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Meta-analyses

Adjustments of iodinated contrast media using lean body weight for abdominopelvic computed tomography: A systematic review and meta-analysis

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ABSTRACT

Purpose: This systematic review aimed to compare the effect of contrast media (CM) dose adjustment based on lean body weight (LBW) method versus other calculation protocols for abdominopelvic CT examinations.
Method: Studies published from 2002 onwards were systematically searched in June 2024 across Medline, Embase, CINAHL, Cochrane CENTRAL, Web of Science, Google Scholar and four other grey literature sources, with no language limit. Randomised controlled trials (RCT) and quasi-RCT of abdominopelvic or abdominal CT examinations in adults with contrast media injection for oncological and acute diseases were included. The comparators were other contrast dose calculation methods such as total body weight (TBW), fixed volume (FV), body surface area (BSA), and blood volume. The main outcomes considered were liver and aortic enhancement. Titles, abstracts and full texts were independently screened by two reviewers.
Results: Eight studies were included from a total of 2029 articles identified. Liver parenchyma and aorta contrast enhancement did not significantly differ between LBW and TBW protocols ($p = 0.07$, $p = 0.06$, respectively). However, the meta-analysis revealed significantly lower contrast volume injected with LBW protocol when compared to TBW protocol ($p = 0.003$). No statistical differences were found for contrast enhancement and contrast volume between LBW and the other strategies.
Conclusion: Calculation of the CM dosage based on LBW allows a reduction in the injected volume for abdominopelvic CT examination, ensuring the same image quality in terms of contrast enhancement.

1. Introduction

Abdominopelvic contrast-enhanced computed tomography (CT) is a common examination used for diagnosis and follow up of oncological, chronic and acute abdominopelvic disorders [1–4]. A precise protocol to determine the amount of iodinated contrast media (CM) injected is necessary to ensure adequate enhancement of relevant anatomical structures and consequently sufficient image quality to answer clinical questions related to each patient [5]. To achieve an optimal contrast enhancement, many factors must be considered such as clinical context, patient presentation, CM concentration, CM injection protocol, and scanner settings [6]. Patient-related factors such as body composition may also further impact contrast enhancement [7].

To the best of our knowledge, there are no established guidelines for CM dosing determination regarding abdominopelvic CT examinations. According to Bae et al. [7], one of the most important patient-related factors affecting vascular and parenchymal contrast enhancement in CT images is body weight. Furthermore, fat is less metabolically active and poorly perfused by the CM compared to solid organs and muscles, thereby reducing its contribution to the dispersion and dilution of CM in

Abbreviations: BSA, Body surface area; BV, Blood Volume; CT, Computed Tomography; CM, Contrast Media; FV, Fixed Volume; HU, Hounsfield Unit; LBW, Lean Body Weight; MHE, Mean Hepatic Enhancement; RCT, Randomised Controlled Trial; TBW, Total Body Weight.

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the blood [8]. As a result, administration of CM based on total body weight (TBW) may lead to overdosing in overweight patients, as an amount of CM does not contribute to tissue contrast enhancement. This excess of CM injected leads to an increased risk of renal toxicity and unnecessary expense.

In clinical practice, other CM dosing strategies than TBW are fixed volume (FV), body surface area (BSA), blood volume (BV) or lean body weight (LBW), [9–12]. Contrast dose calculation based on LBW, excludes the weight of adipose tissue, enabling more consistent tissue enhancement and preventing overdosing. In fact, studies have demonstrated a strong correlation between LBW and hepatic enhancement, suggesting that LBW dosing can potentially decrease interpatient variability in hepatic enhancement [10,11,13,14]. It is crucial to determine the appropriate dosing of CM to achieve the required level of contrast enhancement for a diagnosis while minimising the quantity of CM.

This systematic review aimed to synthetise the current available literature comparing the performance of the LBW injection protocol to other injection protocols with respect to their impact on image contrast enhancement and injected contrast volume for abdominopelvic or abdominal CT examinations.

2. Methodology

This systematic review followed the JBI framework for systematic review [15] and was reported according to the guidance of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement [16].

2.1. Eligibility criteria

To be included in this review, studies had to meet the following criteria: (1) Population – adult patients undergoing abdominopelvic or abdominal CT in portal phase for oncologic and/or acute diseases; (2) Intervention/Comparators – LBW-based methods to calculate CM quantity for an abdominopelvic CT in portal phase were compared to other calculation methods; (3) Outcomes – studies assessing liver parenchyma, portal vein, or aorta enhancement with contrast enhancement index (Hounsfield Unit (HU), HU/g, HE/Iode, HU/g/kg…); (4) Study design – randomised controlled trial (RCT) or quasi-experimental studies. By focusing on RCTs, which are particularly valuable for their ability to minimize bias through randomization and control groups, we aimed to ensure that the comparisons between different contrast media (CM) dosage protocols were as robust and reliable as possible. Studies not published in English or French, exploring non-human context and published before 2002 due to the use of different CT equipment with limited characteristics were excluded.

