Association of Low Back Pain, Somatic Dysfunction, and Lumbar Bone Mineral Density: Reproducibility of Findings

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Context: Somatic dysfunction as diagnosed by palpation should be associated with an objective measure. Bone mineral density (BMD) has been shown to be elevated in lumbar vertebrae with somatic dysfunction and in the lumbar region of individuals with chronic low back pain (LBP).

Objective: To investigate the association of lumbar somatic dysfunction and BMD T-score variability in participants with chronic LBP and without LBP (non-LBP) and to determine the reproducibility of previously published results.

Methods: Two examiners, blinded to symptom history, evaluated participants for tissue texture abnormalities, rotational asymmetry, anterior motion restriction, and tenderness at vertebral levels L1 to L4. Participants also underwent dual-energy x-ray absorptiometry of vertebral levels L1 to L4 for the assessment of BMD T scores. Generalized linear models were used to compare the chronic LBP and non-LBP groups on the presence and severity of somatic dysfunction and to test whether group and the presence and severity of somatic dysfunction were related to BMD T scores.

Results: Forty-three chronic LBP (54%) and 36 non-LBP participants (46%) completed the study. Although the presence of somatic dysfunction in the 2 groups was not significantly different, the presence of tenderness was significantly more common in the chronic LBP group ($P<.001$), as was the severity for tissue texture abnormalities ($P=.03$), motion restriction ($P=.04$), and tenderness ($P<.001$). Of the 316 vertebrae assessed, 31 (10%, all in the chronic LBP group) had moderate/severe tenderness. The vertebral somatic dysfunction burden score, the total somatic dysfunction burden score, the vertebral somatic dysfunction severity score, and the total somatic dysfunction severity score were higher in the chronic LBP group (all $P<.001$). The vertebral BMD T score was significantly higher for vertebrae demonstrating moderate/severe rotational asymmetry compared with those demonstrating mild or no rotational asymmetry ($P=.01$) and for vertebrae demonstrating moderate/severe tenderness compared with those demonstrating no tenderness ($P=.04$).

Conclusion: Study results suggest that somatic dysfunction was more significant in chronic LBP participants. Although the correlation between the presence of somatic dysfunction and segmental BMD T scores was not reproduced, BMD T scores were higher for vertebrae demonstrating moderate/severe rotational asymmetry and tenderness.

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Low back pain (LBP) is one of the most common nonfatal disorders in the world. Globally, LBP affects more than 632 million people annually and is the leading cause of years lived with disability in developed nations.[1] Research into the pathogenesis of chronic LBP has identified many contributing factors, including socioeconomic and psychological influences, genetic predisposition, degenerative changes, and muscle imbalance.[2-7] Within the osteopathic medical profession, researchers have investigated the association of somatic dysfunction and LBP.[8-12] Somatic dysfunction—identified by the presence of the physical findings of tissue texture abnormalities, asymmetry, restricted range of motion, and tenderness (ie, TART criteria)[13]—can be managed with osteopathic manipulative treatment (OMT), making OMT a noninvasive treatment option for patients with chronic LBP.[9,14,15]

In a pilot study completed in 2001,[12] lumbar somatic dysfunction was found to occur with greater frequency and severity in chronic LBP participants than in non-LBP participants. The same pilot study demonstrated an association between the presence of lumbar somatic dysfunction, chronic LBP, and locally elevated bone mineral density (BMD) T scores.[11] Specifically, participants with a history of chronic LBP had higher lumbar BMD than participants without LBP. The presence of somatic dysfunction in the form of rotational asymmetry or motion restriction was associated with elevated BMD at the affected vertebrae.[11] The elevated BMD was theorized to be related to early degenerative changes, such as bony sclerosis and osteophytes, which are common in individuals with chronic LBP[5,16-20] and can appear as elevated BMD when measured by dual-energy x-ray absorptiometry (DXA).[21-25] If the presence or absence of vertebral somatic dysfunction is associated with BMD, then BMD could be useful as an objective outcome measure for the management of somatic dysfunction using OMT. The first step toward further understanding of this relationship is to demonstrate reproducibility of findings.

