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Clinical Studies

Correlation between bone density measurements on CT or MRI versus DEXA scan: A systematic review



Amer Ahmad, MD^a, Charles H Crawford III, MD^{a,b}, Steven D. Glassman, MD^{a,b}, John R. Dimar II, MD^{a,b}, Jeffrey L. Gum, MD^{a,b}, Leah Y. Carreon, MD, MSc^{b,*}

^a Department of Orthopaedic Surgery, University of Louisville School of Medicine, 550 S. Jackson St., 1st Floor ACB, Louisville, KY 40202 USA

^b Norton Leatherman Spine Center, 210 East Gray St, Suite 900, Louisville, KY, 40202 USA

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ABSTRACT

Background: Novel methods of bone density assessment using computed tomography (CT) and magnetic resonance imaging (MRI) have been increasingly reported in the spine surgery literature. Correlations between these newer measurements and traditional Dual-Energy X-ray Absorptiometry (DEXA) is not well known. The purpose of this study is to perform an updated systematic review of correlations between bone mineral density (BMD) from CT or MRI and DEXA.

Methods: Articles published between 2011 and 2021 that reported correlations between the CT-HU or MRI measurements to DEXA t-scores or BMD of lumbar spine or hip were included in this systematic review.

Results: A total of 25 studies (15 CT, 10 MRI) met the inclusion criteria with a total number of 2,745 patients. The pooled correlation coefficient of spine CT-HU versus spine DEXA, spine CT-HU versus hip DEXA and spine CT-HU versus lowest t-score were 0.60, 0.50 and 0.60 respectively. Regarding spine DEXA parameters, the pooled r^2 for spine CT-HU versus spine t-score was 0.684 and spine CT-HU versus spine BMD was 0.598. Furthermore, in patients undergoing spine surgery in four studies, the pooled correlation between spine CT and spine DEXA was (r^2 : 0.64). In MRI studies, the pooled r^2 of spine MRI versus spine DEXA and spine MRI versus hip DEXA were -0.41 and -0.44 respectively.

Conclusions: CT-HU has stronger correlations with DEXA than MRI measurements. Lumbar CT-HU has the highest pooled correlation ($r^2 = 0.6$) with both spine DEXA and lowest skeletal t-score followed by lumbar CT-HU with hip DEXA ($r^2 = 0.5$) and lumbar MRI with hip ($r^2 = 0.44$) and spine ($r^2 = 0.41$) DEXA. Both imaging modalities achieved only a moderate correlation with DEXA. Few studies in both modalities have investigated the correlation in spine surgery populations and the available data shows that the correlations are worse in the degenerative spine population. A careful interpretation of CT HU and MRI measurement when evaluation of BMD as they only moderately correlated with DEXA scores. At this time, it is unclear which modality is a better predictor of mechanical complications and clinical outcomes in spine surgery patients.

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* Corresponding author. Norton Leatherman Spine Center, 210 East Gray St, Suite 900, Louisville, KY 40202, USA. Tel.: (502)-584-7525, fax: (502)-589-0849.

E-mail address: leah.carreon@nortonhealthcare.org (L.Y. Carreon).

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Introduction

With the increase of the aging population, osteoporosis has become a common health problem with low detection and treatment rates [1–4]. Evaluating bone strength is important in patients undergoing instrumented lumbar spine surgeries as it may be associated with mechanical failure and other complications [5]. Currently, bone mineral density (BMD) is considered the best measure for bone quality. Thus, having an accurate method to measure BMD in spine surgery is important for preoperative planning and optimization [6–8].

Dual-Energy X-ray Absorptiometry (DEXA) scans are considered the gold standard for BMD assessment [9,10], yet it has some disadvantages as it tends to overestimate the BMD in patients with degenerative spines, aortic calcifications or with high Bone Mass index (BMI) [3,11–15], characteristics which are commonly seen among patients seeking spine surgery treatment.

Computed tomography (CT) and magnetic resonance imaging (MRI) are frequently used in the preoperative assessment of spine surgery patients and recently they are increasingly used as alternatives to estimate BMD [16,17]. The purpose of this study is to perform an updated systematic review to compare between BMD estimates from lumbar CT and MRI in term of correlation with the more traditional DEXA scans.

