NON CONVENTIONAL METHODS FOR THE ASSESSMENT OF MANDIBLE BONE QUALITY

Malvina Orkoula
Dept. of Pharmacy, University of Patras, 265 00 Patras, Greece

Sofia Panteliou
Machine Design Laboratory, Dept. of Mechanical Engineering and Aeronautics
University of Patras, 265 00 Patras, Greece

Christos Kontoyannis
Dept. of Pharmacy, University of Patras, 265 00 Patras, Greece

Konstantinos Lianos
Machine Design Laboratory, Dept. of Mechanical Engineering and Aeronautics
University of Patras, 265 00 Patras, Greece

Keywords: Damping, Raman, Mandible, Bone Quality.

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

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 combinatio of anthropometric data and panoramic radiographs
3. Torque resistance measurements during implant insertion
4. X-ray absorption methods

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

Orkoula M., Panteliou S., Kontoyannis C. and Lianos K..
NON CONVENTIONAL METHODS FOR THE ASSESSMENT OF MANDIBLE BONE QUALITY.
DOI: 10.5220/0003157103530358
In *Proceedings of the International Conference on Biomedical Electronics and Devices* (BIODEVICES-2011), pages 353-358
ISBN: 978-989-8425-37-9

immediately before implant placement (3,75mm diameter).

The empiric method of Lekholm and Zarb (Branemark P.I., 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 P.O., 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 M.R., 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 measurements accuracy is affected by the fat content of the soft tissue and the discrimination between cortical and trabecular bone is impossible due to superimposition (Blake G.M., 1997). DEXA is mainly used for evaluation of bone mineral density (BMD) of the lower spine and femoral neck. It is used for osteoporosis clinical diagnosis and in epidemiological studies for assessment of fracture risk. In the stomatognathic area it is used only for research purposes and only in the mandible (Horner K., 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. Hence, it is obvious that other more reliable methods are needed, capable to assess bone structural integrity and 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 changes identification e in structural integrity through modal analysis and monitoring of modal damping factor (MDF). From our previous experimental work (Panteliou S.D., 1997a, 1997b, 2000, 2001, 2010) it was shown that damping factor is sensitive to fatigue and change in porosity. For better understanding of experimental results, model has been developed quantifying the relation between changes in damping and porosity. This model, including 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 S.D., 1999, 2004, Anastassopoulos G., 2010, A. Stavropoulou A., 2005, Christopoulou G.E., 2006).

Raman spectroscopy is a recently developed tool for bone chemical quality assessment. A bone Raman spectrum contains information on collagen and bioapatite vibrations, thus chemical analysis of its major constituents can be obtained. Most of available techniques e.g. DEXA, yield information on the mineral content but with Raman additional information is harvested for organic matrix as well, which is also considered important, as, though mineral gives bone hardness, collagen contributes to its elasticity. Raman has been applied on bone samples for various purposes such as evaluation of osteoradionecrosis resulting from radiation therapy (Lakshmi R., 2003), establishment of bone apatite (BAP)/matrix (MTX) ratio (Chen T., 2002, Kosloff K., 2004), assessment of influence of bone tissue specimen preparation, mineralization and biomechanical studies as described by Morris-Finney (Morris M, 2004). Recently, some attempts were made to non-invasively record bones Raman signal (through the skin) but no quantitative results were obtained yet (Eliasson C, 2007, Schulmerich MV., 2009).

The target of this work is the development of non invasive tools, based on MDF and Raman, for objective assessment of mandible bone quality (assessment of structural integrity and chemical quality). The techniques were experimentally applied on cadaveric human mandibles. Besides, conventional DEXA measurements were performed on the same mandibles. The results from the comparison of the measured data with the three methods constitute a promising basis, which reinforces our belief that we can build assessment tools for use in the process of dental implants placement.

2 EXPERIMENTAL WORK

Ten cadaveric human mandibles of random age were used to acquire in-vitro measurements of mandible quality with three methods: Modal Damping Factor (MDF), BMD (Bone Mineral Density) with DEXA and Raman Spectroscopy (RAMAN).

2.1 Modal Damping Factor

Modal Damping Factor is measured with designed and constructed dedicated device (Figure 1). Thorough description of device principle can be found in (Panteliou S.D., 2004).

