Detecting low bone mineral density from dental radiographs: a mini-review

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Summary

Over a number of years researchers have reported associations between osteoporosis or low bone mineral density and signs that can be detected on dental radiographs, particularly in the width of the inferior mandibular cortex and the texture of the trabecular bone. As patients visit the dentist more regularly than they visit their doctor, there is the possibility that such signs could be used as a means of identifying individuals at risk of developing osteoporosis or suffering from consequent fracture. This paper reviews the historical background behind this research and the current status, including recent developments in automation of measurement using computer image analysis.

KEY WORDS: dental radiographs; Bone Mineral Density; osteoporosis; Computer Image Analysis.

Low bone mineral density and osteoporosis

Osteoporosis is a disease characterised by low bone mass and microarchitectural deterioration of bone tissue leading to enhanced bone fragility and a consequent increase of fracture risk (1). The outer, cortical, layers of the bone become thinner while the trabecular structure becomes more open (2). There is a progressive reduction in bone mineral density (BMD) in women after about their fourth decade. While BMD is not the only factor contributing to fracture risk, osteoporosis is defined in terms of an individual’s BMD in comparison with that of young healthy women (3), and it predominantly occurs in post-menopausal women. Bone mineral density can be measured using Dual-Energy X-ray Absorptiometry (DXA), usually at the hip, lumbar spine and forearm, as these are the most common sites of fracture. Fractures resulting from osteoporosis are associated with significant morbidity, and even mortality (4). It is, however, largely underdiagnosed, and usually becomes apparent after a fracture occurs. Screening is not considered to be cost-effective and a “case finding” strategy is recommended (5) to identify those at risk of fractures. A number of factors may be used as predictors of risk of developing osteoporosis. These include age, body mass index, treatment with hormone replacement therapy and family history of osteoporosis. Several clinical indices have been proposed composed of differing weighted combinations of these factors, such as OSIRIS (Osteoporosis Index of Risk) (6), SCORE (Simple Calculated Osteoporosis Risk Estimation) (7), and self-assessment tools such as OST (Osteoporosis Self-Assessment Tool) and ORAI (Osteoporosis Risk Assessment Instrument) (8). The World Health Organisation supports the use of the FRAX tool (9), which uses a larger number of risk factors, and may be calculated with or without BMD measured by DXA. Excluding BMD, the tool provides a basis for referral for DXA scanning. Including BMD it can provide therapeutic guidance for individual patients.

Dental Panoramic Radiographs

Dental panoramic radiographs (DPRs or dental panoramic tomographs - DPTs) are collected by a tomographic imaging technique and show the entire jaw as illustrated in Figure 1. These are taken for a variety of purposes by dental practitioners and in dental hospitals, for example as part of the assessment for implant surgery. Some 1.8 million such radiographs were taken in general dental practices in the UK in 2004-5 (10). The key regions of these images in the context of assessing osteoporosis are the inferior mandibular cortex (a region of cortical bone along the lower edge of the mandible, indicated in Figure 1), and the trabecular bone immediately above it.

One of the earliest reports of oral bone loss associated with osteoporosis was by Groen et al. (11) in 1960. Since then a number of studies has identified specific changes visible in DPRs related to osteoporosis or to reduced bone mineral density. These refer mainly to altered morphology of the inferior mandibular cortex (12-19) and to altered architecture of the trabecular bone visible in DPRs associated with osteoporosis using a three-point visual assessment scale (the mandibular cortical index). This scale characterised the cortex from being homogeneous with a clear border through to appearing porous with many residues of cortical bone appearing above the cortical border. As is common with such subjective, semi-quantitative assessments, it shows poor reproducibility between observers (25). The width of the inferior mandibular cortex provides a straightforward, measurable characteristic, which, in principle, provides a quantitative feature that can be compared...
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with bone mineral density. This feature needs to be measured carefully at a consistent location. As there are few consistent anatomical landmarks in the mandible on DPRs, the chosen position is the mental foramen (indicated on Figure 2). This is a space through which the mental nerve passes, and is not clearly visible to the inexperienced observer. Several studies have reported the significant correlation between measurement of the cortical width at this point and bone mineral density measured by DXA at the hip (18), lumbar spine (13) and forearm (26). This raises the possibility that measurement of image parameters on DPRs could form an opportunistic mechanism for detecting individuals at risk of osteoporosis. Horner et al. (27) were able to conclude that a cortical width measurement of less than 3mm should result in a referral for DXA scanning to confirm the BMD. However great care is needed to carry out the measurement. Devlin et al. (25) found that intra- and inter-observer repeatability were poor when dentists were asked to perform the analysis, and this was not improved by specific training. To be of value the measurement needs to be carried out automatically by computer analysis.

A multi-centre study (the OSTEODENT project) explored a number of aspects of the relationship between dental radiographs and osteoporosis risk, using a large cohort of patients (670 females aged 45-75 years) who received both DPRs and DXA measurements (124 had osteoporosis determined by DXA) in four European centres. These included a thorough investigation with the large image set of the use of mandibular cortical width in osteoporosis risk assessment (19, 28), the accuracy of combining the cortical width measurement with clinical indices (29) and the use of visual assessment of radiographs in identifying women at risk of osteoporosis (30).

