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Original Article

Research trends in trabecular bone score: A bibliometric review from 2008 to 2019

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Abstract

Objective: Trabecular bone score (TBS) is a novel index for assessing bone microarchitecture quality. No bibliometric reviews to date have yet explored the literature of TBS. Therefore, this study aimed to provide a bibliometric review on the trends of research publications on TBS indexed in the Science Citation Index Expanded and the Social Sciences Citation Index from 2008 to 2019. **Materials and Methods:** Using the Science Citation Index Expanded and the Social Sciences Citation Index, articles designated as original articles or review articles were searched using the keyword "trabecular bone score." The retrieved articles were analyzed using Histcite 12.03.17 and VOSviewer v. 1.6.15 to identify top authors, journals, countries, and occurrence of keywords. **Results:** A total of 430 original and review articles on TBS published between 2008 and 2019 were identified. The number of articles increased steadily from 2008 to 2019, reaching 80 articles in 2019 alone. The United States of America, Switzerland, and France were the countries with the highest output of publications. The journal *Osteoporosis International* published the largest number of articles on TBS. Analysis of co-occurrence of author-supplied keywords revealed four clusters, with TBS, bone mineral density, and osteoporosis as the most prominent keywords. **Conclusion:** This bibliometric study on TBS published between 2008 and 2019 revealed the collaborative network of countries and the highly published journals and authors. Co-occurrence of keywords also revealed clusters of research hotspots, which could contribute to the understanding of the current state of TBS research and the identification of research gap.

Keywords: *Bibliometric analysis, Bone mineral density, Osteoporosis, Research trends, Trabecular bone score*

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Introduction

Osteoporosis is a common type of chronic metabolic bone disease in postmenopausal women and older men, affecting >200 million people worldwide. It is characterized by a decrease in bone density, which can lead to osteoporotic fractures associated with significant disability, mortality, and reduced quality of life [1]. Based on a secondary analysis of the Taiwan's National Health Insurance Research Database, the prevalence of osteoporosis was estimated to be 25.0% among those aged 50 years or older in 2011, with 36.0% and 13.3% in women and men, respectively [2]. Since osteoporosis is a silent disease until fractures occur, early diagnosis and treatment are critical to reduce the risk of fracture.

Bone strength can be defined using areal bone mineral density (BMD) and bone quality. BMD is measured using dual-energy X-ray absorptiometry (DXA), which is expressed as grams of mineral, primarily calcium, per square centimeter of the scanned bone. As operationally defined by the World Health Organization, osteoporosis is present when BMD is 2.5 standard deviations (SDs) or more below the average value for young healthy women (a T-score of −2.5 SD or lower). However, recent research indicated that BMD could only partly explain bone strength and fracture risk [3] because BMD is an assessment of the quantity, but not the quality of bone, that is, bone microarchitecture. Nevertheless, the direct assessment of bone microarchitecture is only available by using histomorphometric analysis, micro-computed tomography of invasively obtained bone biopsy, high-resolution peripheral quantitative computed tomography, or magnetic resonance

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imaging [4]. These methods are impractical for routine assessment in clinical settings.

A recent development in an indirect index of trabecular microarchitecture is the trabecular bone score (TBS), introduced in 2008 by Pothuaud *et al*. [5]. TBS is a gray-level textural measurement based on the use of experimental variograms of two-dimensional (2D) projection images obtained during a DXA scan, typically at the lumbar spine. In other words, TBS is not a direct physical measurement of bone microarchitecture, but instead a score computed by the projection of the 3D structure onto a 2D plane. A variogram of the projected images is used to calculate the sum of the squared gray-level differences between pixels at a specific distance. TBS is then calculated by the slope of the log-log transform of the 2D variogram, where the slope represents the rate of gray-level amplitude variations. A high TBS value is considered as better bone structure, whereas a low TBS value indicates worse bone structure [6]. TBS is strongly correlated with the number of trabeculae and their connectivity and inversely with the space between trabeculae. An added convenient feature of TBS is that it can readily be calculated using past DXA images. Therefore, it can be used for the routine evaluation of bone microarchitecture as well as for research applications. Results from meta-analysis also indicated that TBS had predictive value for fracture risk independent of fracture probabilities estimated by the FRAX algorithm [7].