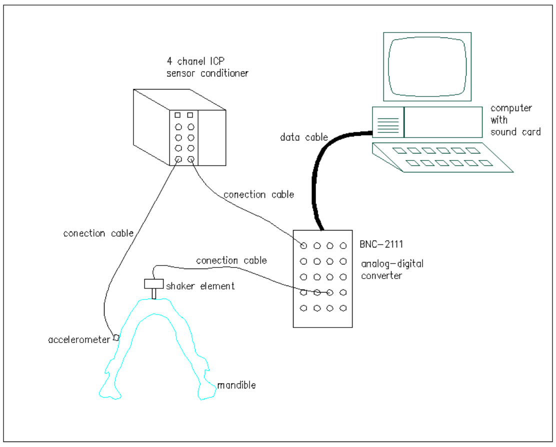

Figure 1: Experimental device for damping measurement.

For MDF calculation half power bandwidth method is applied (Dimarogonas A.D., 1992). The sensor used is a PCB accelerometer of 1 gr. Its output signal is transferred through an A/D converter to a PC. Triggering is produced by computer controlled sound electronics and is applied through a metallic stem to the selected mandible anatomic site. MDF is extracted by Fast Fourier Transform (FFT) analysis of time response data (Dimarogonas A.D., 1992). Ten points are selected on each mandible (Figure 2). Mandible mid-span is selected for triggering. The output sensor (accelerometer) is placed consecutively on the other points. MDF values (approximately 25) are acquired at each mandible point to ensure statistically sufficient population. MDF of each point occurs as average of all 25 measurements. The procedure is repeated for all points of all mandibles. From these data an overall average MDF value is extracted corresponding to each anatomic point selected.

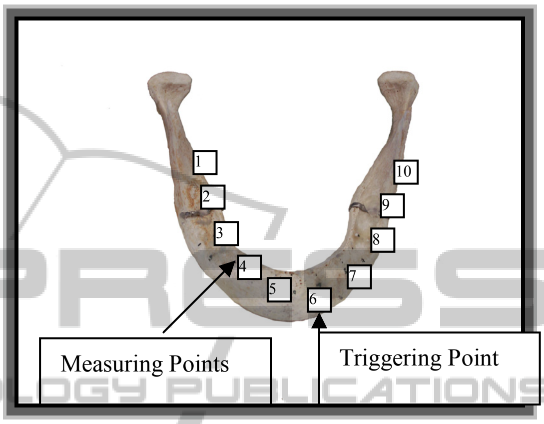

Figure 2: Triggering and measuring points.

2.2 Bone Mineral Density

Bone mineral density is measured according to standard protocol by Dual-energy x-ray absorptiometry (DEXA), using Norland XR-26 MARK-II bone densitometer. Scans are acquired and processed with ultra-high resolution software (from manufacturer). Anatomic regions examined are the same as above mandible points (Figure 2). Time required for typical scan at each point approximately 3 minutes.

Overall average of measured MDF-BMD in relation to anatomic site of measurement are presented in Figure 3, while the correlation between MDF and BMD is presented in Figure 4.

2.3 Raman Spectroscopy

Raman spectra is recorded using a FRA-106/S FT-Raman (Bruker, Karlsruhe, Germany) with the following characteristics: Laser excitation line used is the 1064nm of a Nd:YAG laser. Reference source (He-Ne laser) is used to measure the instrumental response and check the interferometer. Filters are used to remove the Rayleigh line and the optical output of the He-Ne laser.

Scattered light is collected at an angle of 180° (back-scattering). The system is equipped with a LN_2 cooled Ge detector (D 418). The power of

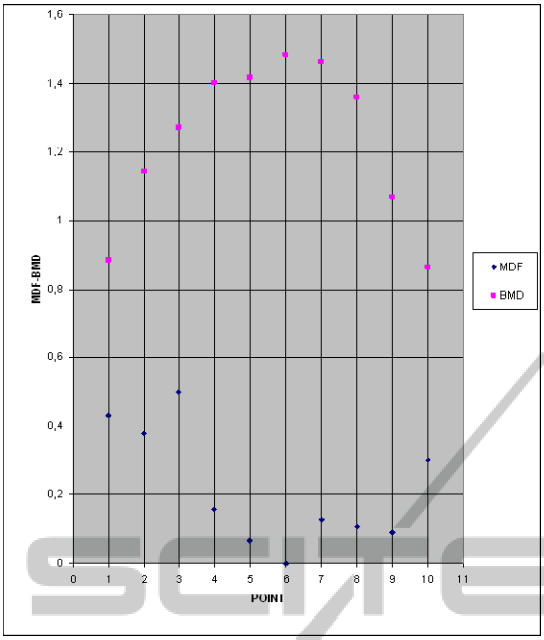

Figure 3: Correlation of MDF-BMD with anatomic site for all mandibles.