Therefore, the purpose of the current study was to assess the reproducibility of the findings of the pilot study[11] in a second, larger study. Our hypothesis was that the presence of somatic dysfunction would be associated with elevated BMD in the affected lumbar vertebrae. We investigated the presence and the severity of somatic dysfunction in chronic LBP and non-LBP populations and the relationship of that somatic dysfunction with lumbar BMD T scores.

Methods

Participants

Participants aged 20 to 40 years with self-reported histories of chronic LBP or no LBP were recruited from July 2004 through February 2006 from 2 university sites and their surrounding communities using e-mail and fliers. The first site included potential participants from the 8 counties surrounding the A.T. Still University–Kirksville College of Osteopathic Medicine (ATSU-KCOM) in Missouri. The second site included potential participants from the 3 counties surrounding the Kansas University Medical Center (KUMC) in Kansas City. For the current study, chronic LBP was defined as pain in the small of the back for a minimum of 5 days per week for at least 3 months. Those who reported no LBP or who reported experiencing occasional nonpersistent LBP that occurred no more than twice per week were classified as having no LBP. Participants who reported LBP 3 or more times per week but who did not meet the chronic LBP criteria were excluded from the study.

Potential participants were excluded from the study if they had any conditions that would prohibit them from lying prone for 30 minutes or that could potentially alter the lumbar bony anatomy. These exclusions included congenital vertebral anomalies, such as spina bifida; history of lumbar or low thoracic vertebral fractures; or history of surgery. Participants who were pregnant or those who had received spinal manipulation within 8 weeks of the study were also excluded.

Information necessary to determine the eligibility of potential participants was obtained from a medical history form and by direct questioning. On the basis of self-

reported history, participants were assigned to either the chronic LBP or non-LBP group. All aspects of the study protocol were approved by the local institutional review boards of both sites, and all participants signed approved informed consent forms. Because the current study was completed before clinical trial registration requirements were standard, the study was not registered.

Somatic Dysfunction Determination Using Palpatory Diagnosis

After providing informed consent, each participant received a palpatory examination while in the prone position. Examinations were performed locally at each study site. During the examination, vertebral levels L1 to L4 were assessed for the 4 elements of somatic dysfunction: tissue texture abnormalities, static rotational asymmetry of the transverse processes, anterior springing motion restriction, and tenderness. The palpatory tests used have been evaluated extensively in the pilot study and associated preliminary studies[11,12,26,27] and have been found to have good interexaminer reliability. Each participant was examined by 2 of 3 trained examiners (K.T.S., B.F.D., and E.J.S.) who were osteopathic physicians board-certified or board-eligible in neuromusculoskeletal medicine/osteopathic manipulative medicine. The examiners were the same trained examiners who participated in the preliminary studies[26,27] and underwent a brief period of recalibration before they participated in the current study. Examiners evaluated each participant separately for all 4 elements of somatic dysfunction and recorded the findings. Then, a consensus on the findings was recorded and used for the current study. Examiners were blinded to the participant's LBP history. *Table 1*[12] summarizes the palpatory examination protocols for each of the somatic dysfunction elements in the order that they were performed. These examinations have also been described in detail in the pilot study.[11,12]

Bone Mineral Density Determination

All participants underwent DXA of vertebral levels L1 to L4 only within 1 to 2 weeks of the palpatory examination. The DXA was performed locally at each study site. A Hologic 4500C Model scanner (Hologic Inc) was used at Northeast Regional Medical Center (NRMC) in Kirksville, Missouri, and a Lunar DPX-Plus central DXA scanner (GE Healthcare) was used at KUMC. Each scanner was calibrated, and all scanner operators were trained according to site-specific quality control protocols. The individual BMD T scores of the vertebral segments (vertebral BMD T scores) and the overall BMD T score for the lumbar region (regional BMD T score) were extracted from the DXA scan report.

Statistical Analyses

On the basis of data from the pilot study,[11] the difference in BMD T scores between vertebral segments with and without somatic dysfunction from the same participant was expected to be 0.8 standard deviations (SDs). Using a paired *t* test, a sample size of 15 participants having vertebral segments with and without somatic dysfunction would have power of 0.80 to detect a difference of 0.8 SDs when the 2-sided α=.05.

