The development of a composite bone model for training on placement of dental implants

Mohamed Ahmed Alkhodary, BDS, MS, PhD, (1) Abdelraheim Emad Eldin Abdelraheim, PhD, (2)
Abd Elaleem Hassan Elsantawy, BDS, MS, (3) Yousef Hamad Al Dahman, BDS, (4) Mohammed Al-Mershed, BDS (4)

Assistant Professor, Department of Prosthetic Dental Science, College of Dentistry, Qassim University, KSA. (1)
Lecturer of Removable Prosthodontics, Faculty of Dentistry, Alexandria University, EGYPT. (1)
Associate Professor, Mechanical Engineering Dept., College of Engineering, Qassim University (2)
Lecturer, Department of Maxillofacial Surgery & Diagnostic Sciences, College of Dentistry, Qassim University (3)
College of Dentistry, Qassim University (4)

Abstract

Objectives: It takes a lot of training on patients for both undergraduate to develop clinical sense as regards to the placement of dental implants in the jaw bones, also, the models provided by the dental implant companies for training are usually made of strengthened synthetic foams, which are far from the composition, and tactile sense provided by natural bone during drilling for clinical placement of dental implants.

Methodology: This is an in-vitro experimental study which utilized bovine femur bone, where the shaft of the femur provided the surface compact layer, and the head provided the cancellous bone layer, to provide a training model similar to jaw bones macroscopic anatomy. Both the compact and cancellous bone samples were characterized using mechanical compressive testing.

Results: The elastic moduli of the cancellous and cortical femur bone were comparable to those of the human mandible, and the prepared training model provided a more lifelike condition during the drilling and placement of dental implants.

Conclusion: The composite bone model developed simulated the macroscopic anatomy of the jaw bones having a surface layer of compact bone, and a core of cancellous bone, and provided a better and a more natural hands-on experience for placement of dental implants as compared to plastic models made of polyurethane.

Keywords: dental implants, bovine bone, mechanical characterization.

Correspondence:

Mohamed A. Alkhodary, BDS, MS, PhD
Head of the Faculty Development Unit,
Assistant Professor of Prosthetic Dental Science,
Board Member, Dental Research Center,
College of Dentistry, Al Qassim University, KSA.
Lecturer, Faculty of dentistry, Alexandria University, EGYPT.
Visiting Graduate Fellow, MAE dept, Princeton University, USA.
Phone: 00966 538950814
Email: dr.mohamed.alkhodary@qudent.org

Introduction

On the academic level, education in implant dentistry was initially found in postgraduate programs, however, it is now taught in most academic undergraduate programs at a basic level within the courses of prosthodontics, periodontics and oral surgery. (1-5) Predictable surgical outcomes are achievable for implants placed by undergraduate trainee students in an adequately structured and conducted multidisciplinary implant training program. The students use heads of sheep or plastic jaws made of polyurethane for training on placement of dental implants. (6,7) Polyurethane allows the building of training models with the desired characteristics of isotropy and modulus of elasticity compatible to that reported in the literature for the human jaw bones. Other models were made using artificial bone made of glass fiber reinforced composite and structural foam. The cross section dimensions of these artificial bones are for a typical mandible. (8, 9)

However, studies using these artificial models do not consider the following facts: (1) variations in material properties for the cancellous core and the overlying cortical bone as regards to the patterns of direction of maximum stiffness, (2) the differences in relative strain magnitudes experienced between the alveolar process and inferior border of the mandibular corpus, (3) the differences in mandibular cortical thickness between the facial and lingual cortices, which decreases from 3.7 mm anteriorly to 1.4 mm posteriorly, (10-12) and finally (4) the differences state of dentulous and edentulous mandibles, where elastic moduli were different among sites on each cortex and between directions due to altered patterns of regional loading and deformation. (13- 15)

Understanding of these differences renders the polyurethane a poor model when it comes to both the tactile sensation experienced during drilling for implant placement and the need for three dimensional simulations of true bone conditions. (13) Hence the need arises to develop models made of true bone material.

In humans, the mandible is the most isotropic bone in the human body, and the tibia falls on the other side being the most anisotropic. For Bovine bones, the most isotropic one is the Femur bone. (15-21)

Based on the presented data, a bone composite model made up of two layers, a compact surface shell and a cancellous bone core, with similar dimensions to those found in the human mandible anterior region will be developed and characterized mechanically to determine its suitability as a training model.

Materials and methods

The study utilized 6 bovine femur bone to develop a two layered model where the shaft of the femur provided the surface compact one layer (1.5 mm thick, and 20 mm long by 20 mm width), and the head of the femur provided the cancellous bone layer (15 mm thick, and 20 mm long by 20 mm width), then the two layers were assembled to each other using a cyanoacrylate layer that is almost 0.1 mm or less in thickness to provide the training model.