2.2. Search strategy

The search strategy was designed to identify both published and unpublished studies, with the support of a biomedical information specialist. The following databases were searched from 2002 onwards on 13th July 2021 with a final update on 20 June 2024: Ovid MEDLINE ALL, Embase.com, CINAHL with full text (EBSCO), Cochrane Central Register of Controlled Trials (Wiley), Web of Science Core Collection, ProQuest Dissertations & Theses A&I ClinicalTrials.gov, WHO International Clinical Trials Registry Platform and Dart Europe (see the full search strategies Appendix I). All search strategies were peer-reviewed by another information specialist using the PRESS checklist [17]. A complementary search was performed on Google Scholar and backward/forward citation searches were performed with Web of Science on all studies selected following the critical appraisal. Following the searches, the retrieved records were imported into EndNote 20 (Clarivate, USA) and the duplicates were removed.

2.3. Study selection and quality assessment

Titles and abstracts were screened by two independent reviewers for selection against the inclusion and exclusion criteria using the web-based citation management system Rayyan (Qatar Computing Research Institute, Doha, Qatar) [18]. Divergences were resolved through discussion to find a consensus. A similar process was used for full-text screening. Two reviewers assessed independently the quality of eligible articles using the JBI critical appraisal checklists for RCT and quasi-experimental studies [19]. Any disagreements between the reviewers were resolved through discussion.

2.4. Data extraction

The data, extracted independently by two reviewers from the selected studies, included: (a) Article: author, year, design (b) Technique: CT-brand, kV, tube current (c) Injection: CM dose calculation, LBW strategies, CM molecule and concentration, factor of gI/kg of LBW (d) Population: sample size, BMI (e) Outcome: enhancement indices, CM volume. Disagreements were resolved through discussion to find a consensus. No automation tools were used to collect data.

2.5. Data synthesis

Meta-analyses were performed with the Review Manager software (Version 5.4.1) [20] using random-effects models (DerSimonian and Laird method [21]) to account for potential heterogeneity among studies. Effect measures were estimated with the mean differences for continuous variables. Missing mean values were imputed based on medians and interquartile intervals using the Wan and colleagues' formula [22]. When two subgroups within a study were similar, they were combined into a single group following the Cochrane's recommendations [23]. This is the case for the measured and calculated LBW of Ho et al. [24]. Statistical heterogeneity was assessed with the Chi^2 tests and the I^2 statistics. The results were presented in forest plots. Where statistical pooling was not feasible, the results were presented narratively.

3. Results

3.1. Study selection

The database search yielded 2029 records. After duplicates removed, 1354 records were screened based on title and abstract and 1305 were excluded. Of the 49 full texts searched, two were not retrieved, leading to the eligibility assessment of 47 studies. At this stage, 36 studies were excluded due to ineligible outcome or study type. A search in google scholar yielded three additional eligible studies. Finally, out of the 14 studies, eight were deemed suitable for inclusion in this systematic review following quality assessment (Fig. 1). The final eight included studies were RCT, and their quality was assessed (Table 1), indicating moderate to good quality.

3.2. Characteristics of included studies

Table 2 shows the detailed characteristics of the eight included studies.

The number of patients studied in these publications ranged from 100 to 529. The eight included studies, compared LBW to TBW, except one, which compared LBW only to FV [25]. In addition to the LBW-TBW comparison, two studies used another comparator: either BV [10] or BSA [11].

LBW was calculated using the James formula in two studies [25,26], while in another it was calculated using the Boer formula [27].

In six studies [10,11,13,24,27,28], LBW was estimated based on body fat percentage using a commercially available body fat monitor, followed by application of the formula: LBW=TBW x (1 − body fat