Material and methods

A systematic search was conducted on October 2021 for articles published from 2011 to 2021 in PubMed and Google scholar data bases using the following terms: “Hounsfield units”, “computed tomography”, “Quantitative CT scan”, “MRI”, “magnetic resonance imaging”, “bone mineral density”, “osteoporosis”, “lumbar spine”, “DEXA”, “DXA” and “correlation”. A total of 1,131 full text articles were identified. Cohort studies written in English that reported the correlation between either the HU/MRI measurements of lumbar spine or specific level and DEXA t-score or BMD in patients older than 18-year-old regardless of CT/MRI protocol used were included. Duplicate studies, Biomechanical and cadaver studies or studies that predict the lumbar BMD using the CT or MRI without reporting the correlation coefficient with DEXA scan were excluded (Fig. 1).

The data from each included CT scan and MRI studies were collected in Excel spread sheet by the Author and included: study design, principal author, year of publication, total number of patients (N), patient's demographics, inclusion and exclusion criteria, CT and MRI protocols and regions, Measurement of Hounsfield unit and MRI methods, DEXA

scores, the mean duration between the CT/MRI and DEXA and the correlation coefficient between the CT/MRI and DEXA. Data was analyzed by two independent reviewers.

Correlation studies included in this review were categorized into 5 groups: spine CT with spine DEXA, spine CT with hip DEXA, spine CT with lowest t-score, spine MRI with spine DEXA and spine MRI with hip DEXA. The pooled correlation coefficient weighted by the sample size was calculated for each group. In addition, a separate pooled correlation coefficient was calculated for CT HU in patients undergoing spine surgery.

Results

A total of 26 studies (16 CT scan, 10 MRI) met inclusion criteria for the review with a total number of 2,745 patients. Among the CT scan correlation studies, additional one study was excluded after further review due to the inconsistency of the spine level used for measuring the HU in breast cancer patients; when L1 HU from chest CT was not available for the measurements due to compression fracture in some patients, either T12 or L2 were used as alternative level without being specified [18].

CT scan studies

All the 15 CT scan studies were retrospective with total number of 2,027 patients. The correlation of HU with spine DEXA was reported in thirteen studies (N=1,979), HU with hip DEXA in 3 studies (N:456) and HU with lowest skeletal t-score in 3 studies (N: 455). Some studies correlated the HU for each lumbar vertebra and others correlated the HU mean value for the lumbar spine (L1–L4) (Table 1) as it has been shown no significant difference between lumbar vertebrae HU values [19]. The pooled correlation coefficient of spine CT vs spine DEXA, spine CT versus hip DEXA and spine CT versus lowest t-score were 0.60, 0.50 and 0.60, respectively. Regarding spine DEXA parameters, HU was correlated with BMD only in 3 studies, with t-score only in 3 studies and with both measurements in 9 studies. The pooled r^2 for spine CT vs spine t-score was 0.684, spine CT versus spine BMD was 0.598. Furthermore, four CT studies correlated the spine CT with spine DEXA in patients undergoing spine surgery with pooled correlation (r^2 : 0.64).

Lumbar CT without contrast was the most used for HU measurements followed by abdominal CT without contrast. There was a variation among the scanning parameters; tube current (range: 30–330mA) and slice thickness (range: 1–5 mm) which were specified in nine stud-

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Table 1
CT scan correlation studies

