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RESEARCH ARTICLE

The outcome of an automated assessment of trabecular pattern in intraoral radiographs as a fracture risk predictor

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Objectives: This study aims to investigate if automated analyses of the trabecular pattern in intraoral radiographs independently contribute to fracture risk assessment when other risk factors incorporated in the Fracture Risk Assessment Tool (FRAX) are taken into account. A secondary aim is to explore the correlation between the automated trabecular pattern assessment in intraoral radiographs and Trabecular Bone Score (TBS).

Methods: A total of 567 intraoral radiographs from older females participating in a large population-based study (SUPERB) based in Gothenburg, Sweden, were selected to analyse trabecular pattern using semi-automated and fully automated software. Associations between trabecular pattern analysis and incident fractures were studied using Cox proportional hazard model, unadjusted and adjusted for FRAX risk factors (previous fracture, family history of hip fracture, smoking, corticosteroids, rheumatoid arthritis, without and with bone mineral density (BMD) of the femoral neck). In addition, the correlation between trabecular pattern analysis and TBS of the lumbar spine was investigated using Pearson correlation analysis.

Results: Neither the unadjusted nor the adjusted trabecular pattern analysis in intraoral radiographs was significantly associated with any fracture or major osteoporotic fracture (MOF). A weak correlation was found between semi-automated trabecular pattern analysis and TBS. No correlation was found between the fully automated trabecular pattern analysis and TBS.

Conclusions: The present study shows that semi-automated and fully automated digital analyses of the trabecular pattern in intraoral radiographs do not contribute to fracture risk prediction. Furthermore, the study shows a weak correlation between semi-automated trabecular pattern analysis and TBS.

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Introduction

Osteoporosis is defined as a systemic skeletal disease characterised by low bone mass and deterioration of bone tissue architecture, leading to an increased risk of fragility fractures.[1] Dual X-ray absorptiometry (DXA) is the validated reference standard for diagnosing osteoporosis. DXA provides a bone mineral density (BMD) value, which is a major determinant of bone strength and fracture risk.[2] However, the method has its limitations,[3] and there is considerable overlap between BMD values in patients with and without fractures,[4] meaning that other factors influence bone strength. In an attempt to improve the estimation of the 10-year fracture probability, a Fracture Risk Assessment (FRAX) tool was developed incorporating all recognised risk factors: sex, age, body mass index (BMI), previous fracture, a parent with hip fracture (heredity), current smoking, glucocorticoid use, rheumatoid arthritis (RA), secondary osteoporosis, and alcohol intake.[5,6] However, neither DXA nor FRAX can capture all skeletal determinants of bone strength. Trabecular Bone Score (TBS) is a novel tool created to reflect bone microarchitecture. It is proposed to be used as a surrogate for bone strength.[7,8] TBS is applied directly on DXA machines and computed successively after areal BMD (aBMD) measurement in the same region of interest of the lumbar spine.[8] The method was first developed on micro-computed tomography (μCT) slices and thereafter adapted for DXA images. A high TBS value reflects a dense trabecular microarchitecture and thus good mechanical strength of bone, while a low TBS value is associated with sparse microarchitecture.[9] Several studies confirm that TBS is an independent and significant risk factor for fragility fractures,[10] and TBS has shown incremental improvement in fracture prediction when combined with FRAX,[11] particularly for hip fracture outcomes.

Research has shown that a correlation exists between BMD of the jaws and other skeletal sites.[12–15] Furthermore, osteoporotic individuals have also demonstrated an altered trabecular pattern of the bone tissue in the jaws compared to healthy subjects.[16] Both visual assessment[17] and digital analyses[18] of the trabecular pattern in intraoral radiographs have shown the potential to identify females at risk of osteoporosis. The possibility of using assessments of the trabecular pattern in intraoral radiographs to identify individuals at high risk of fracture has also been proposed. Both visual assessments and assessments using different digital software[19,20] showed promising results in predicting skeletal fractures. Most digital software is based on semi-automated applications where human influence cannot be ruled out, but recently fully automated software has been launched.

A majority of the Swedish population regularly visit their dentist for dental examinations, including radiographic examinations of the teeth and surrounding bone tissue.[21] The high frequency of visits to dental clinics is another reason why attempts have been made to use the resources available as an opportunity to incorporate osteoporosis and fracture risk assessment into dental clinical practice.