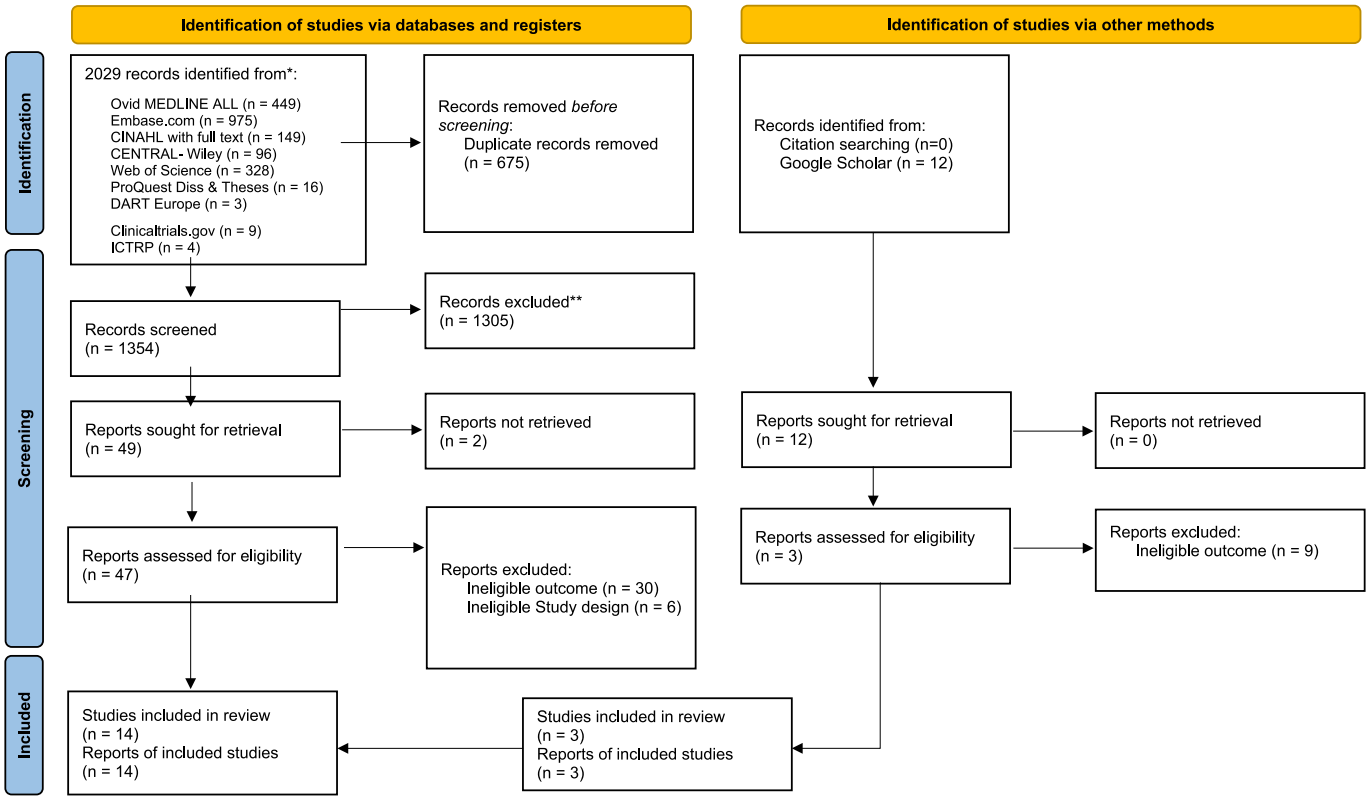

Fig. 1. Flowchart of study selection.

Table 1
Results of the quality assessment with JBI critical appraisal checklist for Randomised Control Trials (RCT).

	Assessment criteria													
	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Costa 2020 [27]	+	+	+	+	+	+	+	+	+	+	+	+	+	13/13
Caruso 2021 [25]	+	NA	+	NA	NA	U	−	+	+	+	+	+	+	8/13
Ho 2007 [24]	+	−	U	NA	NA	+	+	+	+	+	U	U	+	7/13
Kondo 2010 [10]	+	NA	U	NA	NA	U	+	+	+	+	+	+	+	8/13
Kondo 2011 [13]	+	NA	U	NA	NA	+	+	+	+	+	U	U	+	7/13
Kondo 2013 [11]	+	+	−	NA	NA	U	+	+	+	+	+	+	+	9/13
Matsumoto 2019 [26]	+	NA	+	NA	NA	+	+	+	+	+	+	+	+	10/13
Zanardo 2020 [28]	+	NA	+	+	NA	+	+	+	+	+	+	+	+	11/13

Note: +: yes; −: no; U: unclear; NA: not applicable.

Table 2
Studies characteristics,

Study	N	LBW calculated or measured	Comparator	Concentration (mgI/mL)	Contrast agent	gI/kg of LBW	kV	Tube current	Equipment Manufacturer
Costa 2020 [27]	230	calculated and measured	TBW	350	Iohexol	0.7	120	/	Siemens Definition AS and Definition Flash
Caruso 2021 [25]	100	calculated	FV	350	Iomeprol	0.7	120	200 to 600 (mAs)	GE LightSpeed VCT and Philips Brilliance iCT 256,
Ho 2007 [24]	101	measured	TBW/FV	370	Iopamido	0.86 (men)0.92 (women)	140	100 to 380 (mA)	GE LightSpeed 16
Kondo 2010 [10]	120	measured	TBW/BV	300	Iohexol	0.821	120	/	GE LightSpeed QX/i
Kondo 2011 [13]	65	measured	TBW	300	Non-Ionic contrast agent	0.55/0.65/0.75	120	/	GE LightSpeed QX/i
Kondo 2013 [11]	103	measured	TBW/BSA	300	Iohexol	0.75	120	50 to 400 (mA)	GE LightSpeed 16
Matsumoto 2019 [26]	529	calculated	TBW	300	Iohexol	0.679 (men) 0.762 (women)	100	100 to 770 (mA)	GE LightSpeed VCT
Zanardo 2020 [28]	274	measured	TBW	370	Iopamido	0.63	120	100 to 200 (mAs)	Siemens Somatom Definition

Note: LBW- lean body weight; TBW- total body weight; BV- blood volume; BSA- body surface area; FV-fixed volume.

percentage / 100).

Concerning the outcomes, all studies quantified the mean hepatic enhancement (MHE), corresponding to the difference in HU measured in enhanced and unenhanced images. The only exception was Ho et al [24] who used postcontrast attenuation measurements in. Costa et al. [27] additionally reported the MHE normalised according to three different parameters (*i*) the amount of iodine dose (MHE/I), (*ii*) the amount of iodine per kg of TBW (adjusted MHE TBW: $aMHE_T$=MHE/(I/TBW)), and (*iii*) the amount of iodine dose per kg of LBW ($aMHE_L$=MHE/(I/LBW)).

