describes the percentage of variation across studies due to heterogeneity rather than chance [162]

[d] CI, conidence interval

signiicant moderator in body weight loss induced by Ramadan. In our analysis, the small efect size in body weight (Hedges' *g* value of − 0.360, 95% CI − 0.405 to − 0.315) equates to − 1.022 kg, which is less than the mean of weight loss reported by the meta-analyses of Sadeghirad and colleagues [32] and Fernando et al. [33], respectively.

The weight loss induced by Ramadan fasting observed in the current analysis is the sum of reductions in both fat masses (expressed in terms of body fat percent and absolute fat mass), as well as fat-free mass as reported by Fernando and colleagues [33]. This reduction in body weight and body fat compartment induced by intermittent fasting during Ramadan is consistent with the body weight and body fat reductions caused by other models of intermittent fasting regimens [2, 93, 94].

The relatively more signiicant reduction in body weight reported during summer and autumn in comparison to winter is explained by the nature of Ramadan diurnal fasting, which depends on the day hour fasting rather than night hour fasting reported in other religions and intermittent fasting regimens [95, 96]. Because the day hours' fasting during Ramadan increases in summer (reaching 17 h), in comparison to winter (reaching 12 h), it becomes reasonable to lose more weight at the end of Ramadan in the summer season, vs. winter. Further, the higher temperature and humidity during summer favors the reduction of body weight as a result of the excessive sweating and more dehydrated state [97]. However, considering the body weight loss is transient during Ramadan [32, 33], it becomes pivotal to emphasize the importance of maintenance of weight loss after Ramadan, and addressing the factors triggering weight gain after Ramadan in research works.

In fact, according to the Islamic rules and instructions of the Prophetic *Sunnah* directed by the Prophet Mohammad (PBUH), adult Muslims are encouraged to voluntarily fast two days a week (namely Monday and Thursday), any six days in the lunar or "Islamic" month of *Shawwal* (the month after Ramadan, *Hijri*), the three full-moon days (13th, 14th, and 15th days of each lunar month, *Hijri*), the Day of *Ara-fah* (9th of *Dhu'l - Hijja* in the Islamic *Hijri* calendar), to fast as often as possible in the two lunar months before Rama-dan (*Rajab* and *Sha'aban*), and to fast the irst nine days of *Dhu'l-Hijja* in the lunar Islamic calendar for those who are not performing *Hajj* (the pilgrimage to Makkah) [98, 99]. Practicing such voluntary fasting after Ramadan has been reported to maintain weight loss and to improve metabolic markers and food intakes among overweight and obese adult Muslims [98, 100, 101], an efect that may extend for six months after Ramadan [100].

The heterogeneity of the studies included in the cur-rent meta-analysis for the body weight could be ascribed to variable efects and confounding factors, and due to several inconsistencies in designing, conducting, and interpreting results of the studies undertaken during Ramadan. It is conceivable that a critical violation that many fasting people do during Ramadan is skipping a pre-dawn meal (*suhoor*), a matter that could contribute to a signiicant daily caloric deicit, and would be expected to promote metabolic abnor-malities, increased postprandial insulin levels, increased fat oxidation, and conceivably confound the incumbent results [103]. Further, variable changes in lifestyle behaviors such as physical activity and sleep patterns [102, 103] accom-panying the fasting month of Ramadan may impact body weight changes. Thus, future research has to consider all the covariables mentioned above and to control the interfering factors that may hinder Ramadan research results in less accurate, especially total caloric and dietary intakes, physi-cal activity and sleep patterns.

Strengths of the current review stems from that it is the one with the largest number of harvested and analyzed articles ever published in the literature on Ramadan and body weight changes. Second, the strict inclusion and exclusion