Vertebral Somatic Dysfunction Burden

The vertebral somatic dysfunction burden score was calculated as the number of somatic dysfunction elements present in an individual vertebra. Tissue texture abnormalities were calculated for the right and left sides separately, for a total of 5 elements included in the somatic dysfunction burden score (tissue texture abnormalities right, tissue texture abnormalities left, rotational asymmetry, motion restriction, and tenderness). The somatic dysfunction burden score had a possible range of 0 to 5. The total somatic dysfunction burden score for each participant was calculated as the sum of the vertebral somatic dysfunction burden scores for vertebral levels L1 to L4 and had a possible range of 0 to 20. A total somatic dysfunction burden score of 0 indicated that no somatic dysfunction elements were present in any vertebrae. A total somatic dysfunction burden score of 20 indicated that all 5 somatic dysfunction elements were present in all 4 vertebrae (5 elements × 4 vertebrae). The vertebral and total somatic dysfunction burden scores only measured how many somatic dysfunction elements were present and did not take into account the severity of the somatic dysfunction elements present.

Table 1.
Palpatory Examination Protocols in the Assessment of Lumbar Vertebrae in Adult Participants

Palpatory Examination	Assessment Protocol	Indication of Positive Finding	Severity Scale
Tissue texture changes	Assessed by palpating subcutaneous tissues with pads of fingers directly posterior to inferior articular facets of L1-L4.	Localized edema and/or fibrotic changes, rated separately for right and left inferior articular facets of each vertebra.	1=No texture changes 2=Mild texture changes 3=Moderate/severe texture changes
Static rotational asymmetry	Assessed with simultaneous placement of thumbs on the transverse processes of L1-L4. Anterior pressure was applied until transverse processes could be palpated. No motion testing performed.	On the basis of static positioning of transverse processes of each vertebra. Direction of rotation defined by whether right or left transverse process demonstrated prominence.	1=No rotation 2=Mild rotation 3=Moderate/severe rotation
Resistance to anterior springing	Localized extension induced by springing anteriorly with hypothenar eminence on spinous processes of L1-L4. Each examiner could spring anteriorly as many as 3 times.	Resistance encountered to anterior springing, compared with vertebral segment above or below.	1=No motion restriction 2=Mild motion restriction 3=Moderate/severe motion restriction
Tenderness	Applied localized anterior thumb pressure directly over the spinous processes of L1-L4.	Subject verbalized response to development of tenderness as elicited by anterior thumb pressure.	1=No tenderness with as much as 4 kg/cm^2 pressure 2=Tenderness with 2-4 kg/cm^2 pressure 3=Tenderness with $<$2 kg/cm^2 pressure

Source: Reprinted from Snider et al.[12]

Vertebral Somatic Dysfunction Severity

The vertebral somatic dysfunction severity score was calculated as the sum of the severity scores for the somatic dysfunction elements in an individual vertebra (*Table 1*), with 1 indicating no somatic dysfunction, 2 indicating mild somatic dysfunction, and 3 indicating moderate/severe somatic dysfunction for a possible range of 5 (no somatic dysfunction) to 15 (moderate/severe somatic dysfunction for all elements). The total somatic dysfunction severity score was calculated as the sum of the vertebral somatic dysfunction severity scores for vertebral levels L1 to L4 and had a possible range of 20 to 60. A total somatic dysfunction severity score of 20 indicated that none of the somatic dysfunction elements were present in any vertebrae (5 elements × severity of 1 [no somatic dysfunction] × 4 vertebrae). A total somatic dysfunction severity score of 60 indicated that all 5 somatic dysfunction elements were present in all 4 vertebrae with moderate/severe severity (5 elements × severity of 3 [moderate/severe somatic dysfunction] × 4 vertebrae). Therefore, the vertebral somatic dysfunction score and the total somatic dysfunction severity score measured the severity of the somatic dysfunction elements present.

Between-Group Comparisons

The chronic LBP and non-LBP participants were compared on demographic variables using the Fisher exact test for sex and Mann-Whitney test for age and body mass index (BMI). For each of the 4 measured elements of somatic dysfunction, the chronic LBP and non-LBP groups were compared on the presence or absence of each somatic dysfunction element and on the severity of

somatic dysfunction findings using generalized linear mixed models (logistic regression models and proportional odds models, respectively) fit using generalized estimating equations with the participants treated as random effects. Tissue texture abnormality was further examined for differences between chronic LBP and non-LBP groups on sidedness (none present, right side only, left side only, or bilateral) using generalized linear mixed models with generalized logits. Rotational asymmetry was further examined for differences between chronic LBP and non-LBP groups on sidedness (none present, rotated right, or rotated left) using proportional odds models fit using generalized estimating equations. Proportional odds models were also used to compare the 2 groups on the vertebral somatic dysfunction burden score, total somatic dysfunction burden score, vertebral somatic severity score, and total somatic dysfunction severity score.