Finally, all studies except one [13] reported CM volume (Table 3). Matsumoto et al. [26] presented CM volume in milligrams (mg) of iodine per kilogram of TBW, instead of milliliter (mL) of iodine per kilogram. A conversion of mg to mL was performed to include these data into the meta-analysis.

3.3. LBW VS TBW

3.3.1. Liver parenchyma enhancement

The MHE was examined in nine independent comparisons from six studies [10,11,13,26–28]. The overall mean difference between LBW and TBW for MHE was −1.5 HU (95 % CI: −3.12; 0.12) and it was not statistically significant ($p = 0.07$; Fig. 2). There was no significant heterogeneity with a Chi^2 value of 13.66 ($p = 0.09$) and an I^2 of 41 %.

The other three liver parenchyma enhancement indices (MHE/I, aMHET, aMHEL) reported by Costa et al. [25] showed no statistical difference between TBW and LBW groups, for both men and women.

The patient-to-patient variability in each protocol group was assessed in six studies [10,11,13,24,27,28]. In the three Kondo's studies, it was assessed through linear regression concluding with reduced variation in contrast enhancement with LBW strategies although there were no significant differences in the correlation coefficient among the three groups [10,11,13]. In Ho et al. [24] Levene test was performed concluding that the measured LBW group presented the lowest intra-group variability ($p = 0.05$). Costa et al. [27] used F-test of equality of variances to compare interpatient variability between groups concluding that no statistical differences exist ($p > 0.05$). In Zanardo et al. [28] interquartile interval of CT values measured in liver and aorta was used and the difference between groups was not significant for the variability ($p = 0.23$).

The proportion of patients with suboptimal enhancement in liver were reported in two studies [15,28]. In Kondo et al. (2011) [13] only two patients in the LBW group showed suboptimal contrast enhancement in liver and one patient in the TBW group. In Zanardo et al.'s research [28], suboptimal liver contrast enhancement was observed in LBW and TBW groups, with percentages of 48.12 % and 48.94 % respectively.

3.3.2. Aorta enhancement

The aorta enhancement was assessed in five studies [10,11,13,26,28]. The mean difference in the aorta enhancement between LBW and TBW was −6.03 HU (95 % CI: −12.37; 0.31) and was not statistically significant ($p = 0.06$) (Fig. 3). However, there was a significant heterogeneity among clinical trials ($Chi^2 = 22.57$; $p = 0.001$ and $I^2 = 73$ %).

3.3.3. Contrast media volume

The injected CM volume was significantly lower in the LBW compared to TBW protocol (−7.29; 95 % CI: −12.04; 2.54; $p = 0.003$) (Fig. 4). Similarly, the heterogeneity was also significant (Chi2 = 38.82; $p < 0.00001$ and $I^2 = 79$ %). The results of Ho et al. [24] for both measured and calculated LBW in the meta-analysis were compiled.

3.4. LBW versus FV

LBW and FV protocols were compared in two studies, using MHE [25] or postcontrast enhancement in the aorta and liver [24]. Because the outcomes differed, no meta-analysis could be performed. The results of contrast enhancement in liver and aorta were not significantly different in the two studies.

The injected CM volume was not significantly lower in the LBW compared to TBW protocol (−2.40; 95 % CI: −30.36; 25.56 $p = 0.87$) (Fig. 5). A significant heterogeneity was detected among studies (Chi2 = 40.57; $p < 0.001$ and $I^2 = 98$ %). The findings from Ho et al. [24] were compiled for both the measured and calculated LBW in the meta-analysis.

3.5. LBW versus BV

In Kondo et al. (2010) [10], no significant differences were found in aortic or liver contrast enhancement between LBW (n = 40) and BV groups (n = 40). No significant difference in contrast volume was observed between groups ($p = 0.73$).

3.6. LBW versus BSA

In Kondo et al. (2013) [11], MHE exhibited a moderate positive correlation with TBW (r = 0.58, $p < 0.001$), while remaining relatively stable with LBW (r = 0.17, $p = 0.34$) and BSA (r = −0.18, $p = 0.29$). Regarding the contrast volume, there was no statistical difference among groups ($p = 0.66$).

4. Discussion

This study is the first systematic review evaluating the effect of LBW for contrast volume calculation in CT abdominal, presenting a comprehensive analysis of its implications and outcomes. The eight studies included in this review explored the outcomes obtained from a total of 1522 patients comprised in the RCT, which can provide useful evidence for clinical practice even with studies presenting methodological limitations.

The findings from the meta-analysis indicate a trend of higher aorta and liver parenchyma contrast enhancement with the TBW protocol than with the LBW protocol. This observation is expectable, as TBW strategies in overweight individuals involve administering excessive contrast media due to adipose tissue within TBW and in consequence higher contrast enhancement. However, this result was not statistically significant.