Bibliometric analysis is a quantitative approach for analyzing and reviewing the output of scholarly publications [8]. With a rapid rise in the number of scholarly publications, bibliometric analysis provides a convenient way of gaining a comprehensive overview of the publication characteristics concerning about any topic of interest, ranging from antibiotics [9] to Zika virus [10]. However, no studies to date have yet reviewed the literature of TBS using bibliometric analysis. Therefore, the aim of this study was to review the status quo and trends of TBS publications, indexed in the Web of Science (WoS) database from 2008 to 2019.

Materials and Methods

Bibliometric data

The Thomson Reuters WoS website was used to identify research articles on the topic of TBS. The WoS Core Collection online database, which included the Science Citation Index Expanded and the Social Sciences Citation Index, was selected. The search was conducted on March 10, 2020. The journal impact factors were obtained from the Journal Citation Reports 2018 database.

Search strategy

The keyword "trabecular bone score" was used as the search term in the database. The end year of the publication period was set to 2019. Only original articles and review articles were included in the present bibliometric review. Other types of documents such as meeting abstract, editorial material, letter, proceedings paper, and book chapter were excluded.

Bibliometric analysis

The extracted records were analyzed for citation characteristics, including the distribution of the year of publication, languages, countries, journals, articles, authors, and total citations, using HistCite 12.03.17 (HistCite Software LLC) [11]. The top 10 most-cited articles were identified. In addition, VOSviewer v. 1.6.15 for Microsoft Windows (Centre for Science and Technology Studies, Leiden University, The Netherlands) [12] was used to conduct co-occurrence analysis for the visualization of author-supplied keywords and co-authorship for the visualization of countries. To improve the visibility of the clusters, normalization based on the LinLog layout technique and the modularity clustering technique was used, in which the distances used in the computation of attraction and repulsion forces between the clusters were logarithm transformed.

Results

With the keyword "trabecular bone score," a total of 789 articles published between 2008 and 2019 were identified in the WoS Core Collection online database. After excluding meeting abstract, editorial material, proceedings paper, letter, correction, early access, and book chapter, 430 original articles and review articles, published between 2008 and 2019, were included in this review. Table 1 shows the distribution of types of articles on TBS published between 2008 and 2019. In addition, of the 430 articles, 418 (97.2%) were in English language. The remaining 12 articles were written in Spanish (8 articles), German (2 articles), French (1 article), and Russian (1 article).

Analysis of the trend of annual publications

Figure 1 shows the trend of the number of original and review articles on TBS published per year from 2008 to 2019. It can be seen that there were relatively few publications on TBS until 2012. The first review article appeared in 2012, and there were a total of 51 review articles during the whole study period. A steady increase in the number of original articles could be observed starting from 2013 and reached 90 and 80 articles in 2018 and 2019, respectively.

Analysis of countries/regions and their collaborative network

The 430 original and review articles were derived from 50 countries and regions. Table 2 shows that the United States of America, Switzerland, and France were the top three countries with the largest number of original or review articles on TBS,

Table 1: Distribution of types of articles on trabecular bone score published between 2008 and 2019 (*n*=789)

Article type	*n* (%)
Original article*	379 (88.1)
Review*	51 (11.9)
Meeting abstract	330 (76.7)
Editorial material	12 (2.8)
Proceedings paper	5 (1.2)
Letter	5 (1.2)
Correction	4 (0.9)
Early access	2 (0.5)
Book chapter	1 (0.2)

*Only "Original article" and "Review" were included in the analyses of the present study