Study	CT scan	CT HU Region of interest (ROI)	DEXA	Max. Duration between CT & DEXA	patients' population	Mean age (years)	Total number of patients (N)	Year of publication	Study design
Kim et al. [24]	Lumbar CT*	Largest trabecular ROI at mid axial of vertebral body	spine DEXA BMD, hip DEXA BMD	3 mo	Patients undergoing lumbar spine surgery in single center	68.1	180	2019	retrospective
Cohen et al. [25]	Abdominal & Lumbar CT*	Trabecular ROI on mid-axial and mid-sagittal of vertebral body	lowest skeletal T score	6 mo	Arab, Ashkenazi and Sephardic jew in single center	64	246	2021	retrospective
Da Zou et al. [5]	Lumbar CT*	Trabecular ROI on mid axial of vertebral body	spine DEXA T score & BMD	1 mo	Patients undergoing lumbar degenerative spine surgery in single center	Undefined	334	2018	retrospective
Chia et al. [27]	Contrast enhanced CT scan*	Mean of trabecular ROI measured at 3 different locations on axial image	spine DEXA T score, lowest skeletal T score	3 wks	Patients with age 50 and above who underwent CECT for any medical condition in single center	Undefined	50	2021	retrospective
Islamian et al. [21]	Abdominal & Lumbar CT*	Trabecular ROI on mid axial of vertebral body	spine DEXA BMD	3 mo	Patients with spine fracture from minor trauma who underwent both CT and DEXA within 3 mo in single center	60.2	61	2016	retrospective
Alawi et al. [28]	Abdominopelvic & Lumbar CT*	Mean of trabecular ROI measured at 3 different locations on axial image	spine DEXA T score & BMD	2 y	Pre or postmenopausal women who underwent DEXA and CT within 2 years in single center	61.1	78	2021	retrospective
Choi et al. [26]	Lumbar CT*	Trabecular ROI on mid axial of vertebral body	spine DEXA T score & BMD	3 mo	Patients undergoing spine surgery in single center	67.5	110	2016	retrospective
Schreiber et al. [20]	Abdominopelvic & Lumbar CT*	Mean of trabecular ROI measured at 3 different locations on axial image	spine DEXA T score & BMD	12 mo	Spinal trauma or compression fracture in single center	71.3	25	2011	retrospective
Lee et al. [1]	Lumbar CT	Mean of trabecular ROI measured at 3 different locations on axial image	spine DEXA T score	12 mo	Female patients above age 40 with low back pain, single center	Undefined	128	2013	retrospective
Elarjani et al. [33]	Lumbar CT	Trabecular ROI on mid axial vertebral body and mean of 5 trabecular ROI measured at different locations on sagittal image	spine DEXA T score & BMD	1 y	Undefined	60.2	100	2021	retrospective
Kohan et al. [30]	Lumbar CT	Mean of trabecular ROI measured at 3 different locations on axial image	spine DEXA BMD, hip DEXA BMD	Undefined	White female patients undergoing ASD surgery in single center	Undefined	48	2017	retrospective
Kim et al. [23]	Chest LDCT*	Volumetric reconstruction analysis of multiple ROIs on axial image	spine DEXA BMD, hip DEXA BMD	30 d	patients above age 50 who underwent LDCT in single center	65.9	224	2017	retrospective
Amin et al. [10]	Abdominopelvic & Lumbar CT	Mean of trabecular ROI measured at 3 different locations on axial image	lowest skeletal T score	12 mo	Predominantly Asians from different ancestries, single center	Undefined	159	2021	retrospective
Burke et al. [34]	Abdominal CT*	Mean of 3 trabecular ROI on mid axial vertebral body by 3 separate readers	spine DEXA T score & BMD	6 mo	Patients over age 50, had MDCT for other clinical indications	71	171	2016	retrospective
Li et al. [19]	Abdominal CT*	Trabecular ROI on mid sagittal of vertebral body	spine DEXA T score & BMD	6 mo	Chinese patients who underwent CT and DEXA within 6 mo in single center	67	109	2018	Retrospective

* CT tubal voltage: 120 kvp.

Table 2
Correlation coefficients between Spine CT and DEXA (T-score, BMD)