Furthermore, the LBW group demonstrated diagnostic image quality and the least interpatient variability related to liver and aorta contrast enhancement across the four studies [10,11,13,24]. However, in Zanardo et al and Costa et al. [27,28], no differences were shown between TBW and LBW protocol in patient-to-patient uniformity. The absence of variation might be attributed to undisclosed factors that have influenced the outcome trend in a contrary direction, as noted by Zanardo et al. [28]. For instance, the authors noticed a higher variability in the unenhanced CT values within the LBW group compared to the TBW group, which could explain the lack of variability difference between the groups in terms of liver contrast enhancement.

Another outcome evaluating the efficacy of the injection protocol involves its impact on the visibility of lesions and diagnostic accuracy. As described in Heiken et al. [29], to be diagnostic, hepatic parenchymal enhancement during the portal venous phase must be at least 50 HU. As observed in the meta-analysis of contrast enhancement in liver, MHE were above 50 HU in all studies except in Zanardo et al. [28]. However, in Zanardo's study, they confirmed that all examinations reached a diagnostic level. Additionally, given the outdated nature of the diagnostic threshold of 50 HU, it seems necessary to reassess this standard considering technological advancements.

Furthermore, meta-analysis reveals significant heterogeneity in results of aorta contrast enhancement. The observed heterogeneity can be predominantly attributed to the enlarged results observed in Matsumoto et al. [26], where the aorta enhancement was examined across three BMI

Table 3
Studies results.

Author and publication year	Outcome	Comparator	Formula	Contrast enhancement	Region of Interest	Contrast volume (mL)
Costa et al. 2020 [27]	Mean Hepatic Enhancement	TBW	MHE=HU enhanced – HU unenhanced And aMHE (HU/g/kg TBW) or (HU/g/kg LBW)	MHE: *Female* TBW: 54.6 ± 11 LBW: 49.4 ± 14 *Male* TBW: 54.8 ± 11 LBW: 51.5 ± 10 aMHE(HU/g/kg TBW): *Female* TBW: 0.025 ± 0.013 LBW: 0.028 ± 0.014 *Male* TBW: 0.018 ± 0.007 LBW: 0.018 ± 0.006 aMHE (HU/g/kg LBW): *Female* TBW: 0.039 ± 0.016 LBW: 0.042 ± 0.017 *Male* TBW: 0.025 ± 0.009 LBW: 0.024 ± 0.008	Liver	Female TBW: 93.7 ± 20 LBW: 77.5 ± 11 Male TBW: 106.5 ± 20 LBW:98.4 ± 11
Caruso et al 2021 [25]	Mean Hepatic Enhancement	FV	HU enhanced – HU unenhanced	FV: 59.61 ± 15.21 LBW: 59.22 ± 11.14	Liver	FV: 120.00 ± 0.00 LBW: 103.47 ± 17.65
Ho et al. 2007 [24]	Postcontrast Attenuation Measurements	TBW/FV	HU	Liver: FV: 116 ± 15 TBW: 124 ± 13 LBWc:121 ± 14 LBWm: 120 ± 11 Aorta: FV: 145 ± 18 TBW: 152 ± 17 LBWc:148 ± 18 LBWm: 145 ± 13	Liver and Aorta	FV: 125 ± 0 TBW: 130 ± 32 LBWc: 139 ± 25 LBWm: 135 ± 28
Kondo et al. 2010 [10]	Mean Hepatic Enhancement	TBW	HU enhanced – HU unenhanced	Liver: TBW: 46.4–73.6 LBW: 50.1–91.3 BV: 54.0–73.8 Aorta: TBW: 104.7–175.6 LBW: 106.2–183.2 BV: 110.1–161.3	Liver and Aorta	TBW:107 ± 17 LBW: 103 ± 16 BV: 105 ± 16
Kondo et al. 2011 [13]	Mean Hepatic Enhancement	TBW/BV	HU enhanced – HU unenhanced	Liver: 550 mgI/kg LBW:43.1 ± 6.0 650 mgI/kg LBW: 55.4 ± 7.6 750 mgI/kg LBW: 60.8 ± 5.9 600 mgI/kg TBW: 63.5 ± 10.0 Aorta: 550 mgI/kg LBW: 95.1 ± 12.6 650 mgI/kg LBW: 109.9 ± 13.6 750 mgI/kg LBW: 122.4 ± 16.6 600 mgI/kg TBW: 131.2 ± 16.8	Liver and Aorta	–

(*continued on next page*)

Table 3 (*continued*)