General linear mixed models were fit to the data using maximum likelihood estimation, with the participants treated as random effects to test whether group (chronic LBP or non-LBP) and somatic dysfunction findings (presence or absence of each element, vertebral somatic dysfunction burden score, total somatic dysfunction burden score, severity score of each element, vertebral somatic dysfunction severity score, and total somatic dysfunction severity score) were associated with BMD T scores. A Kruskal-Wallis test was used to compare participants from the 2 sites (NRMC and KUMC) on regional BMD T scores. The significance level was set at α=.05. Analyses were conducted using SAS 9.3 statistical software (SAS Institute Inc).

Results

Seventy-nine individuals participated in the current study; 43 (54%) had chronic LBP and 36 (46%) had no LBP. Fifty participants (35 [70%] with chronic LBP) were recruited at the ATSU-KCOM site, and 29 (8 [28%] with chronic LBP) were recruited at the KUMC site. A total of 316 individual lumbar vertebrae were assessed. No significant differences were found between the groups for sex, age, or BMI (*Table 2*).

Between-group differences were not significant for the presence or absence of tissue texture abnormalities (P=.19), rotational asymmetry (P=.53), or motion restriction (P=.13) (*Table 3*). The presence of tenderness was significantly more common in the chronic LBP group (P<.001). No significant differences were found between the chronic LBP and non-LBP groups for the severity of rotational asymmetry (P=.48) (*Table 4*). However, significant differences were found between the 2 groups for the severity of tissue texture abnormalities (P=.03), motion restriction (P=.04), and tenderness (P<.001), with greater severity found in the chronic LBP group than the non-LBP group. Of the 316 vertebrae assessed, 31 (10%) demonstrated moderate/severe tenderness, all of which were in the chronic LBP group.

Table 2.
Demographic Characteristics of Study Participants

Demographic Characteristic	Participants			*P* Value[a]
	All (n=79)	Chronic LBP Group (n=43)	Non-LBP Group (n=36)	
Sex, female, No. (%)	56 (71)	31 (72)	25 (69)	.81
Age, y, mean (SD)	30.3 (5.9)	30.1 (5.5)	30.6 (6.4)	.61
BMI, mean (SD)	27.1 (7.3)	28.1 (8.6)	26.0 (5.1)	.61

[a] Between-group comparisons were made using the Fisher exact test for sex and the Mann-Whitney test for age and body mass index (BMI).

Abbreviations: LBP, low back pain; SD, standard deviation.

Table 3.
Presence of Somatic Dysfunction in Chronic Low Back Pain (LBP) and Non-LBP Groups (N=79)

Somatic Dysfunction Element	Vertebral Segments With Somatic Dysfunction, No. (%)[a]		
	Chronic LBP Group (n=172)[b]	Non-LBP Group (n=144)[c]	*P* Value[d]
Tissue Texture Abnormalities			
Any	161 (94)	127 (88)	.19
Right only	9 (5)	4 (3)	.08[e]
Left only	67 (39)	72 (50)	
Bilateral	85 (49)	51 (35)	
Rotational Asymmetry			
Any	145 (84)	117 (81)	.53
Right	23 (13)	12 (8)	.69[f]
Left	122 (71)	105 (73)	
Motion Restriction	103 (60)	75 (52)	.13
Tenderness	72 (42)	9 (6)	<.001

[a] Vertebral segments examined were vertebral levels L1 to L4.
[b] Sample size shown is total number of lumbar vertebrae for the 43 participants in the chronic LBP group.
[c] Sample size shown is total number of lumbar vertebrae for the 36 participants in the non-LBP group.
[d] *P* value for between-group comparison based on logistic regression fit with generalized estimating equations.
[e] *P* value for between-group comparison on sidedness of tissue texture abnormalities (none present, right only, left only, or bilateral) based on a generalized linear mixed model using generalized logits fit with generalized estimating equations.
[f] *P* value for between-group comparison on sidedness of rotational asymmetry (right, none present, or left) based on proportional odds model fit with generalized estimating equations.