Measuring bone mechanical property

Mechanical testing procedures:

Before cutting the bone to the desired dimensions of the training model, the bone specimens were cut into large pieces using manual and electrical cutting instruments in the form of saws and sand papers in the presence of water cooling (Fig. 1), then a Universal mechanical testing machine was used to apply compressive static loading on the cortical and cancellous bone layers until complete failure of the sample.

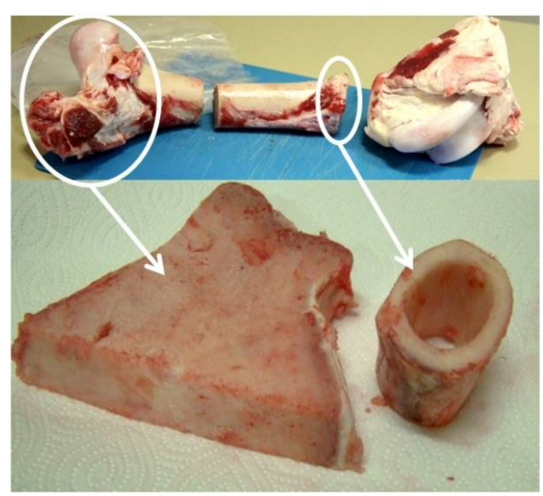

Figure (1): retrieving samples from the bovine femur bone

Pre-test sample preparation:

The retrieved femur bone samples were washed, cleaned and machined to small pieces to fit with the testing machine. The samples were measured from all sides and directions and document by photos and labels. Finally, the samples were marked from the side (direction) of the force application. The samples were preserved with freezing and before conducting the compressive testing, they were allowed to undergo thawing. [22]

Test procedures and after test calculations:

The parallel compression plates of the material tester (WP300 compression manufactured by GUNT) [23] were used to load the samples in vertical direction:

Measuring the cortical bone samples:

The cortical bone sample given in Figures (2) is a hollow shell; accordingly the projected area had to be calculated. The Y and X axes are located in the horizontal plane and the z axis is perpendicular to them. The height of the sample in the Z direction is 27 mm. This specimen was compressed in the (-Z) direction (Fig. 3) until a crack was heard (Fig.4).

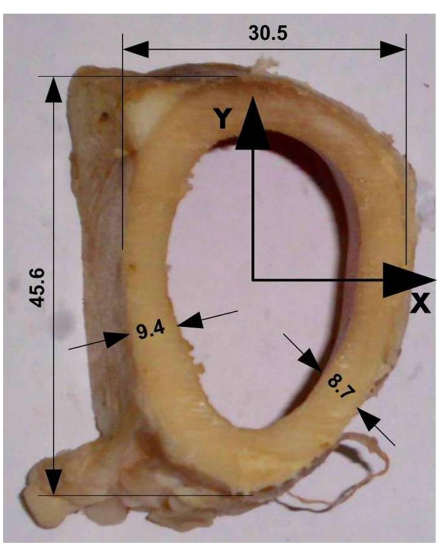

Figure (2) the cortical bone-sample dimensions and axes.

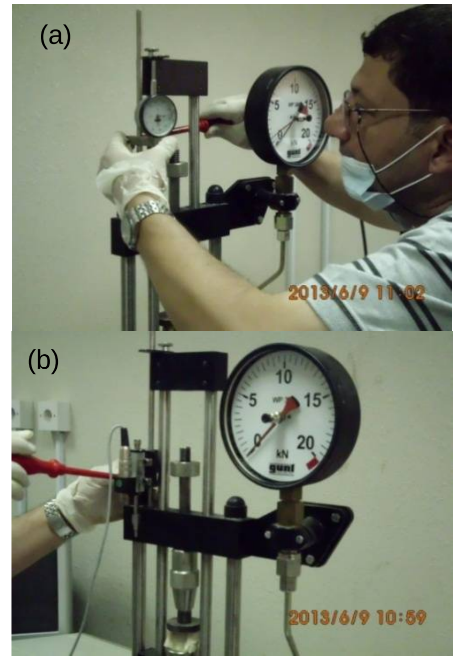

Figure (3): Adjusting the tester: (a) Preparation. (b) installing the deformation gauge

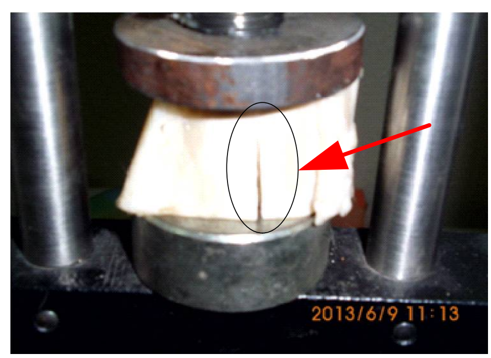

Figure (4): The fracture

Measuring the sponge bone samples:

A very careful approach was followed during cancellous bone sample preparation to maintain the direction of maximum stiffness of each sample, and ensure that the samples were made entirely of sponge bone; the epiphyseal region of the head of the femur was excluded. The directions of force trajectories are very well known for the head of the femur [24] (Fig.5a), and these were plotted on each original cut together with the X, and Y axes that were located in the horizontal plane and the Z axis that was perpendicular to them. The axes were carefully labeled on each of the test samples retrieved from the original cuts.

The original cut is given in Fig. (5b). this sample had been machined to create smaller piece as shown in figure (5c). It is necessary to correlate the X and Y axes in the figure (5a) and (5b). This sample was cut to provide two manufactured sponge bone samples (1 and 2) are shown in figure (5c). Figure (6) shows schematic drawing of the two samples (1 and 2). The figures show the same X and Y axes and the direction of compression. The projected area was also calculated and the samples were compressed until failure.

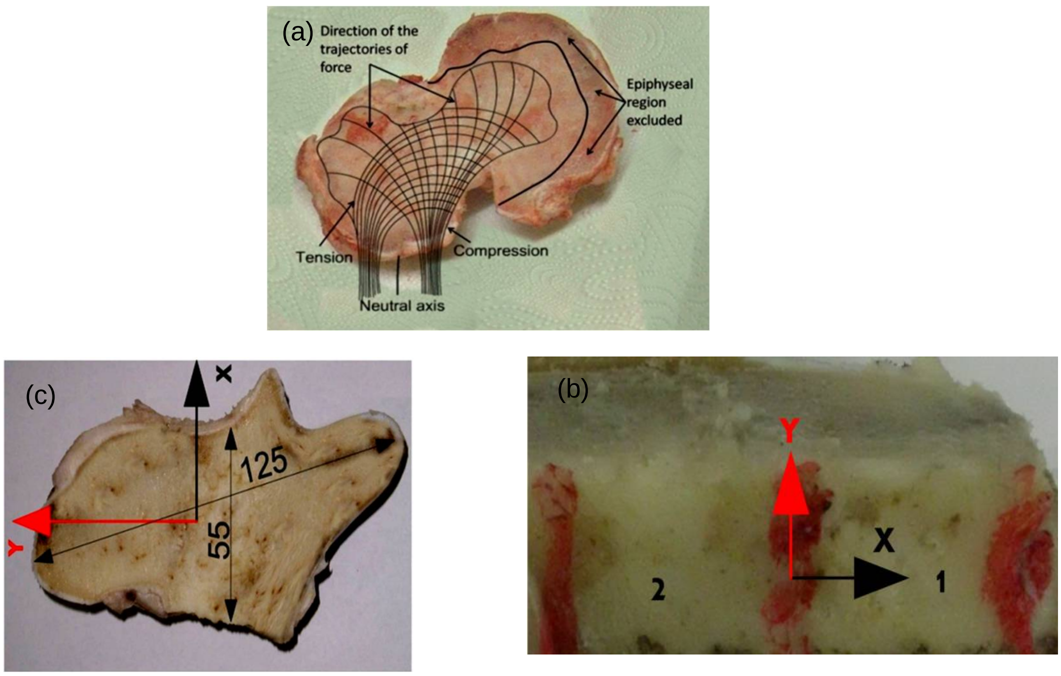

Figure (5) Cancellous bone sample preparation: (a) Directions of the trajectories of force in compression and tension were plotted on each sample to help orient the axes, (b) The sponge bone sample: main dimensions in millimeter and axes. (c) The manufactured sponge-samples and axes.

