Monitoring of Damping for the Assessment of Mandible Bone Quality

S. D. Panteliou[1*], K. A. Lianos[2], D. A. Sarafianos[3], C. G. Bilios[4]

[1]Machine Design Laboratory, Dept. of Mechanical Engineering and Aeronautics, University of Patras, Patras 265 00, Greece
panteliu@mech.upatras.gr
[2]Machine Design Laboratory, Dept. of Mechanical Engineering and Aeronautics, University of Patras, Patras 265 00, Greece
lianos@mech.upatras.gr
[3]Machine Design Laboratory, Dept. of Mechanical Engineering and Aeronautics, University of Patras, Patras 265 00, Greece
sarafia11@hotmail.com
[4]Machine Design Laboratory, Dept. of Mechanical Engineering and Aeronautics, University of Patras, Patras 265 00, Greece
cbilios@gmail.com
Corresponding author

Abstract

The contemporary methods for the assessment of the quality of human mandible, in order to facilitate the decision making for dental implants, include bone density measurements through dual-energy X-Ray absorptiometry (DEXA) or its variations. The estimation of mandible quality with these methods is related to subjectivity, comparability and reliability problems, which results in restricted capability of secure assessment of bone quality.

Monitoring of loss of structural integrity is applied in this work through modal analysis, in order to obtain an objective assessment of mandible bone quality. Specifically, modal damping factor (MDF) and bone mineral density (BMD) measurements are performed on human cadaveric mandibles. From the data acquired clearly arises a very promising correlation between MDF and BMD, reinforcing the belief from our previous research findings that this method can lead to a mandible quality assessment tool, thus encouraging further research investigation.

Keywords: Damping, Mandible, Bone Quality.

1. Introduction

Bone quality is a term that may on occasion refer to one or more of the following: density, macrostructure, microstructure, mechanical properties and biologic response to physiologic stimulae and external influences, one of them being placement of implants.

Bone density is often used as an estimator of bone quality. There is a variety of in vitro and in vivo methods that are used for evaluation of mandibular bone density and they can be broadly categorized in:

1.   Histomorphometry of biopsy samples
2.   Empiric topographic prediction methods based on combining anthropometric data and simple panoramic radiographs
3.   Torque resistance measurements during implant insertion
4.   X-ray absorption methods

The histological and morphometric measurement of the bone has been considered the golden standard for bone density measurements (Molly, 2006). It is an invasive and deleterious method for the donor site, during which, small biopsy specimens 2mm diameter are been harvested from patient's jaws immediately before implant placement (3,75mm diameter).

The empiric method of Lekholm and Zarb (Branemark et all 1985) lacks precision and is related to subjectivity, comparability and reliability problems, which result in restricted capability of secure assessment of bone quality. Although it is an easy and inexpensive method it cannot discriminate between osseous sites at the same individual.

Insertion torque measurements are not a true bone density evaluator. A variety of implant parameters, as design characteristics and insertion technique features, co-influence the actual measurements (Ostman et all, 2005).

From the clinical standpoint, a bone density evaluation method should have a preoperative character, in order to be useful for appropriate treatment planning. Therefore, histomorphometry and insertion torque measurements are not convenient, since the decisions have already been taken and the results can be used only for post insertion evaluation and statistical correlation with success data. The empiric method is a general, crude estimation which is non accurate between potential implant sites.

The most commonly used density evaluation methods in dental practice are the radiographic ones and mainly the computed tomography (CT). Estimation of radiographic density on Hounsfield units allows for site specific presurgical evaluation of bone density and selection of the most suitable implant placement (Norton and Gamble, 2001). The main disadvantage of CTs is the high irradiation dose the patient has to be exposed to. Other radiographic methods with lower irradiation burden are used (panoramic, periapical, cone beam CT) and Dual Energy X-ray Absorptionmetry (DEXA) having the lowest (irradiation dose of 1-10μSV equivalent to the average natural irradiation dose received by the human body (7μSV)). The accuracy of the measurements is affected by the fat content of the soft tissue and the discrimination between cortical and trabecular bone is not possible due to superimposition (Blake and Fogelman, 1977). DEXA is mainly used for evaluation of bone mineral density (BMD) of the lower spine and femoral neck. It is used for the clinical diagnosis of osteoporosis in women and in epidemiological studies for the assessment of fracture risk. In the stomatognathic area it is used only for research purposes and only in the mandible (Horner and Devlin, 1998).