Study	CT scan						
	DEXA score	L1 vertebra	L2 vertebra	L3 vertebra	L4 vertebra	Lumbar spine (L1–4)	
Kim et al. [24]	Spine BMD	0.552	0.535	0.542	-	0.489 [‡]	
	Femur neck BMD	0.349	0.469	0.374	-	0.393	
Da Zou et al. [5]	Spine T-score	0.667 [*]	0.767 [†]	0.64 [*]	0.767 [†]	0.667 [*]	0.764 [†]
	Spine BMD	0.665 [*]	0.771 [†]	0.647 [*]	0.764 [†]	0.662 [*]	0.77 [†]
Chia et al. [27]	Spine T-score	0.683	-	-	-	-	-
Islamian et al. [21]	Spine BMD	-	-	-	-	-	0.766
Alawi et al. [28]	Spine T-score	0.544	0.6	0.611	0.6	-	-
	Spine BMD	0.581	0.623	0.653	0.612	-	-
Choi et al. [26]	Spine T-score	0.3 [*]	0.701 [†]	0.457 [*]	0.709 [†]	0.447 [*]	0.649 [†]
	Spine BMD	0.313 [*]	0.684 [†]	0.499 [*]	0.693 [†]	0.455 [*]	0.639 [†]
Schreiber et al. [20]	Spine T-score	-	-	-	-	-	0.48
	Spine BMD	-	-	-	-	-	0.44
Lee et al. [1]	Spine T-score	0.673	0.794	0.766	0.713	-	-
	Spine BMD	0.657	0.774	0.737	0.673	-	-
Elarjani et al. [33]	Spine T-score	0.592 [§]	0.504 [‡]	0.482 [§]	0.519 ⁺⁺	0.460 [§]	0.458 [‡]
	Spine BMD	0.559 [§]	0.468 [‡]	0.482 [§]	0.504 ⁺⁺	0.453 [§]	0.450 [‡]
Kohan et al. [30]	Spine BMD	-	-	-	-	0.456 [§]	0.353 [‡]
	Femur neck BMD	-	-	-	-	-	0.463
Kim et al. [23]	Spine BMD	0.726	-	-	-	-	0.303
	Femur neck BMD	0.503	-	-	-	-	-
	Total hip BMD	0.665	-	-	-	-	-
Burke et al. [34]	Spine T-score	0.392	-	-	-	-	-
	Spine BMD	0.437	-	-	-	-	-
Li et al. [19]	Spine T-score	-	-	-	-	-	0.62
	Spine BMD	-	-	-	-	-	0.61

* Correlations in degenerative spine group.

† Correlations in nondegenerative spine group.

‡ L1–3 mean value.

§ Correlation with Axial CT HU

‡ Correlation with Sagittal CT HU.

ies only [20–28]. Axial CT was the most common plane used as ROI for HU measurements. The duration between CT scan and DEXA used as a part of inclusion criteria for patients was defined in all except for one study and it varies from 3 weeks to 2 years [Table 2].

The patients among the studies varied in ethnicity, number, inclusion, and exclusion criteria. Most of the cohorts were female (1,193 female, 398 male). Four studies only evaluated the correlation in patients undergoing spine surgery [24,26,29,30]. Patients with lumbar fractures, infections, tumors, previous spine instruments, vertebroplasty or severe spinal degeneration were excluded in most studies.

MRI studies

Seven studies were prospective and three were retrospective with total number of 1,024 patients. Eight studies reported correlations between spine MRI with spine DEXA (N = 812) and two studies with hip DEXA (N = 212). The pooled r^2 of spine MRI vs spine DEXA and spine MRI vs hip DEXA were -0.41 and -0.44 respectively (Table 3).

In most studies, 1.5 Tesla Lumbar MRI without contrast was used. One study used IV contrast to measure the peak enhancement ratio as a parameter for bone marrow perfusion in the vertebral body to correlate with BMD. Another study used three Tesla machine for measuring the synthetic MRI quantitative parameters of bone physical properties. Different MRI sequences with different measurements used for the correlation: Signal-to-noise ratio (SNR) and M-score (3 studies), vertebral bone marrow fat content (4 studies), Vertebral Bone Quality (VBQ) scores, which is calculated from dividing the average signal intensities (SIs) of lumbar spine by cerebrospinal fluid (CSF) signal intensity (2 studies) and peak vertebral enhancement ratio (1 study). The duration between MRI and DEXA varied from 2 weeks to 2 years among the studies (Table 4).

Most MRI correlation studies were on female patients with different ethnicity and inclusion criteria. Mean age among the cohorts ranged from 49.3 to 65 years. Two studies only evaluated the correlation in patients undergoing degenerative spine surgeries [31,32].