To the best of our knowledge, the use of a fully automated software applied on intraoral radiographs and its possibility to predict skeletal fractures have not been investigated, nor has the correlation between TBS and trabecular pattern of the jaws.

Therefore, the present study aims to investigate if semi-automated and fully automated digital analyses of the trabecular pattern in intraoral radiographs independently contribute to fracture risk assessment when other clinical risk factors incorporated in FRAX are taken into account. A secondary aim of this study is to explore the correlation between the automated trabecular pattern assessment in intraoral radiographs with TBS.

Methods and material

This study on fracture risk assessment uses semi-automated and fully automated software to analyse bone tissue in intraoral radiographs.

Subjects

A total of 3028 older Swedish females (75–80 years) living within the greater Gothenburg area were recruited through a national population register to a population-based, prospective study (Sahlgrenska University hospital Prospective Evaluation of Risk of Bone fractures – The SUPERB study) between 2013 and 2016. Those who accepted and could participate (were ambulant and able to follow instructions in Swedish) were invited to a visit at the Osteoporosis Clinic, Department of Geriatrics, Sahlgrenska University Hospital, Mölndal, Sweden.[22,23] Prior to participation, all study subjects have given their informed consent. The Ethical Review Board approved the study protocol at the University of Gothenburg (Dnr T297-15/Ad 929–12).

Dual-energy X-ray absorptiometry

BMD measurements of total hip (TH), femoral neck (FN), lumbar spine L_1 to L_4 (LS) and TBS of L_1 to L_4 were performed using a dual-energy X-ray absorptiometry (DXA) device, Hologic Discovery A (S/N 86491) (Waltham, MA, USA) on most participants in the SUPERB cohort ($n = 2995$). However, a small proportion of females ($n = 33$) were measured with another Hologic Discovery A DXA device (Waltham, MA, USA) due to machine failure. The potential discrepancy between the two machines was considered by performing a cross-calibration study described elsewhere.[24] The BMD of the lumbar spine and TBS were calculated as the mean of L1 to L4, and any fractured vertebra or vertebra with osteosynthesis material was excluded.

Anthropometrics and questionnaire

Body weight was measured to the nearest 0.1 kg using the same scale for all study participants. Body height was measured using a wall-mounted calibrated stadiometer. Data on clinical risk factors for fracture such as medical history, history of fracture, current smoking habits, parental history of hip fracture, use of oral glucocorticoids for three months or more with prednisolone 5 mg or equivalent, diabetes, RA, and alcohol consumption were assessed by questionnaires. Self-reported fractures sustained after the age of 50 and at any location, except the skull and face, were included in the FRAX-score calculations. Current smoking was defined by a validated questionnaire.[25] A limit of 21 standard drinks per week was used as a definition of high alcohol consumption.[26] Medical history, including prior treatment for osteoporosis such as oral bisphosphonates (ongoing or within two years), zoledronic acid (ongoing or within three years), denosumab (ongoing or within one year) and teriparatide, was assessed by questionnaires.

Incident fracture assessment

Incident fractures were recorded using radiographs and radiology reports retrieved from regional archives of the Västra Götaland region. Research nurses initially reviewed the radiology reports and recorded all reported fractures. Then, an experienced orthopaedic surgeon examined all radiographs without available radiology reports or reports with uncertain fracture diagnoses. Major osteoporotic fractures (MOF) included clinical spine, hip, forearm and proximal humerus fractures. All fractures included all incident fractures except for the skull and face.