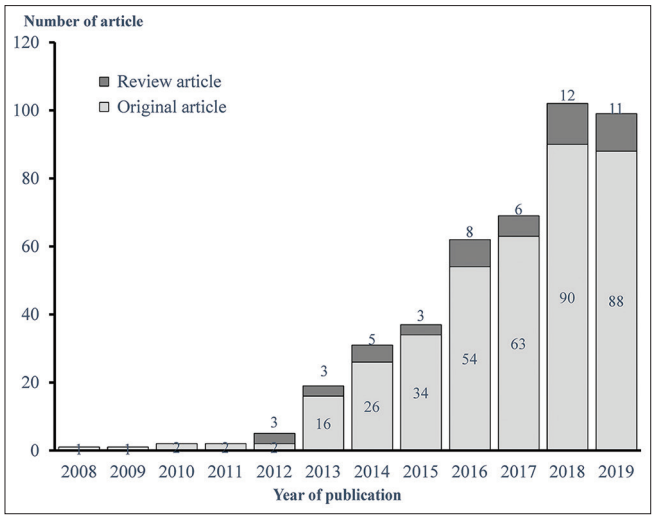

Figure 1: Time trend of the number of original and review articles on trabecular bone score published per year from 2008 and 2019 (n = 430)

Table 2: Top 10 countries and regions with original or review articles on trabecular bone score published between 2008 and 2019 (n=430)

Country or region	Number of articles, n (%)	TGCS	Citations/article
United States of America	105 (24.0)	2136	20.3
Switzerland	89 (20.7)	3624	40.7
France	59 (13.7)	2340	39.7
Italy	51 (11.9)	854	16.8
Spain	39 (9.1)	229	5.9
Canada	38 (8.8)	1977	52.0
England	35 (8.1)	1254	35.8
South Korea	33 (7.7)	220	6.7
Australia	30 (7.0)	303	10.1
Germany	24 (5.6)	682	28.4

TGCS=Total number of citations received, Citations/article=TGCS/number of articles. TCGS: Total Global Citation Score

which represents over 58% of all published original or review articles. The total number of citations received by these 253 articles was 8100. Among the top 10 countries and regions, the 38 articles originated from Canada exhibited the largest citations per article of 52.0.

The collaborative network of authors among different countries and regions is depicted in Figure 2. The size of label in Figure 2 represents the quantity of publications in a given country or region. The thickness of the lines connecting the countries or regions represents their strength of relationship. As conveyed in Table 2, the United States of America, Switzerland, and France represent the three main countries with the largest quantity of publications. Three main collaborative clusters can be observed. Cluster 1 consisted of 11 countries with strong connections between the United States of America, Switzerland, and Canada. Cluster 2 contained four countries with strong connections between France, Japan, and Lebanon. Cluster 3 consisted of eight countries with strong connections between Spain and England. In addition, these clusters are also interconnected

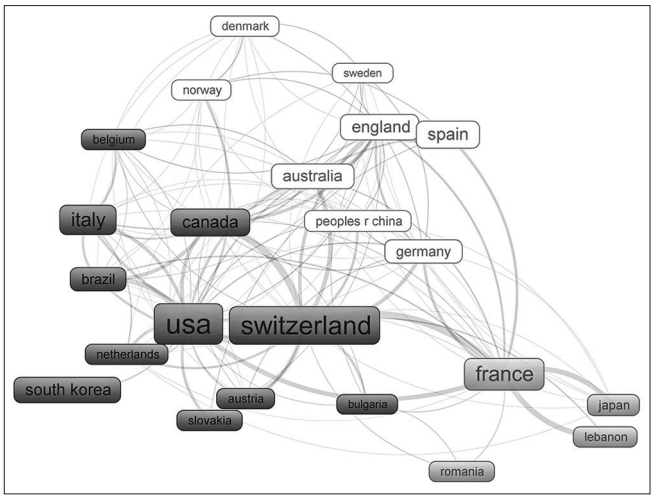

Figure 2: Visualization of collaborative network of countries of original and review articles on trabecular bone score published per year from 2008 and 2019 (n = 430). Three clusters were identified: cluster 1 (dark gray label, left) with 11 countries, cluster 2 (medium gray label, bottom right) with four countries, and cluster 3 (white label, top right) with eight countries

among themselves and particularly between Switzerland and France.