Author and publication year	Outcome	Comparator	Formula	Contrast enhancement	Region of Interest	Contrast volume (mL)
Kondo et al. 2013 [11]	Mean Hepatic Enhancement	TBW/BSA	HU enhanced – HU unenhanced	Liver: TBW: 55.2 ± 6.7 LBW: 53.0 ± 6.8 BSA: 59.1 ± 9.4, Aorta: TBW: 119.2 ± 17.9 LBW:108.6 ± 9.8 BSA:122.9 ± 14.4	Liver and Aorta	TBW: 111 ± 20 LBW: 103 ± 19 BSA: 113 ± 15
Matsumoto et al. 2019 [26]	Mean Hepatic Enhancement	TBW	HU enhanced – HU unenhanced	Low BMI LBW: 76.9 TBW: 76.8 Normal BMI LBW: 76.2 TBW: 75.4 High BMI LBW: 68.8 TBW: 74.4	Liver	LBW: Low BMI: 620.7 (593.0–652.9) Normal BMI: 558.2 (455.6–640.0) High BMI: 507.0 (392.6–581.3) TBW: Low BMI: 600.0 (600.0–607.6) Normal BMI: 600.0 (587.3–609.5) High BMI: 600.0 (584.4–609.4)
Zanardo et al 2020 [28]	Mean Hepatic Enhancement	TBW	HU enhanced – HU unenhanced	Liver: TBW: 97 (91–102) LBW: 97 (90–105) Aorta: TBW: 125 (116–136) LBW: 125 (117–134)	Liver and Aorta	LBW: 83 (69–96) TBW: 82 (72–93)

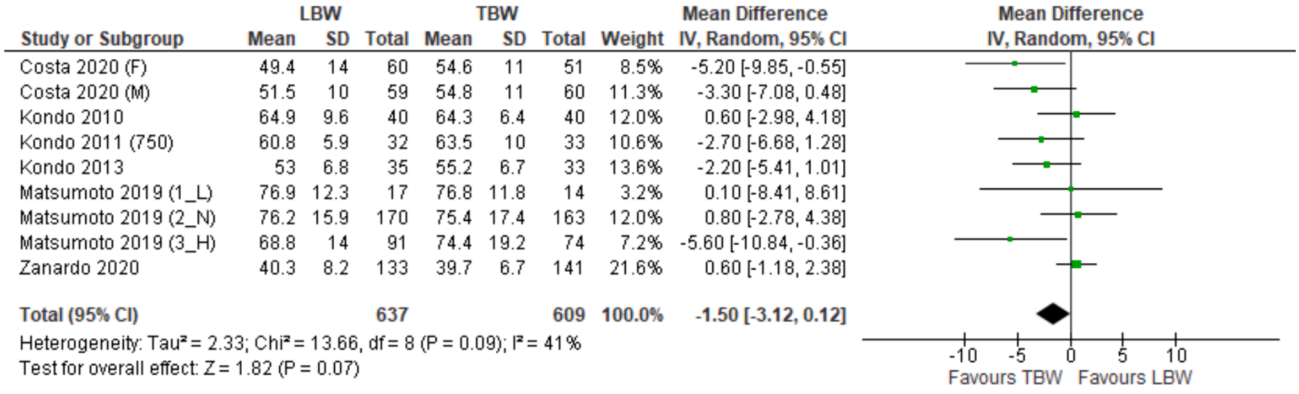

Fig. 2. Meta-analysis and forest plot of the contrast enhancement in the liver (MHE) for the LBW vs. TBW protocol.

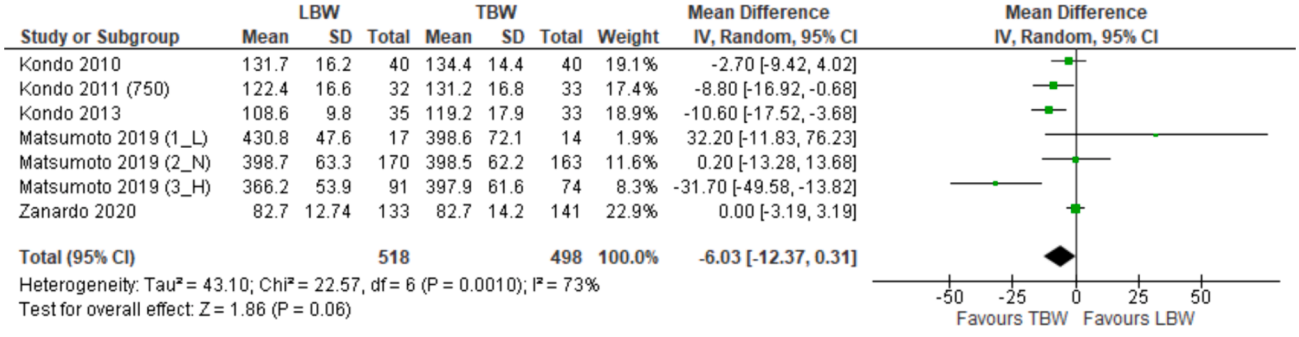

Fig. 3. Forest plot for contrast enhancement in aorta.