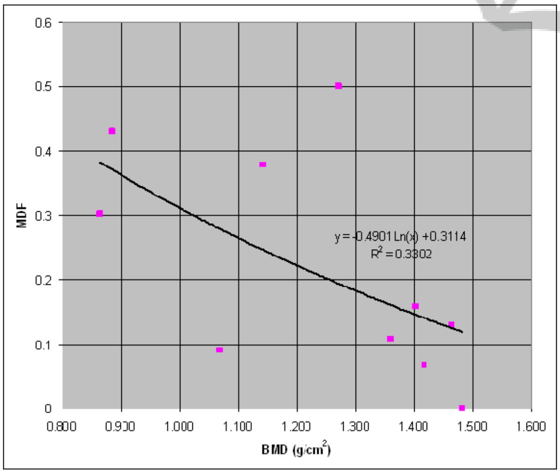

Figure 4: Correlation MDF-BMD for all mandibles.

incident laser beam is about 150 mW on sample's surface. Typical spectral width is 2 cm^{-1}. The system is interfaced with computer. Laser beam spot size on sample is 100 μm^2. An X-Y-Z motor (Bruker, Karlsruhe, Germany) is used for sample "mapping".

Raman spectra are obtained from the same as above mandibles points (Figure 2). Raman spectrum taken on a random spot of a mandible bone is shown in Figure 5. It contains all characteristic bands of its constituents corresponding to their vibrations. For the analysis, peaks at 960 and 1600 cm^{-1}, for biological apatite and collagen respectively, are used.

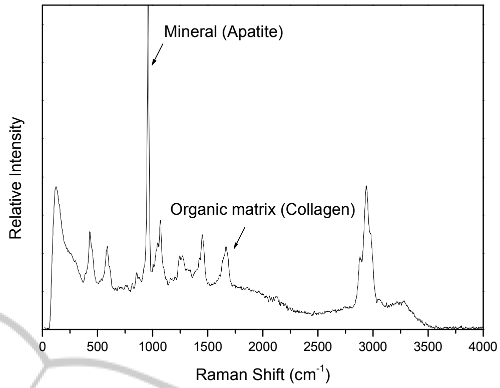

Figure 5: Raman spectrum of mandible bones. Characteristic bands of mineral (960 cm^{-1}) and organic matrix (1600 cm^{-1}) used in analysis are indicated.

Average areas under the 960/cm peak of all mandibles for each measurement point are shown in Fig. 6.

Respective average Raman signals for collagen (areas under the 1600cm^{-1} peak) for all measuring spots are plotted in Fig. 7.

3 DISCUSSION

Bone density measurements (BMD) with DEXA method, as well as assessment of bone mandible structural integrity through measurement of Modal Damping Factor (MDF), and Raman Spectroscopy (Raman) were performed.

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

From both Figures (3, 4), the expected, from our previous research findings (Panteliou S.D., 1999, 2004, Anastassopoulos G., 2010, A. Stavropoulou A., 2005, Christopoulou G.E., 2006), correlation between MDF and BMD is revealed. Specifically, low BMD, expressing reduced bone density and low bone quality, corresponds to high MDF, which in turn expresses bone quality deterioration.

At this point, let's note that MDF is material and system property and index of structural integrity, which takes dimensionless values between (0-1), with higher values corresponding to low and lower values corresponding to high structure quality.

Besides, MDF method has the following

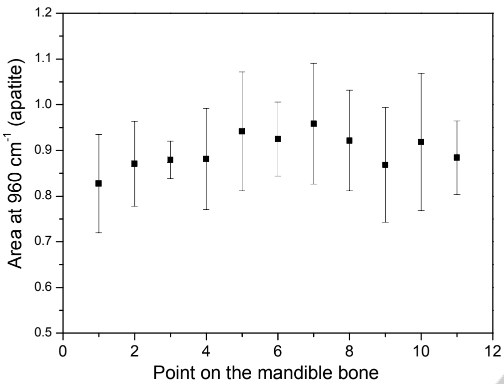

Figure 6: Average Raman signal (area) for mineral part alongside mandible bones.