Analysis of journals

Table 3 shows the distribution of journals with original or review articles on TBS published between 2008 and 2019. A total of 430 articles were published in 145 different journals. The top ten published journals contained 241 articles (56.0%), with *Osteoporosis International* alone published 70 articles (16.3%). With the exception of *PLOS ONE*, which belongs to the category of multidisciplinary sciences, all the other nine journals belong to the category of endocrinology and metabolism. The number of citations per article ranged from the highest of 48.8 in *Journal of Bone and Mineral Research* to the lowest of 2.9 in *Archives of Osteoporosis*, with a median of 18.2. In addition, regarding the journal impact factor, the *Journal of Bone and Mineral Research* had the highest value of 5.854 (first-quartile ranking), whereas *Journal of Bone and Mineral Metabolism* had the lowest of 2.297 (third-quartile ranking).

Analysis of most-cited authors and their patterns of co-citation

Table 4 lists the ten most-cited authors of original or review articles on TBS published between 2008 and 2019. Hans *et al*. [13], Hans *et al*. [14], and Silva *et al*. [6] were the three top-cited authors with a citation score per year of 33.1, 25.8, and 19.2, respectively. The review article by Silva *et al*. [6] was published in 2014, and it provided a comprehensive overview of the principle of TBS and summarized the results of using TBS as a risk assessment tool in both cross-sectional and prospective studies as well as the potential utility of TBS as a clinical tool. The two studies by Hans *et al*. were both published in 2011. One was published in the *Journal of Bone and Mineral Research* [13] and the other was published in *Journal of Clinical Densitometry* [14]. The former article reported the results of a large retrospective cohort study of 29407 older Canadian women in using TBS

Table 3: Distribution of journals with original or review articles on trabecular bone score published between 2008 and 2019 (*n*=430)

Rank	Journal	Web of Science subject category	Number of cited articles, *n* (%)	TGCS	Citations/article	Impact factor* (quartile)
1	Osteoporosis International	Endocrinology and metabolism	70 (16.3)	1425	20.4	3.864 (2)
2	Journal of Clinical Densitometry	Endocrinology and metabolism	45 (10.5)	1110	24.7	2.310 (3)
3	Bone	Endocrinology and metabolism	32 (7.4)	887	27.7	4.147 (2)
4	Journal of Bone and Mineral Research	Endocrinology and metabolism	25 (5.8)	1221	48.8	5.854 (1)
5	Calcified Tissue International	Endocrinology and metabolism	17 (4.0)	271	15.9	3.423 (2)
6	Archives of Osteoporosis	Endocrinology and metabolism	14 (3.3)	41	2.9	2.017 (4)
7	Journal of Clinical Endocrinology and Metabolism	Endocrinology and metabolism	14 (3.3)	453	32.4	5.399 (1)
8	Endocrine	Endocrinology and metabolism	10 (2.3)	100	10.0	3.235 (3)
9	Journal of Bone and Mineral Metabolism	Endocrinology and metabolism	9 (2.1)	53	5.9	2.297 (3)
10	PLOS ONE	Multidisciplinary sciences	5 (1.2)	21	4.2	2.740 (2)
	Median				18.2	3.33

*Impact factors were obtained from the journal citation reports calculated based on the citations in 2019 to items published in 2017 and 2018 divided by the total number of citable items in 2017 and 2018. TGCS=Total number of citations received, Citations/article=TGCS/number of articles. TCGS: Total Global Citation Score

Table 4: Ten most-cited original or review articles on trabecular bone score published between 2008 and 2019 (*n*=430)