Discussion

We included in our review the studies that correlated CT scan or MRI to DEXA measurements in both spine and nonspine cohorts and measured the pooled correlation weighted by the sample size for each study. Our systematic review showed that CT Hounsfield unit has stronger correlations with DEXA than MRI measurements. Lumbar CT has the highest pooled correlation ($r^2 = 0.6$) with both spine DEXA and lowest skeletal t-score followed by lumbar CT with hip DEXA ($r^2 = 0.5$) and lumbar MRI with hip ($r^2 = 0.44$) and spine ($r^2 = 0.41$) DEXA. Both imaging modalities achieved only a moderate correlation with DEXA BMD and t-scores.

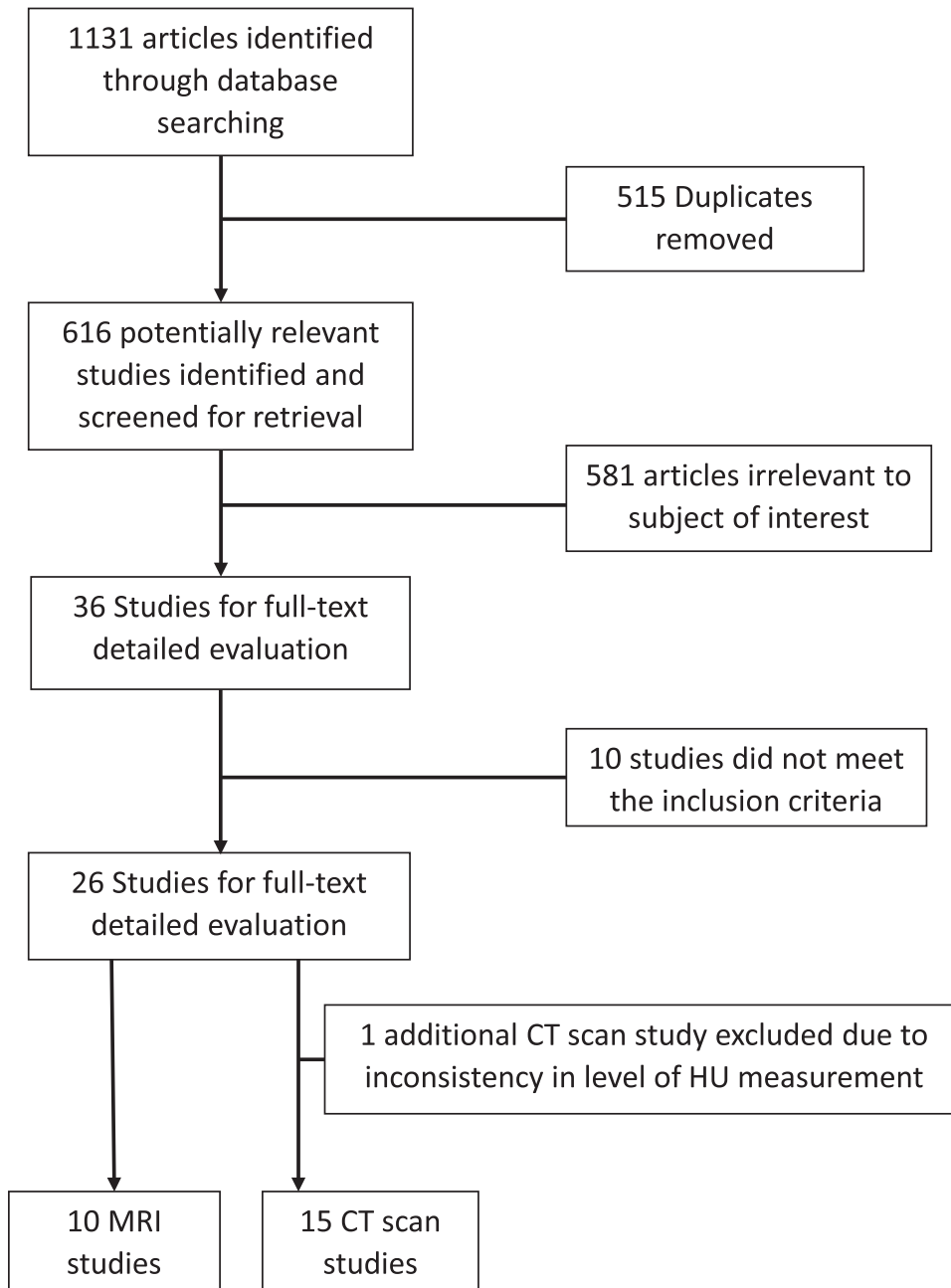
The correlation studies so far either investigated the ability of CT scan or MRI as opportunistic tools for osteoporosis screening in patients with different morbidities [10,19–23,25,27,28,33–42] or as alternatives for DEXA in predicting bone quality in spine surgery population [24,26,29–32]. Few studies in both modalities (4 CT, 2 MRI) have investigated the correlation in spine surgery patients (Table 5). Among the four CT studies, Spine CT-HU with spine DEXA showed the same moderate pooled correlated (r^2 : 0.64) [24,26,29,30]. The pooled correlation could not be calculated for spine patients in MRI studies as there are only two studies, each one of them correlated spine MRI with different DEXA region [31,32].