Despite the wide range of bone density evaluation methods there is both clinical and research interest in the preoperative planning of implant placement, for a non-invasive, non-irradiating, non-destructive method that can be applied in both jaws. Hence, it is obvious that other more reliable methods are needed, which must be capable to assess bone structural integrity as well as the effect of therapeutic treatment in a non invasive manner.

Loss of structural integrity of an ageing component is usually due to fatigue, which in turn leads to initiation and propagation of starting failure points, and finally to structure failure. Methodology has been developed for the identification of change in structural integrity through

modal analysis and monitoring of modal damping factor. From our previous experimental work (Panteliou and Dimarogonas, 1997a,b - Panteliou and Dimarogonas, 2000, - Panteliou et all, 2001, - Panteliou et all, 2009) it was shown that internal damping factor is sensitive to fatigue and change in porosity. For better understanding of experimental results a model has been developed that quantifies the relation between changes in damping factor and porosity. This model, which includes analytic – arithmetic tool and dedicated measuring device, has been successfully applied on components made out of a variety of materials, conventional and advanced. One very successful application of the method was the assessment of bone structural integrity, for monitoring metabolic diseases of bones (i.e. osteoporosis) (Panteliou et all, 1999, - Panteliou et all, 2004, - Anastassopoulos et all, 2009 – Stavropoulou et all, 2005 – Christopoulou et all, 2006 – Anastassopoulos et all, 2010).

The target of this work is the development of a non invasive tool for the objective assessment of mandible bone quality (assessment of structural integrity). This technique is experimentally applied on cadaveric human mandibles. Besides, conventional DEXA measurements are performed on the same mandibles. The results from both methods were compared in order to evaluate the correlation between BMD and MDF and propose the modal damping as future assessment tool in the process of dental implants placement.

2. Materials and Methods

Ten cadaveric human mandibles, were used in order to acquire in vitro measurements of mandible quality with two methods: (1) BMD (Bone Mineral Density) with DEXA, and (2) Modal Damping Factor (MDF).

2.1 Measurement of Bone Mineral Density

Bone mineral density was measured by Dual-energy x-ray absorptiometry (DEXA), using a Norland XR-26 MARK II bone densitometer. Scans were acquired and processed with an ultra-high resolution software program (available from the manufacturer). The time required for a typical scan at each anatomic site was approximately 3 minutes.