Collection of dental radiographs

Dental radiographs collected for this study were gathered retrospectively. All radiographs were taken before the data collection started and were taken on odontological indication and not specifically for the purpose of this study. A detailed flow chart illustrating the collection of radiographs was described previously.[27] In 2015, during the ongoing SUPERB study, the Swedish National Insurance Agency was asked for data on dental examinations (including dental radiographic examinations) from 2010 to 2015 on a subpopulation consisting of the first 2060 consecutively included females. A total of 9303 dental examinations from 337 clinics on 1898 participants were found in the register. Letters requesting intraoral radiographs were sent to the 337 clinics, and out of these, 83 clinics responded, providing radiographs on 376 patients. After excluding images due to invalid image format and missing radiograph dates, images on 230 study participants (3505 images) remained. Due to the poor response rate, we decided not to request data from the Swedish National Insurance Agency on the remaining study participants of the SUPERB cohort recruited in 2016. Instead, in 2017, data on all 3028 participants were requested from regional archives of the Västra Götaland region resulting in 21 175 dental radiographs from 1214 participants. Images from both rounds of data collection were put together, duplicates were removed, and a selection of images took place according to the following criteria: (a) vertical bitewing and/or periapical image including a region of interest (ROI) between roots of premolars in the lower jaw (b) acceptable image quality (image geometry, resolution, sharpness, and contrast) (c) images obtained within three years before or after DXA examination. The first author performed the first rough selection, after which a consensus between two of the authors was reached for the final selection. The most common reason for excluding images from the analysis was a missing region of interest, image quality and image date. The final study sample included a total of 567 intraoral radiographs from the same number of patients. All DICOM images were converted to JPG format using Image J software (Rasband, W.S., ImageJ, U. S. National Institutes of Health, Bethesda, Maryland, USA, 1997–2018). Analogue images were scanned with 1000 dpi using UMAX Mirage IIse (Umax Technologies, Inc., Hsinchu, Taiwan) flatbed scanner.

Boneprox© software

The Boneprox software (Boneprox, Gothenburg, Sweden) is the next generation of Jaw-X software (Crebone AB, Sundbyberg, Sweden).[28] The Boneprox software creates a binary filtered image through digital imaging algorithms to automatically analyse trabecular patterns limited by a trapezoid marker. The marker can be placed and turned manually to perform the analysis. Grey levels in the image are reduced to eight bit-data. The histogram stretch application allows the grey levels to be linearly stretched to cover all intensities (dark areas become black and bright areas become white). The analysis progresses by identifying the largest intertrabecular space, followed by the next largest until the 20 largest spaces have been found. New technology has been introduced to the software making the whole process fully automated from the placement of the trapezoid marker to the analysis of the trabecular pattern within. The final resulting value represents the sum of the sizes and intensities of the spaces between the trabeculae. Scores for the automated analysis of trabecular pattern in intraoral radiographs range between 3000 (dense bone structure) and 9500 (sparse bone structure, *i.e.* large gaps between trabeculae) units. According to manufacturers' recommendations, values equal to or higher than 6500 denoted the risk of osteoporosis. The threshold value was chosen from the reference material.[17] However, there is no threshold value for the risk of fracture. Therefore we investigated if the dichotomisation of scores recommended for assessing osteoporosis also applies to fracture risk. We controlled the distribution of the scores for both semi-automated and fully automated software in the group that sustained a fracture during the study follow-up and the group without a fracture (Figure 1).