CT scans and/or MRIs are routinely done as a part of preoperative evaluation in patients undergoing spine surgery. BMD assessment is important for surgical planning in such patients especially when using instrumentation as it can be proxy for bone strength, healing, and fusion rates. DEXA scan is still considered the gold standard for BMD assessment and bone quality evaluation [9,10]. The inherent inaccuracy of DEXA measurements in patients with degenerative spine and the routine use of CT scan and/or MRI before spine surgery paved the way to study the potential of using these modalities as alternatives for BMD assessment in such patients.

Table 3
MRI correlation studies

Study	MRI measurement technique for ROI	MRI sequence (s) for ROI	DEXA	Max. duration between MRI and DEXA	Patients' population	Control group	Mean age (years)	Total number of patients	Year of publication	MRI measurements Level	Study design
Ergen et al. [38]	BMFF (using T2*-IDEAL technique)	T1W spine echo sequence (TR:660 ms, TE: 8.5ms) and STIR sequence (TR: 3500 ms, TE: 42 ms)	Spine DEXA BMD	3 wk	Female patients with low back pain from single center	NA	49.3	45	2014	L1–4	prospective
Agrawal et al. [37]	BMFF and ADC (using DWI and MR Spectroscopy sequences)	T1W, T2W spine echo sequence	Spine DEXA T score & BMD	18 mo	Indian postmenopausal women who underwent DEXA in recruited randomly from single center	NA	52.4	50	2015	L3	prospective
Shen et al. [41]	BMAT	T1W whole body MRI	Spine DEXA BMD, hip DEXA BMD	Non specified	African American, Caucasian recruited from CARDIA study	NA	Undefined	76	2012	L1–5	prospective
Shih et al. [35]	LWR, lipid LW, water LW (using proton MR spectroscopy sequence)	T1W, T2W spine echo sequence	Spine DEXA BMD	2 wk	Female patients who referred to orthopedic or osteoporosis clinic	NA	58	52	2004	L3	prospective
Saad et al. [42]	M score (calculated from SNR)	T1W spine echo sequence (TR: 400-600 ms, TE: 7 ms)	Spine DEXA T score & BMD	6 mo	Postmenopausal women with low back pain in single center	Healthy female of matched age with normal BMI	59.4	50	2019	L1–4	retrospective
Shayganfar et al. [40]	M score (calculated from SNR)	T1W spine echo sequence (TR:400 ms, TE: 16 ms)	Spine DEXA T score	6 mo	Iranian postmenopausal women who underwent DEXA in single center	Healthy female aged between 20 and 29 y	59.1	82	2019	L1–4	prospective
Shih et al. [36]	Peaked enhanced ratio (BMP) derived from time-Signal intensity curve	T1W spine echo sequence (TR:600 ms, TE: 12 ms)	Spine DEXA BMD	2 wk	Female patients who referred to orthopedic or osteoporosis clinic	NA	57	62	2004	L1–5	prospective
Bandirali et al. [39]	M score	T1W spine echo sequence (TR: 600 ms, TE: 11 ms)	Spine DEXA T score	6 mo	Caucasian female patients with low back pain in single center	Healthy Caucasian female aged between 20 and 29 years with normal BMI	65	226	2015	L1–4	retrospective
Ehresman et al. [31]	VBQ score	T1W spine echo sequence	Hip DEXA T score, lowest skeletal T score	2 y	Patients undergoing degenerative spine surgery in single center	NA	Undefined	68	2019	L1-4	retrospective
Chang et al. [32]	PD (using synthetic MRI sequences; T1 map, T2 map, PD map) and VBQ score, T1 intensity	T1W spine echo sequence	Spine DEXA T score	3 mo	Patients undergoing degenerative spine surgery in single center	NA	61.9	62	2021	L1–4	prospective