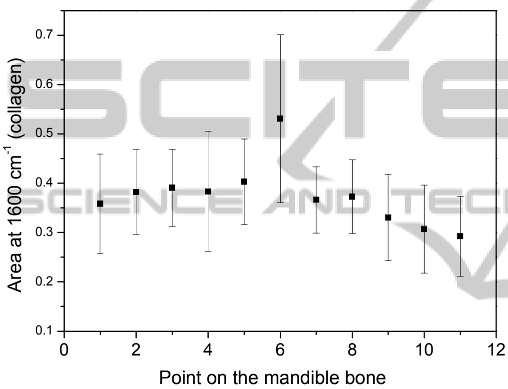

Figure 7: Average Raman signal (area) for organic matrix (collagen) alongside mandible bones.

advantages in comparison to conventional methods for in-vivo and in-vitro bone quality assessment: non-invasive, paneless, short duration, low cost, easy use, portable, more sensitive than all conventional methods (Anastassopoulos G., 2010), objective, data can be tele-transfered for diagnosis of patients in remote areas. In fact, MDF identifies changes in bone structure. Thus, external factors (i.e. soft tissues etc.) do not affect MDF measurements because, once an initial MDF value is obtained, it's subtraction from any other expresses change only in bone density, given that all external factors remain unchanged.

From apatite Raman vibration (Figure 6) it can be seen that the middle part (foreground) exhibits increased apatite signal compared to the sides. This is ascribed to corresponding increased mineral amount in this specific area which is in absolute accordance with BMD measurements (Figure 3). The same trend is recorded in Fig. 7 from collagen vibrations i.e. there is substantial increase for mandible bone foreground part. Matrix content (Figure 7) is consistent with mineral variations (Figure 6) leaving mineral to matrix ratio constant along the mandible. This ratio is a crucial parameter because it is indicative of bone quality status. Ratio disorders conclude to severe pathological conditions (osteoporosis, osteopetrosis, osteogenesis imperfecta etc.). Information on collagen is exclusively harvested by Raman Spectroscopy as none conventional technique (DEXA) refers in any way to collagen. Raman Spectroscopy complements MDF testing, analyzing its chemical constituents in molecular level. Results actually surpass BMD, as they are more accurate in mineral analysis and probe organic matrix.

4 CONCLUSIONS

In our previous research works (Panteliou S.D., 1997a, 1997b, 1999, 2000, 2001, 2004, 2010, Anastassopoulos G., 2010, A. Stavropoulou A., 2005, Christopoulou G.E., 2006) the application of the 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. Specific application was on bones in order to create a bone quality assessment tool applicable for monitoring of metabolic bone diseases, especially osteoporosis. Comparison of measured data with MDF and all conventional methods (DEXA, pQCT, biochemical markers, histomorphometry, Raman Spectroscopy) gave very promising results, and constituted the basis for this initial experimental work, aiming to build an objective assessment tool of human mandible quality 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 as well as Raman data expand in an inverse manner. High BMD values, expressing high bone density, and high Raman intensities indicating more mineral and organic material correspond to low MDF values, which in turn express improvement of bone structure and vice versa. Hence, this work reinforces the belief that MDF can be advanced to a valuable assessment tool for mandible bone quality.

REFERENCES

Anastassopoulos G., Panteliou S. D., Christopoulou G. E., Stavropoulou A., Panagiotopoulos E., Lyritis G., Khaldi L, Varakis J., 2010, Vibrational Bone

Characteristics vs Bone Density in Assessing Osteoporosis in ovariectomized rats, *Journal of Medical Engineering & Technology*, 34(01), pp. 35-42, DOI: 10.3109/03091900903324056.

Blake G. M., Fogelman I., 1997, Technical principles of dual energy X-ray absorptionmetry, *Semin Nucl Med*, 27:210-228.

Branemark P. I, Zarb G. A, Albrektsson T., 1985, *Tissue Integrated Prostheses*, Quintessence Publishing Co., Inc..

Chen T., Shea D., Morris M., 2002, Effect of hydrogen peroxide bleaching on bone mineral/matrix, *Applied Spectroscopy*, 56, pp. 1035-1037.