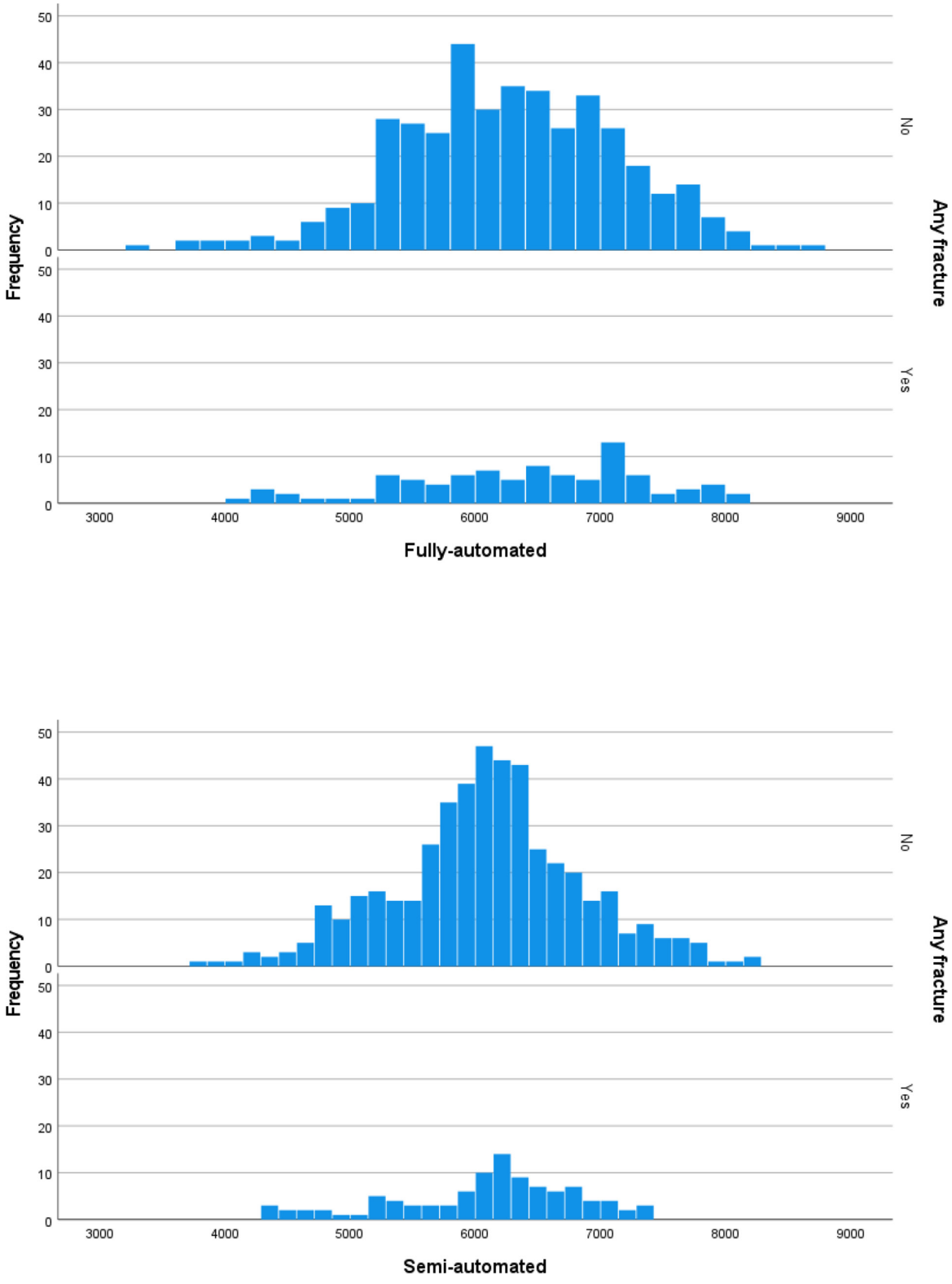
Frequency
Any fracture
No
Yes
Fully-automated
Semi-automated
0
10
20
30
40
50
3000
4000
5000
6000
7000
8000
9000

Figure 1

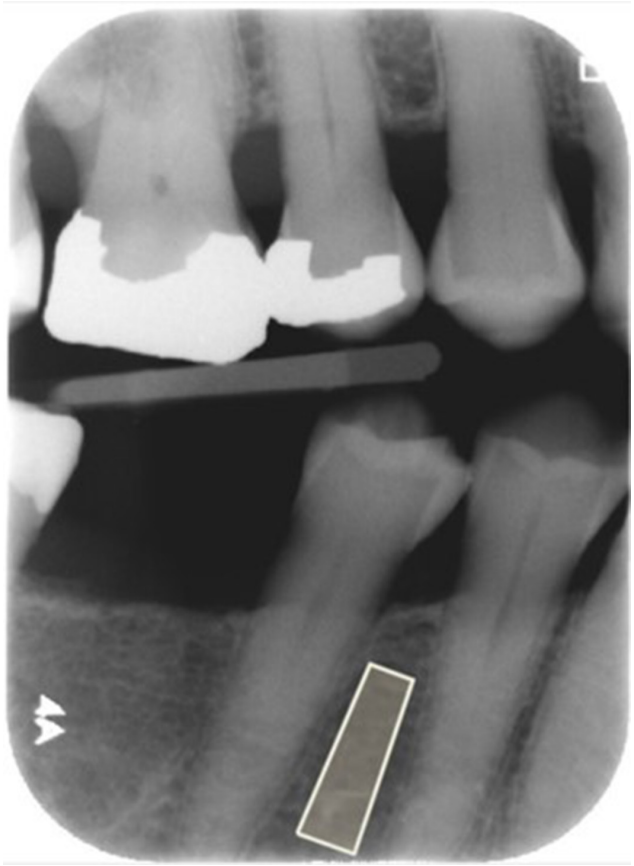

Figure 2

No difference was found between the groups ($p = 0.876$ for semi-automated analysis and $p = 0.198$ for fully automated analysis). Therefore, we chose to continue the analysis without the dichotomisation.