2.2. Measurement of Damping

Modal Damping Factor is measured with designed and constructed dedicated device (Fig. 1). For its calculation half power bandwidth method is applied (Dimarogonas, 1992). The sensor used is an accelerometer of 1 gr. Its output signal is transferred through an A/D converter to a PC. The triggering is produced by computer controlled sound electronics and is applied through a metallic stem to the selected anatomic site of the mandible. Modal Damping Factor (MDF) (Dimarogonas, 1992) is extracted by applying FFT. Consecutive signals are acquired (approximately 25) at the same point of the mandible in order to ensure statistically sufficient population. MDF is the average of all measurements. The procedure is repeated for all selected points of the mandible (Fig. 2).
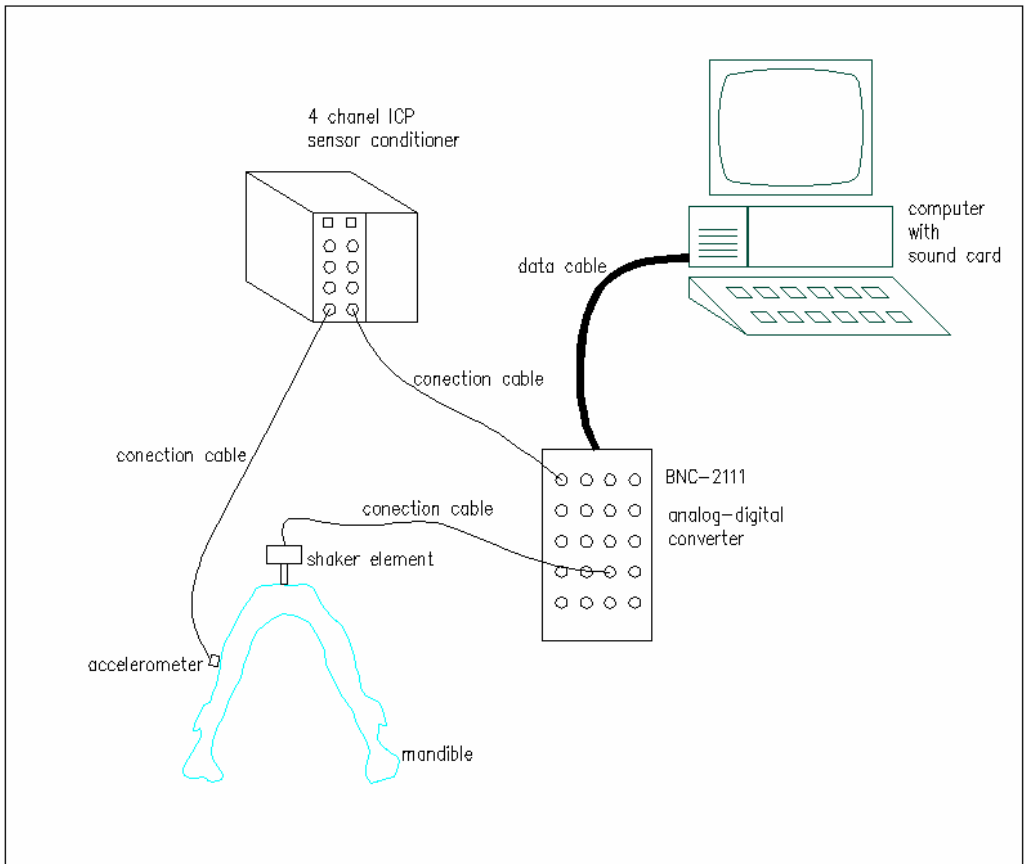
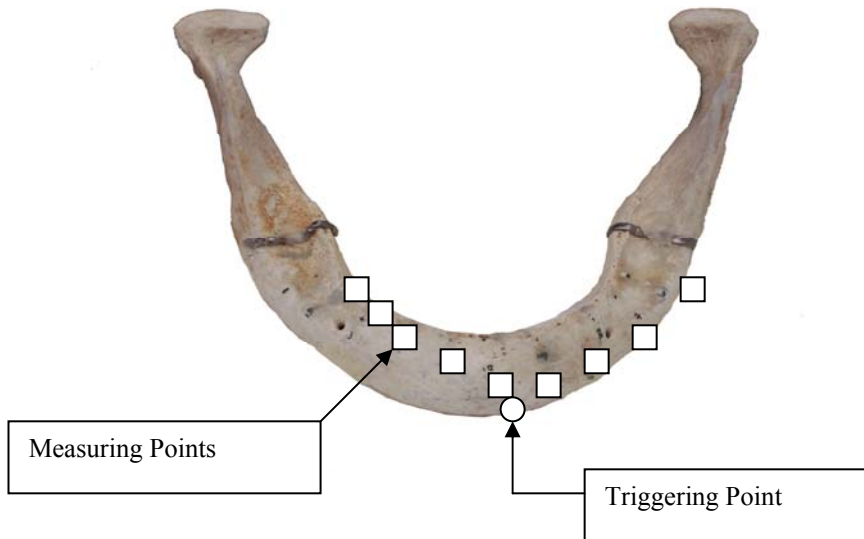**Figure 1.** Experimental device for measurement of damping.

Figure 2. Triggering and measuring points.

