Jaw-X - A method for detecting bone density and osteoporosis in dental digital images

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Abstract

The Jaw-X method determines bone quality and risk of osteoporosis. The method is based on an image processing algorithm that uses intraoral X-ray images from a defined region of the lower jaw premolar area to measure the trabecular density. The values from the image processing algorithm were compared to the corresponding values from DEXA tests of the same patients. A high correlation between DEXA values and the trabecular density in the lower jaw bone was found to exist.

Introduction

Computerized examination of digital images gives a uniform, standardized and operator independent analysis of the bone quality. A computer program has been developed that uses intraoral X-rays from a defined region of the lower jaw (mandible) premolar area to measure the trabecular density and provide a simple indication of the risk of osteoporosis.

The software uses digital imaging algorithms to analyze the trabecular structure in the selected region. A standardized ROI (Region of Interest) marker is placed in-between the premolars in the mandible. The resulting sample undergoes image treatment in order to expose the trabecels. All holes in the trabecular structure are detected.

The method is developed in cooperation with Malmö University Sweden, and is based on conclusions from part of the results of the EU Osteodent project [1] and a patented technology developed by Crebone AB [2].

Scientific background: The Osteodent project [1]

Quote:

//Objectives: To determine the diagnostic validity of mandible bone density, measured between the premolars (mm Aleq) in detecting osteoporosis at the hip or lumbar spine.

Methods: Female subjects between 45 and 70 years of age were recruited from 4 European centers. They underwent dual x-ray energy absorptiometry of the hip and lumbar spine, to provide a gold standard diagnosis of osteoporosis. In addition, intra-oral radiography of upper and lower right premolar region was performed, using an aluminum wedge as a densitometric reference. Jaw bone density in 4 selected regions of interest (ROI) was determined using dedicated software Osteop (Nackaerts et al 2005**). Two ROIs were determined between the upper premolar teeth and another between the lower premolars. 5 observers performed the analysis. Intra- and inter-observer differences and ROC curves were analyzed.

Results: Results from 660 subjects (mean age 54.8y; SD 6.19) were suitable for analysis. 136 of these subjects were classified as having osteoporosis. For ROC analysis, measurement data from all observers were averaged, since there was no significant inter-observer difference. Az values as well as 95% confidence intervals are shown in table 1.

Table 1. Detecting osteoporosis at any site (spine, hip, femoral neck)

ROI 1 upper jaw	Az = 0.691 (0.653 to 0.726)
ROI 2 upper jaw	Az = 0.708 (0.671 to 0.743)
ROI 1 lower jaw	Az = 0.709 (0.672 o 0.745)
ROI 2 lower jaw	Az = 0.702 (0.655 to 0.738)

None of the differences in Az between sites was statistically significant (p always >> 0.05).

Conclusions: Density of the premolar region expressed in mm Aleq is a fair indication for the presence of osteoporosis. More extensive analysis of the OSTEODENT results might reveal an even better predictive tool for osteoporosis screening.// *End Quote*

Method

Image preparation[2]

An image from the mandible is loaded as a JPEG-file (8-bit greyscale) or as a TIFF-file (8, 10, 12 or 16 bit greyscale) into the computer software. An area, the size of which is based on the physical dimension of the image, is manually placed on the region of interest (ROI) on the image. The area is fixed in size and shape but can be moved and rotated. Only pixel data within this area is considered for the analysis. The area is resampled in size to make the resulting image match a fixed reference size. The current implementation uses a bi-linear filter to reduce the dimensions of the image. The reference size is chosen to be small enough to remove noise but still retain the trabecular structure.

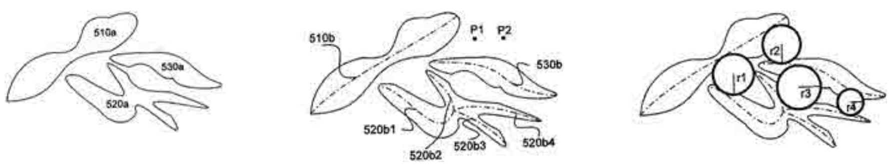
Image processing

The grey levels in the image are linearly stretched to cover all intensities, i.e. dark areas become black and bright areas white (histogram stretch). The grey levels are reduced to 8 bit-data (256 levels). Then a 3x3 median filter is applied on the image in order to to reduce the noise level in the image but not the trabecular information.
The next step removes all pixels which are classified as teeth or “void”, only the jaw bone is of interest. The classification is done by finding the minimum and mean value in a 9x9 neighbourhood to every pixel. If this value is too high (too bright) it is classified as a tooth, and if it is too low (too dark) it is classified as void. The principle is that bone is made up of a structure and is not too bright or too dark.

Next step is to find the trabecular structure within the bone with a similar method. A 9x9 neighbourhood of every pixel is searched and if the minimum value is high enough it is a trabecula, if not it is a space/gap in the bone structure. If too many pixels are classified as a trabecula (and thus to little space) the threshold in step 8 is reduced and step 8 is iterated once more. This threshold value has been chosen from the reference material.