Rank	First author (number of total authors)	Title	Journal (impact factor*)	Year of publication	Global citation score	Global citation score per year
1	Silva BC (9)	TBS: A noninvasive analytical method based upon the DXA image	Journal of Bone and Mineral Research (5.854)	2004	288	19.2
2	Hans D (4)	Bone microarchitecture assessed by TBS predicts osteoporotic fractures independent of bone density: The Manitoba study	Journal of Bone and Mineral Research (5.854)	2011	265	33.1
3	Hans D (6)	Correlations between TBS, measured using anteroposterior DXA acquisition, and 3-dimensional parameters of bone microarchitecture: an experimental study on human cadaver vertebrae	Journal of Clinical Densitometry (2.310)	2011	206	25.8
4	Pothuaud L (3)	Correlations between grey-level variations in 2D projection images (TBS) and 3D microarchitecture: Applications in the study of human trabecular bone microarchitecture	Bone (4.147)	2008	189	17.2
5	McCloskey EV (36)	A meta-analysis of TBS in fracture risk prediction and its relationship to FRAX	Journal of Bone and Mineral Research (5.854)	2016	170	56.7
6	Leslie WD (4)	TBS and diabetes-related fracture risk	Journal of Clinical Endocrinology and Metabolism (5.399)	2013	163	27.2
7	Harvey NC (13)	TBS as a new complementary approach for osteoporosis evaluation in clinical practice	Bone (4.147)	2015	153	38.2
8	Pothuaud L (6)	Evaluation of the potential use of TBS to complement BMD in the diagnosis of osteoporosis: a preliminary spine BMD-matched, case-control study	Journal of Clinical Densitometry (2.310)	2009	125	12.5
9	Bousson V (5)	TBS: Available knowledge, clinical relevance, and future prospects	Osteoporosis International (3.864)	2012	125	17.8
10	Boutroy S (6)	TBS improves fracture risk prediction in nonosteoporotic women: The OFELY study	Osteoporosis International (3.864)	2013	124	20.7

*Impact factors were obtained from the Journal Citation Reports calculated based on the citations in 2019 to items published in 2017 and 2018 divided by the total number of citable items in 2017 and 2018. Global citation score=Citation frequency based on the full Web of Science count at the time the data was downloaded. Global citation score per year=Global citation score/(2019–the year of publication). DXA: Dual-energy X-ray absorptiometry, TBS: Trabecular bone score, FRAX: Fracture risk assessment tool, BMD: Bone mineral density, 2D: Two dimensional

to predict future clinical osteoporotic fractures. The study supported that spine TBS could significantly improve the performance of predicting osteoporotic fractures when used in combination with BMD [13]. The latter article reported

the results of an *ex vivo* experimental study in 30 dried human cadaver vertebrae. The authors reported significant correlations between TBS and various 3D parameters of bone microarchitecture, and these correlations were mostly independent of correlations between TBS and BMD [14]. Findings from these three articles complemented each other in providing the principle of TBS as well as the epidemiological and experimental evidence in supporting its use.

Analysis of co-occurrence of keywords

Figure 3 shows a visualization of the co-occurrence of author-supplied keywords of original and review articles on TBS published between 2008 and 2019. Keyword co-occurrence can be defined as the situation when two or more keywords simultaneously appear in the same article. Keyword co-occurrence visualization can be used to identify the pattern of research hotspots. Four clusters of keywords were identified in this study, including Cluster 1 with strong association between the keyword TBS and BMD. Other associated keywords included microarchitecture, vertebral fracture, body composition, hip structure analysis, body mass index, Vitamin D, and four diseases (chronic kidney disease, rheumatoid arthritis, hyperparathyroidism, and breast cancer). Next, Cluster 2 consisted of seven keywords with osteoporosis linked with keywords of fracture risk, Fracture Risk Assessment Tool (FRAX), fracture assessment, DXA, sarcopenia, and menopause. Moreover, Cluster 3 consisted of four keywords linking diabetes with obesity, bone strength, and quantitative computed tomography. Furthermore, Cluster 4 consisted of only two keywords of medications, including denosumab and teriparatide.