Group by Season	Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
		Statistics for each study						
Autumn	Ramadan 2002	-0.483	0.252	0.064	-0.977	0.012	-1.914	0.056
Autumn	Afrasiabi et al 2003	-0.483	0.252	0.064	-0.977	0.012	-1.914	0.056
Autumn	Kassab et al 2003	-0.286	0.151	0.023	-0.582	0.010	-1.892	0.058
Autumn	Fakhrzadeh et al 2003	-0.217	0.105	0.011	-0.423	-0.010	-2.060	0.039
Autumn	Yucel et al 2004	-0.023	0.168	0.028	-0.351	0.306	-0.134	0.893
Autumn	Rahman et al 2004	-0.834	0.252	0.063	-1.327	-0.340	-3.309	0.001
Autumn	Kassab et al 2004	-0.077	0.145	0.021	-0.361	0.208	-0.527	0.598
Autumn	Aksungar et al 2005	-0.390	0.205	0.042	-0.793	0.012	-1.902	0.057
Autumn	Farshidfar et al 2006	-1.016	0.262	0.069	-1.529	-0.502	-3.877	0.000
Autumn	Al-Numair 2006	-0.295	0.150	0.022	-0.589	-0.002	-1.971	0.049
Autumn	Ziaee et al 2006	-0.376	0.114	0.013	-0.599	-0.153	-3.300	0.001
Autumn	Dewanti et al 2006	-0.577	0.174	0.030	-0.918	-0.235	-3.307	0.001
Autumn	Subhan et al 2006	-0.307	0.148	0.022	-0.598	-0.016	-2.065	0.039
Autumn	Salehi and Neghab 2007	-0.678	0.205	0.042	-1.079	-0.276	-3.309	0.001
Autumn	Al- Hourani and Atoum 2007	-0.262	0.133	0.018	-0.522	-0.001	-1.969	0.049
Autumn	Mansi 2007	-0.247	0.120	0.014	-0.483	-0.012	-2.061	0.039
Autumn	Mansi and Amneh 2007	-0.321	0.155	0.024	-0.626	-0.017	-2.067	0.039
Autumn	Moosavi et al 2007	-0.310	0.094	0.009	-0.494	-0.126	-3.297	0.001
Autumn	Ibrahim et al 2008	-0.518	0.270	0.073	-1.047	0.011	-1.920	0.055
Autumn	Shariatpanahi et al 2007	-0.463	0.140	0.020	-0.737	-0.188	-3.303	0.001
Autumn	Lamri-Senhadji et al 2009	-0.243	0.147	0.022	-0.532	0.045	-1.654	0.098
Autumn		-0.341	0.040	0.002	-0.419	-0.263	-8.597	0.000
Spring	Azizi and Rasouli 1987	-0.659	0.339	0.115	-1.323	0.005	-1.945	0.052
Spring	Takruri 1989	-0.286	0.087	0.008	-0.456	-0.116	-3.296	0.001
Spring		-0.329	0.119	0.014	-0.562	-0.095	-2.759	0.006
Summer	Fedail et al 1982	-0.744	0.225	0.050	-1.184	-0.303	-3.310	0.001
Summer	Norouzy et al 2010	-0.214	0.065	0.004	-0.342	-0.087	-3.294	0.001
Summer	Pathan and Patil 2010	-0.651	0.197	0.039	-1.036	-0.265	-3.309	0.001
Summer	Abedelmalek et al 2011	-1.518	0.468	0.219	-2.434	-0.601	-3.246	0.001
Summer	Assadi et al 2011	-0.029	0.130	0.017	-0.283	0.225	-0.226	0.821
Summer	Unalacak et al 2011	-0.504	0.229	0.052	-0.952	-0.055	-2.199	0.028
Summer	Faris et al 2012a	-0.280	0.142	0.020	-0.558	-0.001	-1.970	0.049
Summer	Faris et al 2012b	-0.487	0.148	0.022	-0.777	-0.198	-3.304	0.001
Summer	Khattak et al 2012	-0.834	0.252	0.063	-1.327	-0.340	-3.309	0.001
Summer	Shehab et al 2012	-0.378	0.127	0.016	-0.627	-0.129	-2.978	0.003
Summer	Agoumi et al 2013	-0.559	0.143	0.021	-0.839	-0.278	-3.900	0.000
Summer	Develioglu et al 2013	-0.595	0.180	0.032	-0.948	-0.242	-3.307	0.001
Summer	Haouari-Oukerro et al 2013	-0.308	0.163	0.027	-0.627	0.011	-1.894	0.058
Summer	Hosseini et al 2013	-1.277	0.389	0.152	-2.040	-0.514	-3.279	0.001
Summer	Norouzy et al 2013	-0.214	0.065	0.004	-0.342	-0.087	-3.294	0.001
Summer	Rohin et al 2013	-0.510	0.154	0.024	-0.813	-0.208	-3.305	0.001
Summer	Sayedda et al 2013	-1.051	0.271	0.074	-1.583	-0.519	-3.872	0.000
Summer	Alzoghaibi et al 2014	-0.376	0.328	0.108	-1.018	0.267	-1.145	0.252
Summer	Cansel et al 2014	0.170	0.156	0.024	-0.137	0.476	1.085	0.278