The average of all measured MDF and BMD data in relation to the anatomic site of measurement are presented in Fig. 3, while the correlation between MDF and BMD data is presented in Fig. 4.
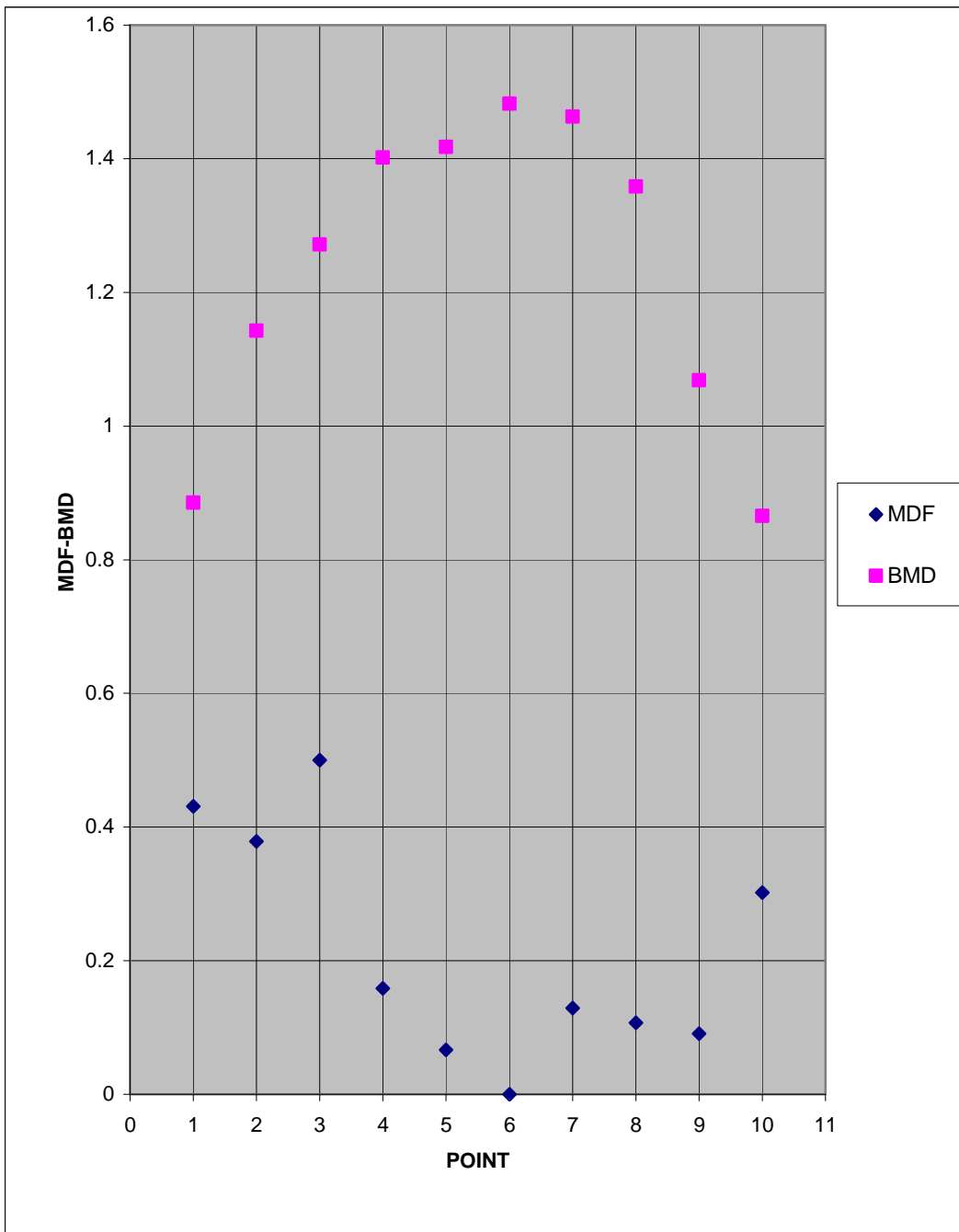
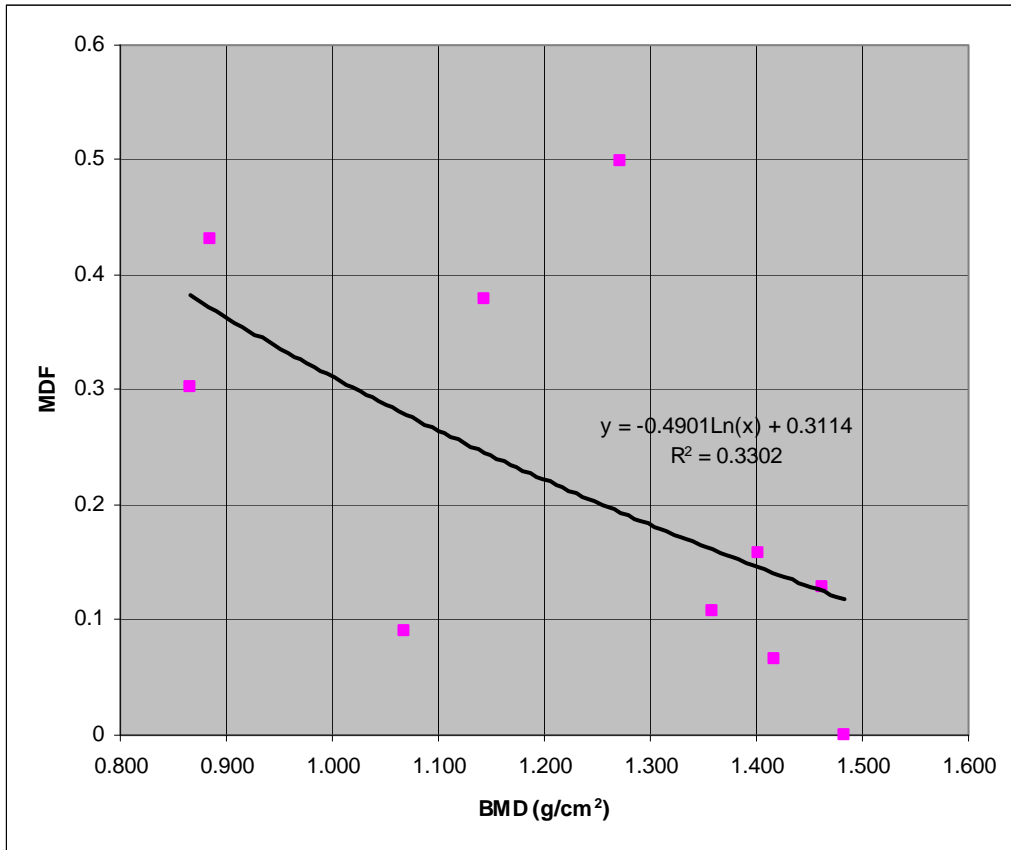**Figure 3.** Correlation between MDF, BMD and anatomic site for all mandibles.