Analyses

One rater (first author) familiar with the analysis technique performed assessments of the intraoral radiographs using semi-automated software. The radiographs were also subject to analysis with a fully automated tool provided by the software developer.

A trapezoid marker symbolising ROI was manually placed between the roots/apices of the premolar area in the lower jaw (Figure 2). In the case of analysis by a fully automated tool, the software itself placed the trapezoid marker. The trabecular pattern was assessed by the algorithm provided in the software.

The analysis was performed using a screen with a resolution of 1920 × 1080 pixels. The observation room was dimly lit as recommended by the American Association of Physicists in Medicine Task Group.[29] The distance to the screen was approximately 50 cm. There was no restriction in the observation time. The rater was blinded to clinical features such as the patient's age, previous medical history and individual DXA results.

Statistical methods

All statistical analyses were performed using SPSS software v. 26.0 for Windows (IBM Corp., Armonk, NY, USA). Descriptive statistics were used to present study sample characteristics. For continuous variables, independent sample t-tests were used to examine differences between groups, and for dichotomised variables, we used the χ^2 test. Associations between trabecular pattern analysis in intraoral radiographs and incident fractures were studied using Cox proportional hazard model. Note that Boneprox scores were expressed in thousands of units in these models for ease of interpretation. The analysis was performed unadjusted and adjusted for FRAX risk factors (previous fracture, family history of hip fracture, smoking, corticosteroids, RA, without and with femoral neck BMD). Because there were no cases of secondary osteoporosis and only two cases of high alcohol consumption in the whole study sample, they were not adjusted for in the model. Correlation between scores of semi- and fully automated analysis of trabecular pattern in intraoral radiographs and TBS of the lumbar spine was investigated using Pearson correlation analysis.

Results

Baseline characteristics

Trabecular pattern analysis was performed on all 567 intraoral radiographs using semi-automated software. The fully automated tool, however, excluded 73 images. The characteristics of the population sample of older females participating in the study are presented in Table 1. During a median follow-up of 3.6 years, 70 study participants sustained a major osteoporotic fracture (12.3%) and 101 any fracture (17.8%).

Trabecular pattern analysis in intraoral radiographs and fracture risk assessment

Incident fractures were divided into two groups: any fracture (included all fractures) and MOF. Tables 2 and 3 present the Cox proportional hazard model results with likelihood-ratio test (LRT) and hazard ratio (HR) used to investigate survival probability for any incident fracture or MOF for the semi-automated and fully automated analysis of trabecular pattern in intraoral radiographs. The model was calculated unadjusted and adjusted for all relevant FRAX risk factors (previous fracture, family history of hip fracture, smoking, corticosteroids, and RA) with and without t-score of FN BMD, respectively. In the model, the only risk factors significantly contributing to the prediction of incident fractures are previous fractures, family history of hip fracture and FN BMD in certain cases. Neither semi-automated nor fully automated trabecular pattern analysis in dental radiographs included in the model independently contribute to the prediction of all

Table 1 Characteristics of study participants (N = 567). Variables are presented as mean ± standard deviation (SD) for continuous variables and as number positive answers (yes) and percentage in parenthesis (%) for categorical data. aBMD = areal Bone Mineral Density, FRAX = Fracture Risk Assessment Tool, MOF = Major Osteoporotic Fracture (spine, hip, forearm, proximal humerus), IO = intraoral