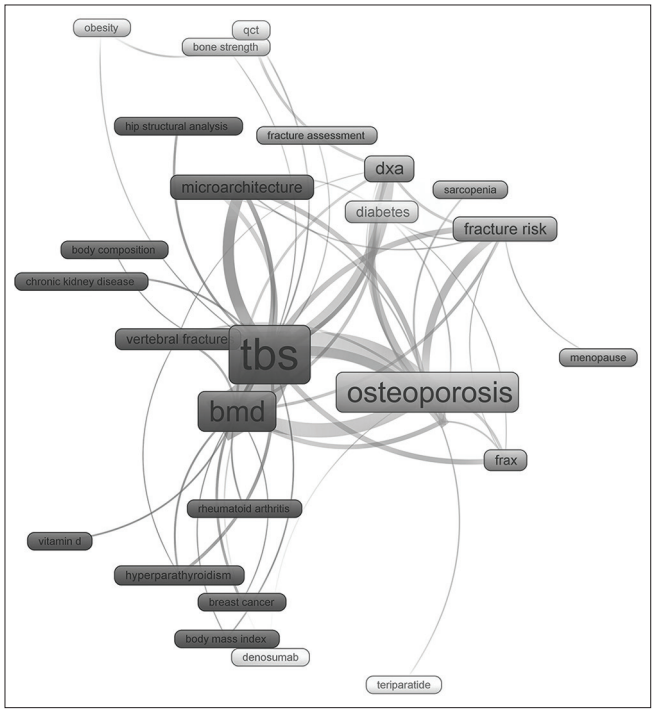

Figure 3: Co-occurrence network of author-supplied keywords of original and review articles on trabecular bone score published between 2008 and 2019. Cluster 1 (dark gray label, left) with 12 keywords, cluster 2 (medium gray label, right) with seven keywords, cluster 3 (light gray label, top) with four keywords (obesity, qct, bone strength, and diabetes), and cluster 4 (white label, bottom) with two keywords. bmd: Bone mineral density; dxa: Dual-energy X-ray absorptiometry; frax: Fracture Risk Assessment Tool; qct: Quantitative computed tomography; tbs: Trabecular bone score

Discussion

In this bibliometric review study, we analyzed original and review articles on TBS published between 2008 and 2019. To the best of our knowledge, this is the first study to analyze the global research productivity pertaining to TBS. Based on the trends of the number of publications over the 12-year period since the first TBS article appeared in 2008 by Pothuaud *et al.* [5], it could be observed that TBS has become an increasingly important topic of research. With increasing life expectancy and declining birth rates in many parts of the world, health-related issues associated with an aging population will be substantial. One of the issues is the increased risk of osteoporosis and occurrence of fragility fractures in older adults. Improving the performance of current fracture prediction models, such as by combining TBS in the model, will likely to be a continuing focus of research. Our data have also shown a clear growing trend in the quantity of both original articles and review articles on TBS during the study period.

While University Hospital of Bordeaux in France was the institution of the first author of the earliest article of TBS, Dr. Pothuaud [5], the two countries with the largest number of original or review articles on TBS were the United States of America and Switzerland. The latter could be explained by one of the co-authors of Dr. Pothuaud, Dr. Hans was affiliated with the University of Lausanne in Switzerland. A strong link between the two countries was evident in Figure 2. The large number of publications (n = 105) in the United States of America emerged from several different research teams, but Dr. Silva alone was involved in 14 articles. Based on our findings, South Korea was the only country in Asia that ranked within the top-ten highest number of published articles (n = 33).

The analysis of collaborative network of authors among different countries and regions can contribute to the understanding of the structure and dynamics of research networks. Previous research indicated that academic research has become increasingly collaborative [15], and international collaboration can generally produce publications with higher citation rates and therefore a greater research impact, than purely domestic production [16]. In this study, we observed clear patterns of international collaborative activities that focalized mainly among the United States of America, Switzerland, France, and Canada. One way to improve global visibility of local research in other countries and regions is to put greater efforts in seeking and establishing international networks with TBS researchers in the above-mentioned North American and European countries.