Comparisons between the chronic LBP and non-LBP groups for the somatic dysfunction burden and severity scores are presented in *Table 5*. The mean (SD) vertebral somatic dysfunction burden score was significantly higher in the chronic LBP group (2.8 [0.9]) than in the non-LBP group (2.3 [0.8], $P<.001$), and the mean (SD) total somatic dysfunction burden was higher in the chronic LBP group (13.2 [3.1]) than in the non-LBP group (10.5 [2.5], $P<.001$). The mean (SD) vertebral somatic dysfunction severity score was significantly higher in the chronic LBP group (7.7 [1.5]) than in the non-LBP group (6.9 [1.3], $P<.001$), and the mean (SD) total somatic dysfunction severity score was higher in the chronic LBP group (37.1 [5.3]) than in the non-LBP group (32.9 [3.9], $P<.001$).

A history of chronic LBP alone was not significantly related to mean vertebral BMD T score ($P=.41$) or regional BMD T score ($P=.42$). After accounting for group (chronic LBP or non-LBP), no significant association was found between vertebral BMD T score and the presence or absence of tissue texture abnormalities ($P=.69$), rotational asymmetry ($P=.58$), motion restriction ($P=.90$), or tenderness ($P=.45$) (*Table 6*). Additionally, the vertebral somatic dysfunction burden score was not significantly related to the vertebral BMD T score ($P=.40$), and the total somatic dysfunction burden was not significantly related to the regional BMD T score ($P=.41$).

After accounting for group, there was a statistically significant association between vertebral BMD T score and the severity of rotational asymmetry ($P=.01$) (*Table 7*). The vertebral BMD T score was higher for vertebrae demonstrating moderate/severe rotation compared with

Table 4.
Severity of Somatic Dysfunction in Chronic Low Back Pain (LBP) and Non-LBP Groups (N=79)

Somatic Dysfunction Element	Severity Rating of Somatic Dysfunction, No. (%)[a]				
	Chronic LBP Group[b] (n=172)		Non-LBP Group[c] (n=144)		
	Mild	Moderate/Severe	Mild	Moderate/Severe	*P* Value[d]
Tissue Texture Abnormalities					
Any	108 (63)	53 (31)	101 (70)	26 (18)	.03
Right only	8 (5)	1 (1)	4 (3)	0	.05[e]
Left only	65 (38)	2 (1)	68 (47)	4 (3)	
Bilateral	35 (20)	50 (29)	29 (20)	22 (15)	
Rotational Asymmetry					
Any	107 (62)	38 (22)	72 (50)	45 (31)	.48
Right	19 (11)	4 (2)	10 (7)	2 (1)	.66[f]
Left	88 (51)	34 (20)	62 (43)	43 (30)	
Motion Restriction	70 (41)	33 (19)	63 (44)	12 (8)	.04
Tenderness	41 (24)	31 (18)	9 (6)	0	<.001

[a] Vertebral segments examined were vertebral levels L1 to L4. Severity rating is based on a 3-point scale: 1, no somatic dysfunction; 2, mild somatic dysfunction; 3, moderate/severe somatic dysfunction.
[b] Sample size shown is total number of lumbar vertebrae for the 43 participants in the chronic LBP group.
[c] Sample size shown is total number of lumbar vertebrae for the 36 participants in the non-LBP group.
[d] *P* value for between-group comparison based on proportional odds model fit with generalized estimating equations.
[e] *P* value for between-group comparison on sidedness and severity of tissue texture abnormalities (none present, right mild/moderate/severe only, left mild/moderate/severe only, bilateral mild, or bilateral moderate/severe) based on a generalized linear mixed model using generalized logits fit with generalized estimating equations.
[f] *P* value for between-group comparison on sidedness and severity of rotational asymmetry (right moderate/severe, right mild, none present, left mild, or left moderate/severe) based on proportional odds model fit with generalized estimating equations.