**Automatic measurement of cortical width**

Arifin et al. (31) described a method based on image processing of digital images, combined with user interaction for measuring the cortical width. They reported sensitivity and specificity of around 88% and 57.5% for identification of osteoporosis at the lumbar spine and femoral neck in 100 post-menopausal women. Allen et al. (32) used an image analysis method for detecting the edges of the cortex automatically, making use of a statistical model of the shape and appearance of the cortex, known as an Active Shape Model (ASM) (33). The automatic detection of the boundary, without the need for interactive guidance, meant that the cortical width did not need to be measured at the mental foramen, the best identification of osteoporosis being obtained at a point further towards the antegonion (Figure 1). These Authors reported that sensitivity and specificity of detection were improved if a semi-automated method was adopted, incorporating a straightforward user interaction identifying points on the lower cortical border, near the mental foramen and antegonion. The image data set used by Allen et al. for training the statistical shape models and determining the measurement parameters was totally separate from the OSTEODENT image set, which was subsequently used by Devlin et al. (34) in a Receiver Operating Characteristic (ROC) analysis, applying the ASM method for identifying osteoporosis at the hip, spine and femoral neck. They reported values of the area under the ROC curve (sometimes referred to as $A_z$) of 0.759 and 0.816 for detection of osteoporosis at any of the three measurement sites using the fully automated and semi-automated analysis respectively. $A_z$ values of 0.805 and 0.835 were reported for automatic and semi-automated identification of osteoporosis specifically at the femoral neck. Subsequently Roberts et al. (35) made use of Active Appearance Models (AAM) (36, 37), which employ a richer description of image appearance than Active Shape Models. By doing so they improved the $A_z$ values for fully automatic measurement of the cortical width to 0.799 and 0.851 for identification of osteoporosis at any of the three measurement sites or at femoral neck respectively. These $A_z$ values correspond to
Figure 2 - Detail of the lower part of the DPR showing (a) a healthy mandible and (b) an image of an individual with osteoporosis. The reduced width of the cortex is clear in (b). The position of the mental foramen and the site for manual measurement of cortical width are indicated.

sensitivity/specificity values of 80/61\% (any site) and 80/77.5\% (femoral neck).

As part of the OSTEOSDENT study, Devlin et al. (38) showed that combining the cortical width measure with the OSIRIS risk score resulted in a prediction of skeletal BMD that was better than the use of either test alone. This combination was termed the OSTEOSDENT index. It was later shown (39) that the OSTEOSDENT index was significantly related to the 10-year probability of fracture as determined by the FRAX tool without BMD. No significant difference was found between the OSTEOSDENT and FRAX indices when used as tests for therapeutic intervention.

More recently Muramatsu et al. (40) have developed an automated measurement system using a database of 100 DPRs from patients and volunteers, of whom 26 were diagnosed with osteoporosis. The group included both males and females. The images were analysed using edge detection and an Active Contour Model (41) to detect the borders of the cortical bone and to measure the cortical width at the mental foramen. An Active Contour Model operates in a similar way to an Active Shape Model in finding a smooth boundary when image contrast may be weak, but is not constrained to find shapes that are consistent with a trained statistical description. They reported sensitivity and specificity for detecting osteoporosis of 88.5 and 97.3\% respectively.

Using the automatic measuring method of Roberts et al. (35, 42) investigated the variation of cortical width with age in men and women. They measured the cortical width in 4949 men and women in the age range 15-94 years and found that there is progressive cortical thinning in women from the age of 42.5 years, following closely the rate of reduction in BMD. For men there is also a rather slower, progressive cortical thinning with age from the age of 36.

Measurement of image texture

Osteoporosis not only results in a loss of cortical bone mass, but in changes in trabecular structure of trabecular bone (1). This has led a number of Authors to propose that measures of image texture in projection images of trabecular bone may provide additional information in assessing fracture risk (43, 44). In the context of mandibular imaging, image texture has usually been addressed by measurement of fractal dimension (23, 45-47). There is no reason to believe that the texture pattern in the trabecular bone exhibits fractal properties, such as self-similarity across scale, and the fractal dimension in these studies is being used as a more general "roughness" measure. Different algorithms are used to calculate fractal dimension, which vary in their response: some returning lower values in the case of osteoporosis, and some higher. Roberts et al. (48) showed that, while there is a relationship between fractal dimension measured in the mandible and reduced BMD, this is not strong enough to be useful as a discrimination measure. They found, however, that texture features based on the use of co-occurrence matrices (49) provided greater discrimination. Measurement of texture in the trabecular bone was less useful than texture in the cortex, which was found to be associated with Klemetti's (24) semi-quantitative scale. ROC analysis showed that cortical texture alone showed similar discriminating ability to cortical width, while combining cortical texture and width measurements increased the discrimination power slightly over either individually.

Conclusion

Features measured on dental panoramic radiographs have been shown to be strong predictors of skeletal bone mineral density. Bone loss associated with osteoporosis occurs throughout the body. The spine, hip and forearm are chosen as the normal sites for BMD measurement, mainly because of accessibility and the higher vulnerability to fracture. Measurement of features at the mandible has the advantage that radiographs are collected at this site for other reasons, opening the possibility of opportunistic case finding prior to fracture, even when the individual concerned may not have considered the risk of osteoporosis. Automatic measurement using computer image analysis would allow this case finding to proceed without affecting the normal conduct of a dental examination. Of course, patients identified in this way would need to be referred for bone-density assessment by DXA, and this would require ready communication between dentists and general medical practitioners. As patients visit their dentists regularly, there is an opportunity for the dental practitioner to become more closely involved in monitoring the general well-being of the patient. Bone health is an area where dentists have a particular interest and opportunity to contribute.
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