Figure 4. Correlation between MDF and BMD for all mandibles.

3. Comments of results

In this work, bone density measurements (BMD) with DEXA method, as well as assessment of bone mandible structural integrity through measurement of Modal Damping Factor (MDF), were performed.

The average values of all MDF – BMD measurements in relation to the anatomic site of the mandibles are presented in Figure 3, while the correlation between all MDF - BMD average values for all mandibles tested is presented in Figure 4.

From both Fig. (3, 4), the expected, from our previous research findings (Panteliou et all, 1999 - Panteliou et all, 2004 – Anastassopoulos et all, 2009 – Stavropoulou et all, 2005 – Cristopoulou et all, 2006 – Anastassopoulos et all, 2010), correlation between MDF and BMD is revealed. Specifically, low BMD, which expresses reduced bone density and low bone quality, corresponds to high MDF, which in turn expresses deterioration of bone quality. At this point, let's note that MDF is material and system property and index of structural integrity, which takes values in the range (0-1), with higher values corresponding to low, and lower values corresponding to high quality of structure.

4. Conclusions

In our previous research works (Panteliou and Dimarogonas, 1997a,b - Panteliou and Dimarogonas, 2000, - Panteliou et all, 2001, - Panteliou et all, 2009 – Panteliou et all, 1999 - Panteliou et all, 2004 – Anastassopoulos et all, 2009 - Stavropoulou et all, 2005 – Cristopoulou et all, 2006 – Anastassopoulos et all, 2010), the application of the thermodynamic damping method as a tool for assessment of structural integrity for a variety of materials (conventional and advanced, i.e. composites) and geometries, has been elaborated. A specific application was on bones in order to create a bone quality assessment tool applicable for the monitoring of metabolic diseases of bones, especially osteoporosis. The comparison of measured data with MDF and all conventional methods (DEXA, pQCT, biochemical markers, histomorphometry, Raman Spectroscopy) gave very promising results, which constituted the basis for this initial experimental work, aiming to build an objective assessment tool of the quality of the human mandible that will help the decision making during dental implants placement.

The results of this work present a clear correlation in the expected direction. Specifically, MDF and BMD expand in an inverse manner. High BMD values, expressing high bone density, correspond to low MDF values, which in turn express improvement of bone structure and vice versa.

The results from the comparison of the measured data with the two methods constitute a promising basis, which reinforces our belief that we can build an assessment tool to be used in the process of placement of dental implants.

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