As expected, the journals with the greatest number of articles on TBS belonged all to the category of endocrinology and metabolism, with only one exception in the category of multidisciplinary sciences. While the journal with the largest number of cited articles was *Osteoporosis*

International (n = 70), the journal with the highest journal impact factor of 5.854 was the *Journal of Bone and Mineral Research*, which is the official journal of the American Society for Bone and Mineral Research. This indicated research on TBS was well received by the research community.

The analysis of co-occurrence of keywords is a useful approach to understand the relationship of research hotspots. Four clusters were revealed with the largest cluster linking research on TBS and BMD with microarchitecture, vertebral fracture, body composition, hip structure analysis, body mass index, Vitamin D, and diseases. As shown in visualization, only chronic kidney disease, rheumatoid arthritis, hyperparathyroidism, and breast cancer had been explored. The associations of TBS with other chronic diseases should also be explored in future studies. For example, our research team has recently investigated the association between TBS and coronary artery calcification in healthy adults [17] and the association between TBS and BMD in patients with cardiovascular disease [18]. The second cluster linked osteoporosis with keywords associated with research on fracture, including fracture risk, FRAX, fracture assessment, DXA, sarcopenia, and menopause. This cluster reflected that the use of TBS in fracture risk assessment was a research hotspot.

The third cluster of co-occurrence of keywords linked diabetes with obesity, bone strength, and quantitative computed tomography. Previous research reported that patients with diabetes was associated with an increased fracture risk, despite that they had a high BMD [19,20]. It is generally considered that the risk of fractures in patients with type 2 diabetes was underestimated by FRAX and bone densitometry [21,22]. Therefore, with the availability of quantification of bone quality by TBS, various studies have attempted to use it to elucidate the exact relationship between body mass index and fracture risk among patients with diabetes [23,24]. Until the complex pathogenesis of fragility fractures in patients with diabetes has been delineated [25], studies in this area will likely to remain as a focus of TBS research.

The fourth cluster of co-occurrence of keywords consisted of only two keywords of medications, namely, denosumab and teriparatide. This represents studies that used TBS as an additional measure to evaluate bone health in studies of pharmacological treatment for or prevention of osteoporosis [26,27]. A review article assessed the evidence of the utility of TBS in assessing bone quality in osteoporosis treatment with the anabolic agent teriparatide [28]. In the two reviewed studies [29,30], the increase in TBS was small in response to teriparatide. Nevertheless, the authors noted that there were yet neither studies of long-term teriparatide treatment nor studies using fracture incidence as the final outcome [28]. It is clear that further long-term prospective studies will be required to clarify the role of TBS over BMD in assessing osteoporosis treatment. At present, according to the International Society of Clinical Densitometry Official Position Paper 2019, the use of TBS for monitoring the skeletal effects of antiresorptive medications, such as denosumab and bisphosphonates, is unclear. However, TBS is potentially useful for monitoring the effects of osteoanabolic therapy, such as teriparatide and abaloparatide [31].

A few limitations on the scope of this bibliometric review study should be mentioned. First, we used the WoS database as the source to retrieve all publications pertaining to TBS, and therefore, the contribution of other databases could have been underestimated. Second, we focused on original articles and review articles and excluded document type of meeting abstract, which could be a possibility for future research to complement the findings from this study. Third, WoS is known to have an English-language bias [32], which might not include all relevant articles written in other languages.

Conclusion

This bibliometric review study provided a comprehensive overview of research on TBS published between 2008 and 2019. The collaborative network of countries and regions, the highly published journals, and authors were identified. In addition, co-occurrence of keywords revealed four clusters of research hotspots, namely, associations originated from (1) TBS and BMD, (2) osteoporosis, (3), diabetes, and (4) medications. Findings from this study could contribute to the understanding of the current state of TBS research and the identification of research gap.

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Conflicts of interest

There are no conflicts of interest.

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