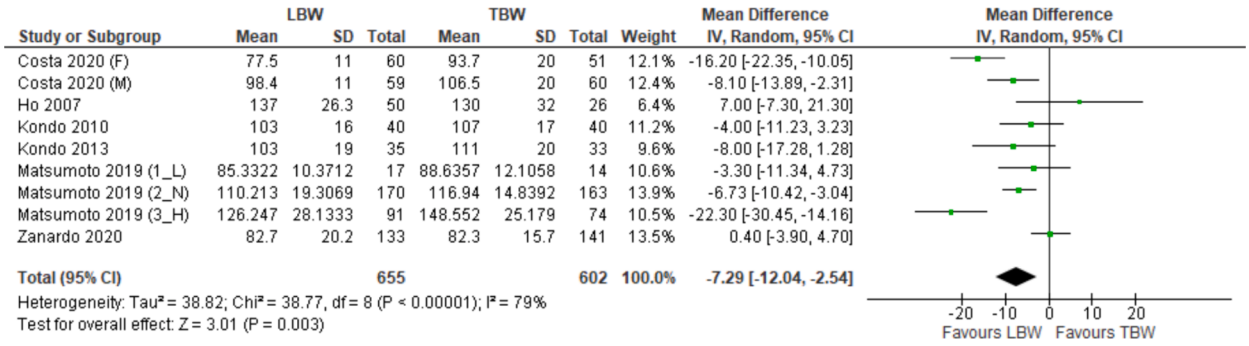

Fig. 4. Meta-analysis and forest plot of the administered contrast media volume (in mL) for the LBW vs. TBW protocol.

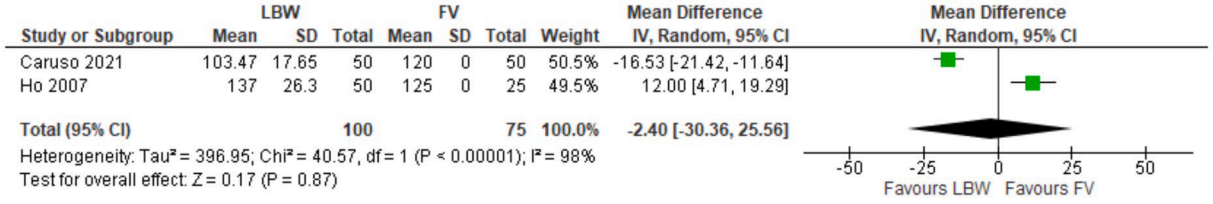

Fig. 5. Meta-analysis and forest plot of the administered contrast media volume (in mL) for the LBW vs. FV protocol.

categories: low, normal, and high BMI. The meta-analysis revealed higher mean contrast enhancement differences with low and high BMI groups, with 32.30 and −31.70, respectively. Moreover, these results highlighted that LBW strategies are more advantageous for population with high BMI. In fact, body weight is one of the most important patient-related factors affecting the magnitude of vascular and parenchymal contrast enhancement [8,29–32]. Due to the high variation of patient's characteristics, it is recommended larger samples to ensure a more representative description of the main population issues [33]. Nevertheless, most of the included studies used small sample sizes, ranging from 25 to 40 participants, except for three studies investigating samples exceeding 100 individuals per group [26–28]. In addition, the limited number of studies comparing LBW with alternative strategies such as BSA or BV rather than TBW implies that conducting additional research in this domain might help mitigate the observed heterogeneity in the meta-analysis.

The CT equipment and the exposure parameters settings used varied across all studies, promoting more heterogeneity in the HU values observed (Table 2) which could influence the contrast enhancement outcomes. For example, there were variations in the kV settings among the included studies, ranging from 100 kV in Matsumoto et al. [26] to 140 kV in Ho et al. [24]. Matsumoto et al. [26] using the lower kV setting, reported higher contrast enhancement values in the liver for individuals with high BMI compared to the other studies. Moreover, HU variations across CT scanners and protocols can affect meta-analysis, highlighting the importance of aligning vendor parameters and emphasizing proper acquisition techniques to minimize scanner effects [34,35]. Furthermore, the differences in methodology regarding image quality assessment varied among studies, particularly in contrast enhancement measurement methods, ROI placement, and sizes, leading probably to increased result heterogeneity results [35].

Regarding CM volume, the meta-analysis revealed a significantly lower volume administered with the LBW protocol compared with the TBW protocol, indicating a mean difference of 7.29 ml. This reduction in volume across all yearly examinations could potentially lead to enhanced patient safety against nephropathy induced by contrast media. Furthermore, the reduction of contrast volume could have a positive environmental impact by decreasing the burden associated with the production and disposal of iodine-based contrast agents. This is particularly important due to the extensive use of iodinated contrast for diagnostics, marked by high injection levels and the product's low biodegradability [36,37].In fact, contrast media constitute an increasing environmental risk through their production and patient urinary excretion, contaminating drinking water sources in numerous locations worldwide [37]. Additionally, efforts to recycle or recover contrast media are gaining attention. The findings of the GREENWATER study by Zanardo et al. [38] will contribute to initiating a comprehensive evaluation of the role of on-site wastewater treatment solutions. In this context, it is important to make health professionals aware of the opportunity to take the lead now in more conscious decisions regarding use of contrast media. Saving 7.29 mL of CM per patient represents therefore an opportunity to reduce the amount of contrast media excreted by patients after examinations. Moreover, the lockdowns associated with Covid-19 in 2022 led to a shortage of iodinated CM [39]. This event provided an opportunity to reassess injection protocol and the use of iodinated CM for upcoming practice as it offers many advantages regarding patient safety, environmental impact, and costs. The statistically significant heterogeneity observed in the meta-analysis is primarily attributed to the two groups that benefit the most from the LBW protocol: females in Costa et al. [27], experiencing a mean reduction in volume of 16 mL (17 %), and patient with high BMI in Matsumoto et al. [26], with a mean reduction of 22 mL (15 %). In fact, sex is likely related to a higher contrast enhancement in female than male for a given weight and height due to the fact that BV is lesser in female [46]. Indeed, this sex difference in adiposity could be explained by the higher proportion of fat for woman and higher muscle mass for men [40,41]. Regarding high BMI, it is well-established that contrast medium volume based on body weight may lead to an overestimation in overweight patients due to the poor migration of contrast medium through adipose tissues [42–45]. Another factor potentially implicated in the significant heterogeneity is the difference in gI/kg of LBW used in the various studies, as shown in Table 2. For example, significant heterogeneity was also observed in the meta-analysis when comparing contrast volume between LBW and FV ($p < 0.001$). The higher mean contrast volume injected in LBW group in Ho et al. [24] may be attributed to the higher factor of gI/kg per LBW of 0.92 used, the small number of patients in each protocol group, and the difference in BMI between groups.