	Total		*W/o any incident fracture (N = 466)*	*With any incident fracture (N = 101)*
Variables	*Value*	*SD*		
Age (years)	78.0	±1.7	77.9	78.1
Height (cm)	161.3	±5.9	161.2	162.2
Weight (kg)	69.1	±12.0	69.1	69.0
Body Mass Index (kg/m^2)	26.5	±4.4	26.6	26.2
Femoral Neck aBMD (g/cm^2)	0.66	±0.10	0.67	0.63
Hip aBMD (g/cm^2)	0.80	±0.11	0.80	0.77
Lumbar spine aBMD (g/cm^2)	0.95	±0.16		
Trabecular Bone Score	1.2	±0.1	1.2	1.2
Osteoporosis based on T-score spine or hip, n (%)	119 (21.0)		91	28
Osteopenia spine, n (%)	216 (38.1)		174	42
Osteopenia femoral neck, n (%)	377 (66.5)		311	66
FRAX MOF w/o BMD (%)	31.0	±11.7	30.8	31.5
FRAX hip fracture probability, w/o BMD %	18.0	±12.0	18.2	17.4
FRAX MOF probability, with BMD (%)	23.3	±11.7	22.9	24.7
FRAX hip fracture probability, with BMD (%)	11.1	±11.0	11.1	11.3
Previous fracture, n (%)	217 (38.3)		166	51
Parental history of hip fracture, n (%)	101 (18.1)		90	11
Current smoking (%)	35 (6.2)		26	9
Glucocoricoid use (per oral), n(%)	15 (2.6)		13	2
Rheumatoid Arthritis, n (%)	20 (3.5)		16	4
Secondary osteoporosis, n (%)	0 (0.0)		0	0
Excessive alcohol consumption (>21 units per week), n (%)	2 (0.4)		2	0
MOF (incidence), n %	70 (12.3)			
Any Fracture (incidence), n %	101 (17.8)			
Osteoporosis, semi-automated trabecular pattern analysis, n (%)	144 (25.4)		117 (25.1)	27 (26.7)
Osteoporosis, fully automated trabecular pattern analysis, n (%)	204 (36.0)		160 (34.3)	44 (43.6)

incident fractures or MOF. In other words, the analysis of survival probability for any incident fracture or MOF for the semi-automated and fully automated analysis of trabecular pattern in intraoral radiographs, neither the unadjusted nor the adjusted model showed a significant association with any incident fracture or MOF.

Correlation with TBS

A relatively weak correlation was found between intraoral radiographs' trabecular pattern analysis using semi-automated and TBS (Table 4). The significance of this correlation disappears when adjusted to the number of cases analysed by the fully automated method (N = 493). A fully automated analysis of the trabecular pattern in intraoral radiographs found no correlation to TBS.

Discussion

In the present study, we demonstrate that neither the semi-automated nor the fully automated assessment of trabecular pattern in intraoral radiographs shows the predictive value for fragility fracture. Furthermore, the correlation with TBS was rather weak and was only present for the semi-automated software.

The topic of fracture prediction using dental radiographs has been under investigation since the correlation was established between the trabecular pattern of the jaws and osteoporosis.[16] Previous research indicates that individuals with a sparse trabecular pattern are at greater risk of osteoporosis.[17] However, osteoporosis is nowadays considered one of many risk factors increasing the risk of fracture. Most individuals with fragility fractures show BMD values within the normal or osteopenic range.[30] Therefore, efforts have instead been directed at evaluating the predictive value of assessment of trabecular pattern in intraoral radiographs for fracture risk.

Already in 1987, the analysis of vertebral bone showed that the biomechanical competence of the trabecular bone was more closely related to age-related changes of the three-dimensional bone structure than to its mineral content.[31] While there

Table 2 Cox proportional hazard model with likelihood-ratio test (LRT) and hazard ratio (HR) for semi-automated trabecular pattern analysis (TPA) in dental radiographs for all incident fractures (Any fracture) and major osteoporotic fractures (MOF). The model was calculated unadjusted and adjusted for FRAX risk factors (previous fracture, family history of hip fracture (heredity), smoking, corticosteroids, rheumatoid arthritis (RA)) with and without t-score of BMD of Femoral Neck (FN), respectively. CI = confidence interval