The previous steps have resulted in a binary image which contains the trablecular structure. Now a distance transform is applied with respect of the trabeculae. A 3x4 metric is chosen. The result is a distance map where each pixel inside a trabecula contains the shortest distance to bone space. From this distance map all local maxima are found. The set of all these points gives a skeleton (and width) of all trabeculae (like “centre of maximum discs”-method). This gives a binary image. From this binary image a distance transform is applied with respect to the space between the trabeculae skeleton. This results in a distance map which in each pixel contains the distance to the closest trabecula skeleton (center line).

The highest value in this distance map is determined. The result is the point which is furthest away from any trabeculae, ie the largest space within the bone structure. The coordinates and value for this point are saved into a list. All pixels within a radius given by the value are removed from the distance map.
Next step is then iterated, and the next largest space in the bone structure is found. This is iterated until the 20 largest spaces in the bone structure are found.



Schematic picture of the analysis of the trabecular density

For each of these coordinates a mean value of the grey levels from step 6 in a 3x3 neighbourhood is calculated. These values are weighted (with inverted values, a dark pixel gives a high value) together with the corresponding value from the previous step to give a result that includes both the size of the space and the darkness/shade of the pixels within the space.

All values are then weighted and combined into a final value which represents the size and intensity of the spaces between the trabeculae. The current implementation gives values between approx. 3500 (healthy, compact bone) and 9500 (large gaps between trabeculae).

Image quality

The quality of the X-ray image is of great importance to find a ROI (Region of Interest) and also for the software to make a proper calculation. The most important quality issues are:

- A proper projection
- An image where the anatomic circumstances are clear and sufficient in size to place the ROI-marker correctly

With a proper image the discrepancies between different operators with different skills are eliminated.

During the ongoing development the possibility of creating a “tolerance filter” that sorts out inferior images, will be explored. Notable is that the images from the Osteodent EU-project are exposed on analog film and digitized with a flat bed scanner. The centers that exposed the X-ray images used a different technique as well as different equipment.

Results and discussion

Our results show that it is feasible to analyze bone density with intraoral X-ray images. A high correlation between DEXA values and the trabecular density in the lower jaw bone exists.

The values from the image processing algorithm were compared to the corresponding values from DEXA tests of the same patients. The resulting values of calculated trabecular density were related to a scale that indicates whether a patient has osteoporosis, osteopenia or is well. The scale indicating trabecular density has a minimum value of 3500 that represents a very dense structure to 9500 which represents a very thin trabecular structure.

Based on the reference values, X-rays of 123 patients have been analyzed. Analog film X-rays have been scanned on a flatbed scanner and treated digitally. Three images have been disposed; two cases of abnormal anatomy which prohibited the placement of the ROI marker and one because of inferior quality.

The remaining 120 images from the Osteodent material contain:

- 72 images showing patients that are not at risk for osteoporosis.
- 11 images showing that the patients have osteoporosis and
- 37 images of patients that show osteopenia.

In our study we have used a lower border of 6500, which suggests risk for osteoporosis. An upper border of 6200 suggests that the patient is healthy. Results between 6500-6200 imply a risk for osteopenia. Table 2 shows the borders compared to those of the WHO T-Score (the golden standard).

Table 2. Jaw-X borders compared to T-score borders

Bone density	T-Score value	Jaw-X value
Normal	> -1 SD	< 6200
Osteopenia	-2.5 SD – -1.0 SD	6200 – 6500
Osteoporosis	< -2.5 SD	> 6500

Results of Jaw-X tests

Of the 72 images of patients that are well, related to osteoporosis in the DXA test:

- 2 images differ in value because of differences in the anatomy and bone structure and should therefore not have been used.
- 2 images show that the patients have osteopenia bordering to osteoporosis.
- 67 images from the Jaw-X test show the same result.

Of the 11 images showing that the patients have osteoporosis from the DXA test the same values are reached with the Jaw-X method.

Of the 37 images from DXA tests indicating that the patients have osteopenia the same values are reached with the Jaw-X method.

- Osteoporosis 100% conformity
- Osteopenia 100% conformity
- Well 95.7% conformity

Continued development

With the above results as a basis, the remaining material from the EU Osteodent project has been tested. This material covers 672 women. Three independent testers with dental and radiology experience have gone through the Osteodent material with the test software. 652 images of the mandible bone from the original osteodent images have been used. In a comparison of the analyses of the 652 images, the results show a discrepancy between the testers in 94 cases (14%).

After a review of the quality of the used material, images with inferior quality, unusable because of anatomical limitations, bad projection, darker or brighter than the software can handle, were discarded. The remaining material consisted of 559 images. With this material, the discrepancy in the results reached by the three testers was now only 9 cases (1.8%).