Christopoulou G. E., Stavropoulou A., Anastassopoulos G., Panteliou S. D., Papadaki E., Karamanos N. K, Panagiotopoulos E., 2006, Evaluation of modal damping factor as a diagnostic tool for osteoporosis and its relation with serum osteocalcin and collagen I N-telopeptide for monitoring the efficacy of aledronate in ovariectomized rats, *Journal of Pharmaceutical and Biomedical Analysis*, 41, pp. 891-897.

Eliasson, C, Matousek P., 2007, A Noninvasive method for deep Raman Spectroscopy of living tissue and powders *American Laboratory,* 39, pp. 42.

Horner K., Devlin H., 1998, The relationship between two indices of mandibular quality and bone mineral density measured by dual energy X-ray absorptionmetry, *Dentomaxillofac Radiol*, 27:17-21.

Kosloff K., Carden A., Bergwitz C., Forlino A., Uveges T., Morris M., Marini J., Goldstein S., 2004, *J. Bone Miner Res* 19, pp. 614.

Lakshmi R., Alexander M., Kurien J., Mahato K., Kartha V., 2003, *Applied Spectroscopy,* 57, pp. 1100.

Molly L. 2006, Bone Density and Primary Stability in Implant Therapy. Clin Oral Impl Res, 17:214-135).

Morris M. and Finney W., 2004, Recent developments in Raman and infrared spectroscopy and imaging of bone tissue *Spectrosc-Int. J.* 18, pp. 155-159 and references therein.

Norton M. R., Gamble C., 2001, Bone classification: an objective scale of bone density using the computerized tomography scan, *Clin Oral Impl Res*, 12:79-84.

Ostman P. O., Hellman M., Sennerby L., 2005, Direct implant loading in the edentulous maxilla using a bone density-adapted surgical protocol and primary implant stability criteria for inclusion. Clin Impl Dent Relat Res, 7(supp I):S60-S69).

Panteliou S. D., Dimarogonas A. D., 1997a, Thermodynamic Damping in Porous Materials with Ellipsoidal Cavities, *Journal of Sound and Vibration*, 201(5), 555-565.

Panteliou S. D., Dimarogonas A. D., 1997b, Thermodynamic Damping in Porous Materials with Spherical Cavities, *Journal of Shock and Vibration*, Vol. 4, No. 4, pp. 261-268.

Panteliou S. D., Abbasi-Jahromi Hassan, Dimarogonas A. D., Kohrt W., Civitelli R, 1999, Low-Frequency Acoustic Sweep of Bone Integrity and Osteoporosis, *Journal of Biomechanical Engineering*, Aug. 99, Vol. 121, pp. 423-431.

Panteliou S. D., Dimarogonas A. D. 2000, Damping Factor Associated with Porosity and Crack in Solid, *Theoretical and Applied Fracture Mechanics*, 34 217-223.

Panteliou S. D., Chondros T. G., Argyrakis V. C, Dimarogonas A. D., 2001, Damping Factor as an Indicator of Crack Severity, *Journal of Sound and Vibration*, 235-245, 241(2).

Panteliou S. D., Xirafaki A. L., Panagiotopoulos E, Varakis J., Vagenas N. V., Kontoyannis C. G., 2004, Modal Damping for Monitoring Bone Integrity and Osteoporosis", *Journal of Biomechanical Engineering*, Vol. 126, pp. 1-5.

Panteliou S. D., Zonios K., Chondrou I. T., Fernandes H. R., Agathopoulos S., Ferreira J. M. F., 2010, Damping Factor Associated with Porosity in Alumina, *International Journal of Mechanics and Materials in Design*, 5:167-174, DOI 10.1007/s10999-008-9092-0.

Schulmerich M. V., Cole J. H., Kreider J. M., Esmonde-White F., Dooley K. A., Golstein S. A., Morris M. D., 2009, Transcutaneous Raman Spectroscopy of Murine Bone In Vivo *Applied Spectroscopy* 63, pp 286-295.

Stavropoulou A., Christopoulou G. E., Anastassopoulos G., Panteliou S. D., Lyritis G. P., Spiliotis B. E., Karamanos N. K., Panagiotopoulos E., Lambiris E., 2005, Alteration in serum leptin correlates with alterations in serum N-telopeptide of collagen type I and serum osteocalcin during the progression of osteoporosis in ovariectomized rats, *Clinical Chemical Laboratory Methods*, 43(12): 1359-1365.