COX proportional hazard model	*Variable*	*Any fracture*				*MOF*			
		p-value (LRT)	HR	95.0% CI for HR		*p*-value (LRT)	HR	95.0% CI for HR	
				Lower	Upper			Lower	Upper
Unadjusted		0.853	1.025	0.789	1.322	0.235	0.828	0.607	1.131
Adjusted for FRAX risk factors w/o BMD	Semi-automated TPAa	0.966	1.006	0.771	1.312	0.167	0.800	0.583	1.097
	Previous fracture	0.006	1.745	1.172	2.596	0.009	1.888	1.169	3.049
	Heredity (fracture)	0.046	0.528	0.282	0.989	0.072	0.487	0.222	1.066
	Smoking	0.159	1.640	0.824	3.264	0.571	1.302	0.522	3.248
	Corticosteroids	0.702	0.759	0.185	3.114	0.548	0.544	0.075	3.957
	RA	0.434	1.500	0.543	4.140	0.426	1.608	0.499	5.185
Adjusted for FRAX risk factors with BMD FN	Semi-automated TPAa	0.829	0.970	0.740	1.273	0.095	0.758	0.548	1.049
	Previous fracture	0.015	1.645	1.102	2.455	0.024	1.746	1.077	2.831
	Heredity (fracture)	0.041	0.519	0.277	0.974	0.067	0.480	0.219	1.052
	Smoking	0.179	1.604	0.806	3.195	0.613	1.266	0.507	3.159
	Corticosteroids	0.789	0.824	0.200	3.394	0.626	0.610	0.083	4.459
	RA	0.328	1.665	0.599	4.631	0.348	1.755	0.542	5.681
	BMD FN	0.020	0.747	0.583	0.956	0.027	0.709	0.522	0.961

[a]Expressed in thousands of units for this model

is a relationship between BMD and fracture risk, evidence suggests that BMD measurements reflect only one component of bone strength.[32] Factors other than BMD influence bone strength and fracture risk, including microarchitectural deterioration of bone tissue.[33] A large variety of different modalities have been applied for assessment of skeletal microstructure, from histomorphometric analysis of transiliac crest bone biopsy, high-resolution peripheral quantitative computed tomography (HRpQCT),[34] microCT (μCT),[35] to Magnetic Resonance Imaging (MRI).[36] However, these techniques are costly, time-consuming and not always available in routine clinical practice. Moreover, they have been mainly used in peripheral sites and are not part of standardised imaging protocols yet.[7] Therefore, TBS was developed to meet the demand for an instrument assessing trabecular microarchitecture. Its proponents define TBS as a textural parameter that evaluates pixel grey-level variations in the DXA image.[8] Similarly, the trabecular structure of the jaw bone is revealed indirectly by periapical radiographs, which are considered high-resolution two-dimensional images. The diagnostic value of periapical radiographs for assessing bone tissue characteristics has been investigated.[37] Based on studies showing a correlation between BMD in the mandible and other skeletal sites, we found it interesting to explore two methods, TBS and Boneprox, that are both based on evaluation of three-dimensional trabecular bone structure from two-dimensional images.

Assessment of trabecular pattern in dental radiographs for the purpose of prediction of fracture has been investigated previously. However, only a few studies have a similar approach to our study. Visual index for assessment of trabecular pattern proposed by Lindh[17] and applied on both intraoral[28,38] and panoramic radiographs[20,39] showed some promising results in the fracture risk prediction. Automated analysis of the trabecular pattern in intraoral radiographs is a rather novel method that has not yet been explored enough. Jonasson and Billhult[28] compared visual index for assessing trabecular pattern in intraoral radiographs with the analysis using semi-automated software (Jaw-X, Crebone AB, Sundbyberg, Sweden). Neither of the two methods in this study showed a significant correlation in the prediction of incident fractures. Although the study's limitation is the sample size (N = 136), their results agree with ours. A recent systematic review concluded that based on low certainty of the evidence, trabecular bone evaluation on dental radiographs might predict fractures in adults without a prior diagnosis of osteoporosis, and based on very low certainty of the evidence, it is uncertain whether digital image analyses of trabecular bone can identify individuals with osteoporosis.[40] These conclusions are,

Table 3 Cox proportional hazard model with likelihood-ratio test (LRT) and hazard ratio (HR) for fully automated trabecular pattern analysis (TPA) in dental radiographs for all incident fractures (Any fracture) and major osteoporotic fractures (MOF). The model was calculated unadjusted and adjusted for FRAX risk factors (previous fracture, family history of hip fracture (heredity), smoking, corticosteroids, rheumatoid arthritis (RA)) with and without t-score of BMD of Femoral Neck (FN), respectively. CI = confidence interval