Recent advances in imaging technologies like dual-energy CT and photo-counting CT offer promising advancements in image quality and radiation dose reduction and have the potential to improve CM

administration protocols. Dual-energy imaging techniques, for instance, enhance contrast with low monochromatic reconstructions, leading to a significant reduction in CM volume. However, at lower kVp levels, noise tends to escalate, which can be mitigated through the implementation of iterative reconstruction or deep-learning image reconstruction methods [46–48]. These advancements have significantly enhanced image quality over the years, particularly for specific populations such as overweight patients [49] leading to a reduction in the amount of contrast media injected [50,51]. The photon counting technology have also demonstrated comparable image quality despite significant reduction in contrast volume [52,53]. A synergistic optimisation strategy could potentially be implemented to tailor contrast volume adjustments employing either dual-energy or photon counting technologies in conjunction with the LBW-based CM volume calculation method.

Considering the intricacy and time required for implementing a personalized approach to contrast dosing in body CT is crucial. While LBW-based dosing can optimize CM use and potentially reduce adverse effects, it may also increase procedure time compared to simpler methods like fixed-volume dosing. Implementing strategy LBW-based CM dosing protocols in clinical settings involves several practical considerations: The first consideration is the population that could benefit from an injection based on LBW such as oncologic imaging or abdominal CT, especially in overweighted patient. In scenarios where rapid dosing is crucial, such as in emergency settings, a fixed-volume approach might be more practical. For vascular imaging, which primarily depends on blood volume and cardiac output, a fixed-volume strategy could also be appropriate and does not require LBW-based calculation for CM. The second challenge is the need for accurate and feasible methods to estimate LBW, such as bioelectrical impedance analysis. However, implementing bioelectrical impedance analysis to measure LBW might not be feasible for patients with disabilities or those confined to beds. For these patients, the James or Boer formula (depending on patient demographics) could be used on an Excel spreadsheet or web LBW calculator.

This study presented several limitations. Firstly, this systematic review was limited to English and French-language publications, which can limit the inclusion of other studies and the generalisation of results considering all variables that impact the outcome. Secondly, the number of included studies was limited. However, this systematic review represents the actual most concise overview of the effectiveness of LBW protocol injection for abdominopelvic CT compared with other injection strategies. This systematic review has also numerous potential confounding variables that might have influenced the outcomes include differences in patient populations (e.g., variations in body composition, underlying health conditions), CT scanner technology, image acquisition protocols across the studies and methodology used to assess image quality. We addressed these by performing subgroup analyses where possible and excluding studies with significant methodological differences. However, residual confounding cannot be entirely ruled out. Future studies could benefit from standardizing these variables and employing more homogenous patient cohorts.

A suggested approach entails undertaking a more rigorous and stratified RCT with a larger sample size and considering all previously mentioned outcomes related to patients and interventions, to improve the accuracy and the reproducibility of results. This approach aims to provide robust evidence, support research/evidence-based practice, leading to promote effective patient care and outcomes.

In conclusion, our study highlights the potential superiority of LBW-based protocols over TBW protocols in abdominopelvic CT imaging, particularly for female and overweight patients. The consistent enhancement of liver and aorta coupled with a significantly reduced volume, underscores the advantages of LBW protocols. Nevertheless, the limitations inherent in current studies, including the complexity of LBW calculation, the lack of consideration for emerging technological advancements such as deep learning reconstruction algorithms, and the recent developments in spectral imaging, warrant cautious interpretation of these findings. Further research incorporating these factors is essential to establish the broader applicability and efficacy of LBW-based protocols in clinical practice.

Ethics approval

This is a meta-analysis. No ethical approval is required.

CRediT authorship contribution statement

Marianna Gulizia: Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Sandrine Ding:** Writing – review & editing, Validation, Methodology, Formal analysis, Data curation, Conceptualization. **Cláudia Sá dos Reis:** Writing – review & editing, Validation, Methodology, Formal analysis, Data curation. **Cécile Jaques:** Writing – review & editing, Software, Methodology, Data curation, Conceptualization. **Clarisse Dromain:** Writing – review & editing, Validation, Supervision, Methodology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ejrad.2024.111631.

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