Summer	Celik et al 2014	-0.537	0.162	0.026	-0.855	-0.219	-3.306	0.001
Summer	Feizollahzadeh et al 2014	-0.406	0.123	0.015	-0.648	-0.165	-3.301	0.001
Summer	Hassan and Isawumi 2014	-0.160	0.128	0.016	-0.412	0.091	-1.248	0.212
Summer	McNeil et al 2014	-0.314	0.220	0.049	-0.746	0.118	-1.425	0.154
Summer	Salahuddin and Javed 2014	-0.228	0.180	0.032	-0.581	0.125	-1.265	0.206
Summer	Begum et al 2015	-0.441	0.134	0.018	-0.703	-0.179	-3.302	0.001
Summer	Gnanou et al 2015	-0.614	0.236	0.056	-1.076	-0.152	-2.607	0.009
Summer	Hosseini and Hejazi 2015	-0.421	0.203	0.041	-0.818	-0.023	-2.076	0.038
Summer	López-Bueno et al 2015	-0.522	0.134	0.018	-0.785	-0.260	-3.900	0.000
Summer	Sijavandi et al 2015	-0.358	0.108	0.012	-0.570	-0.145	-3.299	0.001
Summer	Suriani et al 2015	-0.381	0.147	0.022	-0.670	-0.093	-2.589	0.010
Summer	Talib et al 2015	-0.400	0.152	0.023	-0.699	-0.102	-2.626	0.009
Summer	Bahammam et al 2016	-0.123	0.111	0.012	-0.341	0.095	-1.104	0.269
Summer	Ganjali et al 2016	-0.517	0.156	0.024	-0.823	-0.210	-3.305	0.001
Summer	Syam et al 2016	-0.530	0.160	0.026	-0.844	-0.216	-3.305	0.001
Summer	Nugraha et al 2017	-1.078	0.246	0.061	-1.561	-0.595	-4.373	0.000
Summer	AbdulKareem et al 2017	-0.625	0.297	0.088	-1.208	-0.042	-2.103	0.035
Summer	Alsubheen et al 2017	-1.010	0.384	0.147	-1.763	-0.258	-2.632	0.008
Summer	Bakki et al 2017	-0.092	0.115	0.013	-0.316	0.133	-0.800	0.423
Summer	Khan et al 2017	-0.279	0.169	0.028	-0.610	0.051	-1.657	0.097
Summer	Kiyani et al 2017	-0.297	0.113	0.013	-0.518	-0.075	-2.620	0.009
Summer	Latiri et al 2017	-0.005	0.181	0.033	-0.359	0.350	-0.025	0.980
Summer	Malekmakan et al 2017	-0.350	0.106	0.011	-0.557	-0.142	-3.299	0.001
Summer	Mohammadzade et al 2017	-0.651	0.197	0.039	-1.036	-0.265	-3.309	0.001
Summer	Norouzy et al 2017	0.563	0.292	0.085	-0.010	1.135	1.927	0.054
Summer	Ongsara et al 2017	-0.235	0.124	0.015	-0.478	0.009	-1.888	0.059
Summer	Pallayova et al 2017	-0.246	0.229	0.052	-0.694	0.203	-1.075	0.283
Summer	Roy and Bandyopadhyay 2017	-0.317	0.167	0.028	-0.645	0.011	-1.895	0.058
Summer	AL-barha and Aljaloud 2018	-0.002	0.148	0.022	-0.292	0.288	-0.013	0.990
Summer	Nachvak et al 2018	-0.271	0.082	0.007	-0.432	-0.110	-3.296	0.001
Summer	Prasetya and Sapwarobol 2018	-0.693	0.209	0.044	-1.103	-0.282	-3.309	0.001
Summer	Faris et al 2019	-0.454	0.137	0.019	-0.723	-0.184	-3.303	0.001
Summer	Haghighi et al 2019	-0.382	0.201	0.040	-0.776	0.012	-1.901	0.057
Summer	Jarrar et al 2019	-0.545	0.175	0.031	-0.888	-0.201	-3.108	0.002
Summer	Rahbar et al 2019	-0.289	0.171	0.029	-0.624	0.047	-1.688	0.091
Summer	Alam et al 2019	-0.460	0.118	0.014	-0.691	-0.229	-3.899	0.000
Summer		-0.376	0.031	0.001	-0.437	-0.314	-11.973	0.000
Winter	El Ati et al 1995	-0.483	0.252	0.064	-0.977	0.012	-1.914	0.056
Winter	Adlouni et al 1997	-0.473	0.182	0.033	-0.831	-0.116	-2.596	0.009
Winter	Finch et al 1998	-0.074	0.153	0.024	-0.375	0.226	-0.485	0.628
Winter	Maislos et al 1998	-0.409	0.215	0.046	-0.829	0.012	-1.904	0.057
Winter	Bilto 1998	-0.229	0.117	0.014	-0.458	-0.001	-1.967	0.049
Winter	Kaykcoglu et al 1998	-0.473	0.182	0.033	-0.831	-0.116	-2.596	0.009
Winter	Akanji et al 2000	-0.271	0.143	0.021	-0.552	0.010	-1.891	0.059
Winter		-0.298	0.062	0.004	-0.419	-0.177	-4.826	0.000