COX proportional hazard model	*Variable*	*Any fracture*				*MOF*			
		p-value (LRT)	HR	95.0% CI for HR		*p*-value (LRT)	HR	95.0% CI for HR	
				Lower	Upper			Lower	Upper
Unadjusted		0.306	1.128	0.895	1.421	0.663	0.941	0.716	1.237
Adjusted for FRAX risk factors w/o BMD	Fully automated TPAa	0.429	1.099	0.870	1.390	0.464	0.901	0.682	1.191
	Previous fracture	0.160	1.671	1.099	2.541	0.027	1.776	1.067	2.957
	Heredity (fracture)	0.103	0.589	0.312	1.112	0.129	0.541	0.245	1.196
	Smoking	0.096	1.802	0.902	3.601	0.450	1.425	0.568	3.574
	Corticosteroids	0.797	0.831	0.202	3.410	0.590	0.580	0.080	4.221
	Rematoid Arthritis	0.410	1.531	0.556	4.215	0.357	1.731	0.538	5.572
Adjusted for FRAX risk factors incl. BMD FN	Fully automated TPAa	0.552	1.074	0.848	1.360	0.358	0.876	0.662	1.161
	Previous fracture	0.032	1.590	1.041	2.428	0.054	1.661	0.991	2.782
	Heredity (fracture)	0.085	0.572	0.303	1.081	0.109	0.522	0.236	1.155
	Smoking	0.102	1.783	0.891	3.567	0.475	1.399	0.557	3.514
	Corticosteroids	0.849	0.871	0.212	3.586	0.636	0.618	0.085	4.516
	RA	0.316	1.685	0.607	4.673	0.282	1.906	0.588	6.176
	BMD FN t-score	0.083	0.793	0.609	1.031	0.109	0.765	0.552	1.061

[a]Expressed in thousands of units for this model

however, based on only three studies included in the final syntheses.

A number of strengths and limitations of this study must be considered. Although we reached out to the general dental clinics in a structured manner, both by mail and phone, we received very few responses, making data collection difficult. Another limitation originates from the retrospective study design, which meant that images were collected from many different clinics with no details regarding exposure parameters, were acquired using different technologies (analogue radiographs, digital radiographs) and in various file formats (DICOM, JPEG, TIFF, and BMP). This could be considered a source of bias but could also be seen as a strength of the study as it reflects the reality of general dental practice. Finally, the Boneprox software investigated in this study is the next generation of the software earlier referred to as Jaw-X. As the company owning the rights to the algorithm has a trade secret protecting the software, it is not easy to establish in detail the similarities and differences between the previous and the current versions of the software. It is also difficult to compare it to other software for the analysis of trabecular pattern in intraoral radiographs.

The main strength of our study is that it was part of a large cohort with a small age span (75–80 years) where the study participants underwent a thorough clinical examination and answered a detailed questionnaire which made it possible to acquire a large amount of data for analysis. Another strength of our study is that we used incident fracture as the outcome measure instead of BMD. BMD is used by most studies of diagnostic or therapeutic protocols for osteoporosis but suffers from the limitation that it is, after all, an imperfect surrogate of osteoporotic fracture.

Table 4 Pearson correlation analysis between Trabecular Bone Score (TBS) and semi-automated and fully automated analysis of trabecular bone pattern in intraoral radiographs. The correlation for semi-automated analysis was calculated for both the total number of analysed cases (N = 565) and for the selection of cases corresponding to the fully automated analysis (N = 493)

		TBS	
Trabecular pattern analysis	*N*	*Pearson Correlation*	*Sig. (2-tailed)*
Semi-automated	565	−0.093	0.027
	493	−0.068	0.130
Fully automated	493	−0.059	0.187

Conclusion

The present study shows that semi-automated and fully automated digital analyses of the trabecular pattern in intraoral radiographs do not contribute to fracture risk

prediction. Furthermore, the study shows a weak correlation between semi-automated trabecular pattern analysis and TBS.

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