Fig. 1. Literature review workflow



In 2011, Schreiber et al introduced the Hounsfield unit for the first time as a measuring tool for BMD using Region of interest (ROI) on conventional CT scan without exposing patients to higher radiation doses compared with Quantitative CT scan [13,20]. More studies have used different CT protocols for BMD measurements in different populations to validate this method further in terms of reliability and applicability. According to the pooled correlation analysis, Spine CT showed moderate correlation with both spine and hip DEXA. Further correlation with the two spine DEXA measurements (t-score and BMD) were calculated. t-score showed a better correlation (r^2 : 0.684) with HU comparing with BMD (r^2 : 0.598). In addition, as the lowest t-score from spine and hip DEXA is now recommended by WHO for osteoporosis screening and treatment [43], we calculated from the available studies the pooled correlation for HU and the lowest skeletal t-score which showed the same moderate result as with hip or spine DEXA alone (r^2 : 0.60).

Among the CT studies, there was a variation in the correlations between lumbar spine HU mean values and DEXA measurements. The strongest correlation was 0.766 [21] while the lowest was 0.303 [30]. This variation could be a result of the inconsistency between the studies in terms of cohort's spine degenerative status, the durations between the images or the variations of CT calibrations (slice thickness and tuba currency) used. These variations can affect in a way or another HU measurements and DEXA differently, hence the variation in the correlation between these modalities among studies. On the other hand Using different HU ROI methods can probably not result in such variation, as the literature showed no significant difference between these different methods [13].

Despite the moderate correlation, CT scan has advantages over DEXA in spine surgery patients. It provides a three-dimensional (3D) estimate for trabecular BMD without being affected by cortical degenerative changes (sclerosis and osteophytes) or aortic calcifications which

Table 4
Correlation coefficients between spine MRI and DEXA (T-score, BMD)

study	MRI measurement*	DEXA	L1 vertebra	L2 vertebra	L3 vertebra	L4 vertebra	Lumbar spine
Ergen et al. [38]	BMFF	Spine BMD	-	-	-0.420	-	-
Agrawal et al. [37]	BMFF	Spine T-score	-	-	-0.450	-	-
		Spine BMD	-	-	-0.345	-	-
Shen et al. [41]	BMAT	Spine BMD	-	-	-	-	-0.45
		Hip BMD	-	-	-	-	-0.399
Shih et al. [35]	Lipid LW	Spine BMD	-	-	-0.67	-	-
Saad et al. [42]	M score	Spine T-score	-	-	-	-	-0.48
		Spine BMD	-	-	-	-	-0.37
Shayganfar et al. [40]	M score	Spine T-score	-	-	-	-	-0.551
Shih et al. [36]	Peaked enhanced ration	Spine BMD	-	-	-	-	0.63
Bandirali et al. [39]	M score	Spine T-score	-	-	-	-	-0.682
Ehresman et al. [31]	VBQ	Femur neck T-score	-	-	-	-	-0.51
		Total hip T -score	-	-	-	-	-0.41
Chang et al. [32]	Proton Density	Spine T-score	-	-	-	-	-0.565
	VBQ score		-	-	-	-	-0.651

* All MRI measurements have negative correlation with DEXA except for “Peaked enhanced ratio” which has a positive correlation.