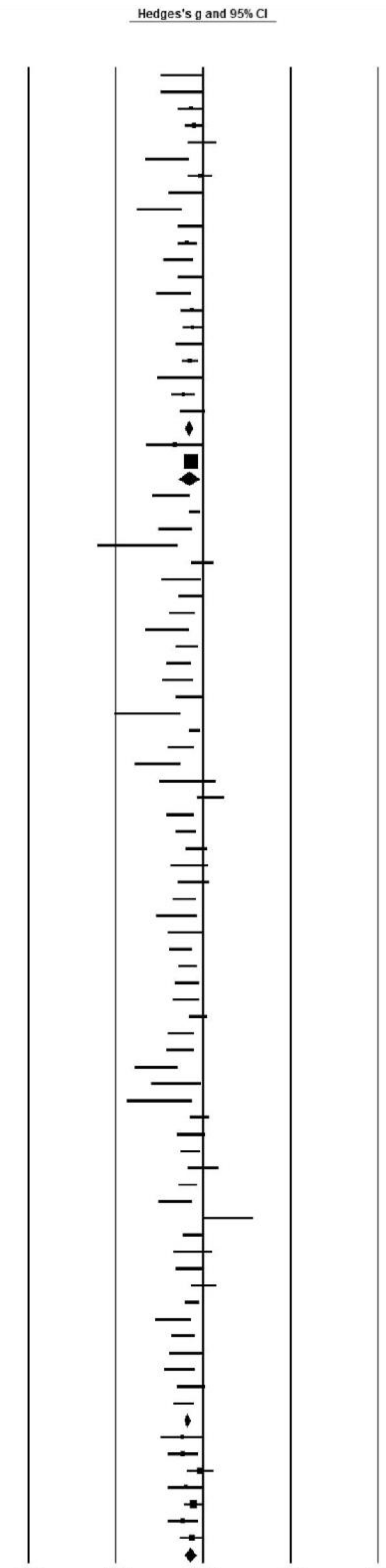


Fig. 8 Hedges' *g* values for changes in body weight for studies included in the meta-analysis according to the season during which the study was conducted. Hedges' *g* value is considered small when value = 0.2, medium = 0.5, large = 0.8.

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criteria applied give a more robust and reliable estimate for the efect size. The last strength is that we performed subgroup analyses and meta-regressions (adjustment for covariates) which were not performed before. However, the current work entailed two major limitations that should be considered: irst, the fact that the study population was mostly men; makes it diicult to generalize the results on both male and female fasting people. Second, calorie intakes pre- and post-RDIF were not measured in the analysis, a matter that should be considered in any future research on Ramadan fasting and body weight changes.

Conclusions

In conclusion, RDIF elicits a signiicant, but small, reduction in body weight. The heterogeneity in the indings likely relects the variable dietary and lifestyle behaviors practiced during the month of Ramadan, along with the variation in the time duration of fasting and variable climatic and geographical conditions surrounding fasting people in diferent countries. Through this work, it can also be emphasized that weight loss is by no means universal and that weight gain is possible and does happen in a signiicant group of people who fast during Ramadan.

Supplementary 1 for combined means calculation

https://www.dropbox.com/s/nds744tcpqhsc5g/Supplementary%201%20222020.docx?dl=0

Supplementary 2 for quality assessment

https://www.dropbox.com/s/dhol3u83kpgbgrq/Supplementary%202%20222020.doc?dl=0

Data repository link

https://www.dropbox.com/s/40t9f6w70o8lbtd/Final%20Ramadan%20meta%20data%20472019%20%28Weight%20and%20BMI%29.xlsx?dl=0

MOOSE checklist repository link

https://www.dropbox.com/s/u23n0hlk4fb457d/MOOSE_Checklist%2011122019%20FINAL.pdf?dl=0

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