those demonstrating mild rotation or no rotation. In contrast, no significant association was found between vertebral BMD T score and the severity of tissue texture abnormalities (*P*=.34) or motion restriction (*P*=.55). Because there were no vertebrae in the non-LBP group with moderate/severe tenderness, analysis of the relationship between vertebral BMD T score and severity of tenderness was performed without accounting for group. There was a significant association between vertebral BMD T score and severity of tenderness (*P*=.04). The vertebral BMD T score was higher for vertebrae demonstrating moderate/severe tenderness compared with those demonstrating no tenderness. But, there was no difference between the vertebral BMD T scores for vertebrae demonstrating moderate/severe tenderness and mild tenderness or between vertebrae demonstrating mild tenderness and no tenderness. After accounting for group, the vertebral somatic dysfunction severity score was not significantly related to the vertebral BMD T score (*P*=.08), and the total somatic dysfunction severity score was not significantly related to the regional BMD T score (*P*=.17).

The mean (SD) regional BMD T score was 0.23 (1.11) for participants at NRMC (n=50) and 0.61 (0.87) for participants at KUMC (n=29). There was no significant difference between the 2 sites for participants' regional BMD T scores (*P*=.18).

Discussion

The current study verified many of the findings found in the pilot study that correlated somatic dysfunction with chronic LBP. The pilot study[12] demonstrated that motion restriction and tenderness were significantly more

Table 5.
Vertebral and Total Somatic Dysfunction Burden Scores and Vertebral and Total Somatic Dysfunction Severity Scores in Chronic Low Back Pain (LBP) and Non-LBP Groups (N=79)

Measure[a]	Mean (SD) Score		*P* Value[d]
	Chronic LBP Group[b]	Non-LBP Group[c]	
Vertebral Somatic Dysfunction Burden[e]	2.8 (0.9)	2.3 (0.8)	<.001
Total Somatic Dysfunction Burden[f]	13.2 (3.1)	10.5 (2.5)	<.001
Vertebral Somatic Dysfunction Severity[g]	7.7 (1.5)	6.9 (1.3)	<.001
Total Somatic Dysfunction Severity[h]	37.1 (5.3)	32.9 (3.9)	<.001

[a] Vertebral segments examined were vertebral levels L1 to L4.
[b] Sample size shown is 172 lumbar vertebrae for the 43 participants in the chronic LBP group.
[c] Sample size shown is 144 lumbar vertebrae for the 36 participants in the non-LBP group.
[d] *P* value for between-group comparison based on proportional odds model fit with generalized estimating equations.
[e] Vertebral somatic dysfunction burden is the number of the 5 somatic dysfunction elements (tissue texture abnormalities right, tissue texture abnormalities left, rotational asymmetry, motion restriction, tenderness) present in an individual vertebra with a possible range of 0 to 5.
[f] Total somatic dysfunction burden score is the sum of the vertebral somatic dysfunction burden scores for L1 to L4, with a possible range of 0 to 20.
[g] Vertebral somatic dysfunction severity score is the sum of the severity scores for the somatic dysfunction elements in an individual vertebra, with a possible range of 5 to 15.
[h] Total somatic dysfunction severity score is the sum of the vertebral somatic dysfunction severity scores for L1 to L4, with a possible range of 20 to 60.

common in the chronic LBP group ($P<.001$ and $P=.002$, respectively), but no significant differences were found between groups for incidence of tissue texture abnormality or rotational asymmetry. The vertebral somatic dysfunction burden score was also significantly higher for the chronic LBP group ($P=.001$). The total somatic dysfunction burden score was not calculated in the pilot study. The chronic LBP group had significantly greater severity of tissue texture abnormality ($P=.006$), rotational asymmetry ($P=.008$), motion restriction ($P<.001$), and tenderness ($P=.001$) than the non-LBP group, with the vertebral somatic dysfunction severity score also significantly higher in the chronic LBP group ($P<.001$).[12] The total somatic dysfunction severity score was not calculated in the pilot study.

In the current study, both the vertebral and the total somatic dysfunction burden scores were higher in the chronic LBP group. Likewise, the vertebral somatic dysfunction severity score and the total somatic dysfunction severity score were significantly higher in the chronic LBP group. Tenderness was more common in the chronic LBP group, but motion restriction was not found to be more common in this group, as was found in the pilot study. The chronic LBP group had higher severity of tissue texture abnormalities, motion restriction, and tenderness, but not motion restriction. Only the chronic LBP group had moderate/severe tenderness, suggesting that moderate/severe tenderness may have a high predictive value for chronic LBP.