Table 5
Correlations between CT scan/ MRI and DEXA of lumbar spine in patients undergoing lumbar spine surgery

Study	Modality	Spine DEXA BMD	Spine DEXA T score	Hip DEXA BMD	Hip DEXA T score
Kim et al. [24]	Axial CT HU	0.489	-	0.393	-
Da Zou et al. [5]*	Axial CT HU	0.650 [†]	0.658 [†]	-	-
		0.760 [‡]	0.754 [‡]	-	-
Choi et al. [26]	Axial CT HU	0.426 [†]	0.398 [†]	-	-
		0.721 [‡]	0.734 [‡]	-	-
Kohan et al. [30]	Axial CT HU	0.463	-	0.303	-
Ehresman et al. [31]	MRI VBQ	-	-	-	-0.510 (Femur neck)
					-0.410 (Total hip)
Chang et al. [32]	MRI VBQ	-	-0.651	-	-
	MRI PD		-0.565		

* The mean values of this study are calculated.

[†] correlations in degenerative spine group.

[‡] correlations in non-degenerative spine group.

are common findings among these patients. This may explain the better correlation between CT and DEXA in nondegenerative spine populations (Table 5). In addition, the trabecular bone is affected the most by osteoporosis and correlated better with bone mechanical strength [44] thus can predict the fracture risk and surgical outcomes more accurately in such patients.

MRI has also been investigated as a possible surrogate for bone quality evaluation. Multiple quantitative methods have investigated measuring the trabecular bone microstructure or bone marrow fat content based on differences in signal intensities within bone tissues [31,32,35–42]. Changes in these parameters has a relevant negative correlation with osteoporosis and bone quality.

M-score, a novel MRI score simulating DEXA t-score calculation, has been introduced by Bandirali et al. [39] for the first time in 2015. It has been evaluated further by other studies [40,42] which showed a better correlation with BMD (pooled r^2 : -0.58) comparing with other MRI measurements. Another promising measurement is the peaked enhanced ratio (r^2 : 0.63). It measures the IV contrast uptake within the vertebral body as a reflection of bone marrow perfusion which in turn is affected by aging and osteoporosis [36]. The disadvantage of this method is that it requires contrast, which cannot be used routinely for BMD assessment.

The pooled correlation was calculated from different MRI measurements which could not be representing the actual pooled correlation for each of them. The paucity of studies of each certain method can justify calculating pooled correlation from these different measurements.

As with CT studies, MRI studies showed that same inconsistency regarding the cohorts and duration between the images which may again add to the variation in the correlations between MRI and DEXA among the studies. In addition, most patients in MRI studies are female and

the mean age is younger when compared to CT studies (49.3–65 years vs. 60.1–71 years) which may make the correlations of MRI not representative for spine population as alternative imaging for bone density evaluation.

As with CT scans, MRI measurements are also not be affected by degenerative cortical changes. Moreover, MRI lacks the radiation risk which make it even more desirable. On the other hand, claustrophobia and metallic implants are unique limitations for this modality. The existing literature has several limitations: Most MRI and CT cohorts were females, which means the results could not be necessarily applied to the general populations. Focusing on such population can be justified since the guidelines for DEXA screening and osteoporosis treatment are designed for pre- and post-menopausal women only and no consistent ones for male patients yet [6].

Both MRI and CT studies lack the consistency in cohort's populations, imaging protocols and durations between the imaging. In addition, Studies targeting spine surgical patients are still few and more investigation is needed not only to understand how effective these modalities are in predicting bone strength, but also to acknowledge the reliability in predicting surgical outcomes and complications in such patients. Finally, both CT scans and MRIs have limitations, despite showing superiority over DEXA in BMD measurement in degenerative spine, they still have limited application in pathologies that affect the cancellous bone (eg.: tumors, infections, or fractures). Vertebroplasty and previous spinal instrumentation also can affect the measurements in both modalities.

In conclusion, CT-HU has stronger moderate correlation with DEXA than MRI. Both modalities are superior to DEXA in degenerative spine which gives them a great potential in evaluating bone quality in spine

surgery populations. There are inconsistencies among correlation studies regarding cohorts, imaging timing and protocols which can be responsible for the heterogeneity of the results. Studies targeting spine surgical patients are still few and more investigation is needed to understand the correlation better between these modalities and clinical outcomes.

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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