Golden standard comparison [3]

A comparative diagnosis with the golden standard T-score method yields the results in table 3. By simplifying the diagnosis as either healthy or at risk for osteoporosis or osteopenia, the results in table 4 are obtained, which minimizes the deviation between the two methods.

- With a T-score value below -2.5, the patient has been classified as ill with osteoporosis provided that the BMD-hip value is below 0.875.
- With a T-Score value between -1.5 and -2.5, the patient has been classified as at risk or having osteopenia.
- Patients with a T-Score value above -1.5 have been classified as healthy.

Table 3. Number of patients with different diagnosis in the Osteodent material.

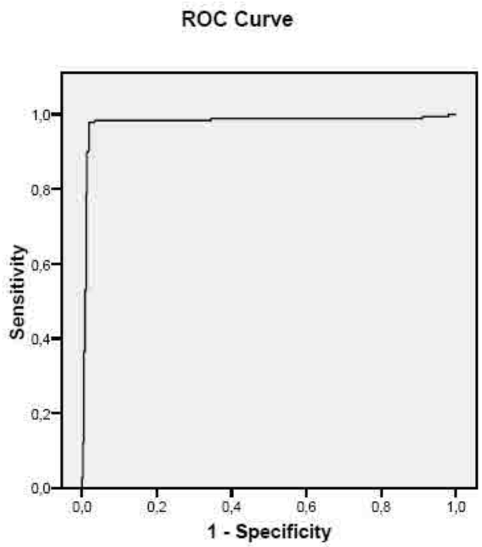
	T-score	Jaw-X
Healthy	370	364
Osteopenia	78	81
Osteoporosis	111	114
Sum	**559**	**559**

Table 4. Osteoporosis and osteopenia are added to form a new group called *at risk*.

	T-score	Jaw-X	Deviation
Healthy	370	364	6
at risk	189	195	-6
Sum	**559**	**559**	

ROC-analysis.

Data in table 4 expressed In a ROC-curve gives this result:



Area Under the Curve

Test Result Variable(s): Mätvärde

Area	Std. Error[a]	Asymptotic Sig.[b]	Asymptotic 95% Confidence Interval	
			Lower Bound	Upper Bound
.979	.008	.000	.963	.996

The test result variable(s): Mätvärde has at least one tie between the positive actual state group and the negative actual state group. Statistics may be biased.

a. Under the nonparametric assumption

b. Null hypothesis: true area = 0.5

The Method in use in dental practice

Clinical risk evaluation

All subjects are interviewed using a standard battery of questions to provide the information required to calculate the Osteoporosis Index of Risk (OSIRIS).[4] This is based on four variables: age, body weight, current hormone replacement therapy (HRT) use and history of previous low impact fracture. The index is calculated by adding together:

- Age multiplied by −2 (rounded down to the nearest integer),
- Weight in kg multiplied by 2 (rounded down to the nearest integer),
- −2 if a current user of HRT,
- −2 if there is a history of low trauma fracture in the family.

An OSIRIS score of:

<−3	indicates a high risk of low BMD,
>−3and <+1	intermediate risk,
>+1	low risk

In this study, an OSIRIS score of <+1 is used as a positive test result.

Compilation of patient risk for bone fragility

Patient at risk

- If the X-ray assessment shows more than 6500 the patient is at risk. The patient shall be referred to medical care.
- If the X-ray assessment shows between 6200 and 6500 and additional risk factors > -3 the patient is also at risk and shall be referred to medical care.

Patient to observe

- If the X-ray assessment shows between 6200 and 6500 and additional risk factors are present the patient should be recalled for a new test in one year. The patient is considered healthy but should be observed in the future.

Healthy patient

- If the X-ray assessment shows below 6200 and none of the other risk factors are present the patient is considered healthy.

Clinical studies

A practical – clinical evaluation of the Jaw-X method

A clinical study in 9 dental practices started in May 2007 and is still running. In the study the Jaw-X software is used in real life dentistry with X-ray images from digital X-ray systems using sensors and image plates. The tests are combined with the risk anamneses mentioned above.

Dental staff participating in this clinical evaluation using Jaw-X have gone through a full day of training. The training covers:

- Bone physiology and bone pathology

- Endocrinology
- Treatment of Osteoporosis
- How to take proper X-rays
- How to use the Jaw-X software

Around 150 patients will be tested and sent to medical care for DEXA tests if found to be at risk. The referrals will be answered after some time and the final results are planned to be ready and compiled in March 2008. A more exact study will be presented when the clinical tests are ready. However, the results that have arrived this far predict a very high sensitivity and specificity for the method as such.

Retrospective study

A study of approx. 250 patients that have been treated for fragility fractures at the Sahlgrenska University Hospital will be compiled starting spring 2008. The patients will have dental X-rays taken and assessed with the Jaw-X software. This study will explore the correlation between bone density in jaws and patients which manifest fragility fractures.

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