The increased presence and severity of tenderness observed in the chronic LBP group in the current study may be a sign of central sensitization.[28,29] Central sensitization[30] is a hypersensitivity to pain within the central nervous system that develops in response to sustained nociceptive stimuli, such as chronic localized musculoskeletal pain.[28] Nociceptive neurons become facilitated in the presence of ongoing stimulation so that the firing threshold becomes lower. As a result, sensory input that would normally be subthreshold can cause the nociceptive neurons to fire.[30] The tenderness associated with central sensitization is typically diffuse rather than localized.[31] Jensen et al[31] found that individuals with a 1- to

Table 6.
Relationship of the Presence or Absence of Somatic Dysfunction and Bone Mineral Density T Score

Somatic Dysfunction Element	Present		Absent		*P* Value
	n[a]	BMD T Score, Mean (95% CI)	n[b]	BMD T Score, Mean (95% CI)	
Tissue texture abnormalities	288	0.35 (0.12-0.58)	28	0.41 (0.05-0.76)	.69
Rotational asymmetry	262	0.36 (0.13-0.60)	54	0.30 (0.02-0.59)	.58
Motion restriction	178	0.36 (0.12-0.60)	138	0.35 (0.11-0.59)	.90
Tenderness	81	0.41 (0.06-0.76)	235	0.29 (0.06-0.53)	.45

[a] Sample sizes shown (n) equal the number of vertebral segments (4 per participant) with the indicated element of somatic dysfunction.
[b] Sample sizes shown (n) equal the number of vertebral segments (4 per participant) without the indicated element of somatic dysfunction.

Abbreviations: BMD, bone mineral density; CI, confidence interval.

3-month history of LBP were more likely to report ongoing pain and disability after 1 year if they had widespread tender points at their baseline presentation. The current study assessed for localized tenderness on the spinous processes of vertebral levels L1 to L4 without assessing the tenderness of the paraspinal regions. Therefore, the presence of the diffuse tenderness associated with central sensitization was not assessed and is an area for future study.

The current study did not find a statistically significant difference between groups for the presence or severity of vertebral rotational asymmetry as was found in the pilot study.[12] The predominance of left rotational asymmetry found in the current study and the pilot study[12] is consistent with the common compensatory pattern defined by Zink and Lawson.[32] The common compensatory pattern arises from groupings of common somatic dysfunctions throughout the body that allow relatively normal function in the presence of musculoskeletal asymmetry. In this model, symptoms are more likely to occur when the somatic dysfunctions are out of pattern.[32] For example, Shaw et al[33] recently reported a predominance of left lumbar rotational asymmetry in a palpatory and ultrasound assessment of asymptomatic osteopathic medical students. The current study did find a higher frequency of right rotation in the chronic LBP group, but the difference was not statistically significant. The current study also found a predominance of left-sided tissue texture abnormalities, suggesting that left rotational asymmetry and left-sided tissue texture abnormalities are associated. Future studies are needed to investigate the relationship between these 2 somatic dysfunction elements.

The pilot study assessing the association between somatic dysfunction and BMD found a significant association between the presence of rotational asymmetry and motion restriction and elevated lumbar vertebral BMD T scores ($P=.002$ and $P=.03$, respectively) and a significant association between history of chronic LBP and elevated regional lumbar BMD T scores ($P<.001$).[11] These findings were not reproduced in the current study. However, the current study did find that the BMD T scores were higher for vertebrae demonstrating moderate/severe rotational asymmetry, but neither the vertebral somatic dysfunction severity score nor the total somatic dysfunction severity score was related to the BMD T score. The pilot study did not analyze the association between somatic dysfunction severity and BMD.[11]

Table 7.
Relationship of the Severity of Somatic Dysfunction and Bone Mineral Density T Score

Somatic Dysfunction Element	Somatic Dysfunction Severity: None Present n[a]	None Present BMD T Score, Mean (95% CI)	Mild n[b]	Mild BMD T Score, Mean (95% CI)	Moderate/Severe n[c]	Moderate/Severe BMD T Score, Mean (95% CI)	*P* Value
Tissue texture abnormalities	28	0.43 (0.07 to 0.78)	209	0.38 (0.14 to 0.61)	79	0.24 (−0.03 to 0.51)	.34
Rotational asymmetry	54	0.27 (−0.01 to 0.56)	179	0.29 (0.05 to 0.53)	83	0.55 (0.29 to 0.81)	.01
Motion restriction	138	0.35 (0.10 to 0.59)	133	0.34 (0.10 to 0.58)	45	0.47 (0.16 to 0.79)	.55
Tenderness	235	0.29 (0.05 to 0.52)	50	0.35 (−0.00 to 0.71)	31	0.72 (0.33 to 1.10)[d]	.04

[a] Sample sizes shown (n) equal the number of vertebral segments (4 per participant) without the indicated element of somatic dysfunction.
[b] Sample sizes shown (n) equal the number of vertebral segments (4 per participant) with mild severity for the indicated element of somatic dysfunction.
[c] Sample sizes shown (n) equal the number of vertebral segments (4 per participant) with moderate/severe severity for the indicated element of somatic dysfunction.
[d] Mean and 95% confidence intervals (CIs) were estimated from model without group (chronic low back pain [LBP] or non-LBP) because there were no non-LBP participants with moderate/severe tenderness.

Abbreviation: BMD, bone mineral density.

Vertebral BMD is determined by a complex relationship between genetic, chemical, and biomechanical factors.[34,35] Somatic dysfunction may influence BMD through impaired or altered biomechanical loading on the vertebral bodies and facet joints. A similar example is the altered loading that occurs with scoliosis. In scoliotic curvatures, osteophytes develop more frequently on the concave side of the curve, with disk herniations occurring more frequently on the convex side.[36] These osteophytes are known to increase DXA lumbar BMD readings in adult lumbar scoliosis, making DXA less reliable for monitoring spinal osteoporosis in individuals with lumbar spondylosis.[37,38] The association of moderate/severe rotational asymmetry and elevated BMD seen in the current study may be a result of early osteophytic changes, such as those that occur in scoliotic curvatures. If somatic dysfunction is manageable with OMT, then objective measures such as BMD may change with treatment. Studies that show the intravertebral BMD distribution, such as magnetic resonance imaging or computed tomography, would be appropriate for future research assessing the association of somatic dysfunction with BMD and the potential impact of OMT on objective measures. Such research may aid in the understanding of the structure-function relationships between somatic dysfunction and the underlying anatomic structures.

The current study found that the BMD T scores were higher for vertebrae demonstrating moderate/severe tenderness. However, like the pilot study,[11] the presence of tenderness alone was not related to elevated vertebral BMD. Further study with a larger sample size is needed to better understand the relationship between this element of somatic dysfunction and BMD.

Limitations

In addition to the relatively small sample size, the primary limitation of the current study was the lack of verification of accurate localization of the vertebral segments. In a study conducted after the current study, the same investigators used lumbar radiographs to assess the accuracy of the palpatory method used in the current study and determined that its accuracy was 67% to 78%.[39] This result means that potentially 20% to 30% of the somatic dysfunction data collected in the current study may have been attributed to the wrong vertebrae. Additionally, the prone physical examination used in the current study was limited to 4 palpatory assessments that

had previously demonstrated interexaminer reliability in preliminary studies.[26,27] In a clinical setting, physicians use a wider variety of somatic dysfunction assessments with the patient in multiple positions, such as seated or supine. Therefore, the association between somatic dysfunction and BMD must be limited to those assessments used in the current study until future research is completed. An additional limitation includes potential variability of DXA measurements between study sites. Although each DXA scanner was calibrated and scanner operators were trained following site-specific quality control protocols, variation in internal BMD reference ranges may have affected the results.

Conclusion

The current study replicated many findings of the pilot study, including the finding that somatic dysfunction is more frequent and of higher severity in individuals with chronic LBP. Additionally, the current study found that that the BMD T scores were higher for vertebrae demonstrating moderate/severe rotational asymmetry and tenderness. However, the current study was unable to reproduce the pilot study's findings that the presence of rotational asymmetry and motion restriction, regardless of severity, and the history of chronic LBP were associated with higher lumbar BMD T scores. Although the current study did not reproduce all findings of the pilot study, the current findings support the need for a larger study using objective verification of vertebral level to investigate the association between lumbar somatic dysfunction and BMD, and ultimately the effect of OMT on both somatic dysfunction and BMD.

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