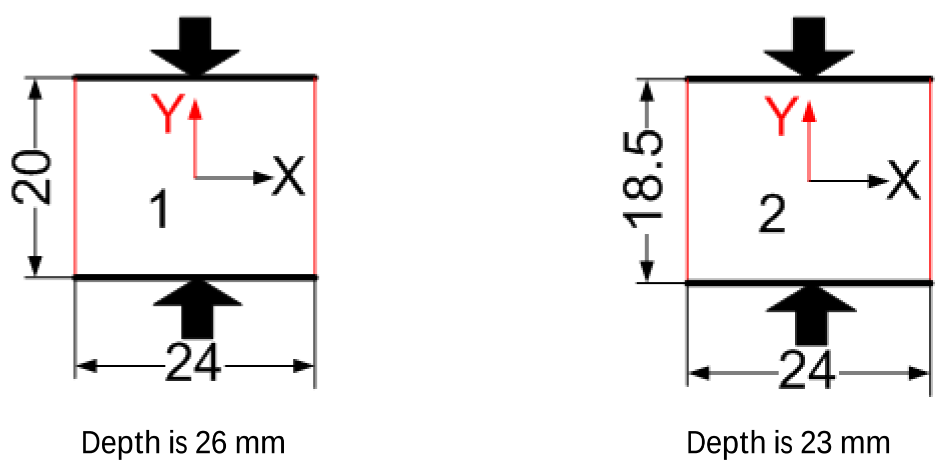

Figure (6): Schematic drawing of the two samples (1 and 2)

Training model preparation:

The bovine femur bone shaft provided the surface compact one layer (1.5 mm thick, and 20 mm long by 20 mm width), and the head of the femur provided the cancellous bone layer (15 mm thick, and 20 mm long by 20 mm width), then the two layers were assembled to each other using a cyanoacrylate layer that is almost 0.1 mm or less in thickness. (Figure 7)

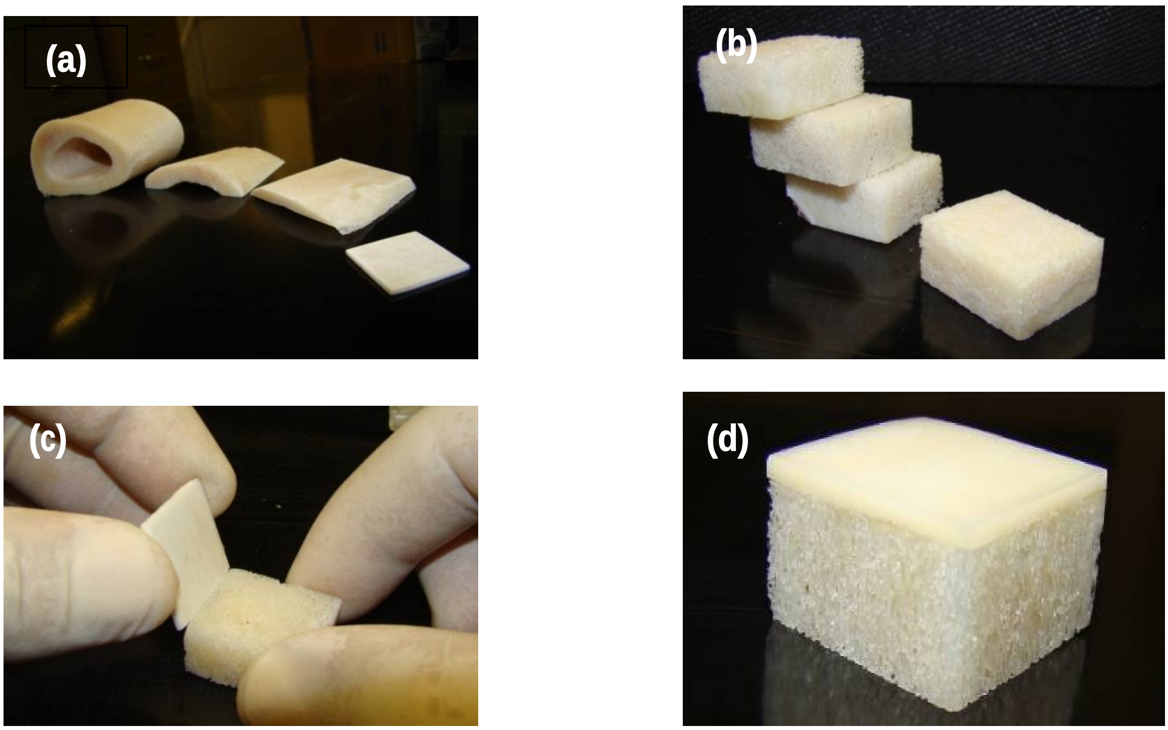

Fig (7): preparation of the training model: (a) the cortical bone and the prepared surface layer, (b) the prepared cancellous bone blocks, (c) assembly of the composite bone model after application of the adhesive to the surfaces of the bone layers, (d) the final composite bone model ready for use after setting of the adhesive.

Results:

Measuring bone mechanical property

Figure (8) represents the stress-strain diagram for the some cortical and cancellous bone samples. The stress and strain were calculated according to the following equations.

$$= \frac{F}{A}$$

$$\epsilon = \left|\frac{\delta L}{L}\right|$$

Where F is the applied compression force in [Newton], A is the mean projected area in [m^2], □ is the stress in [Pascal], L is the original mean specimen length [mm], □L is the compression deflection in [mm] and □ is the strain.

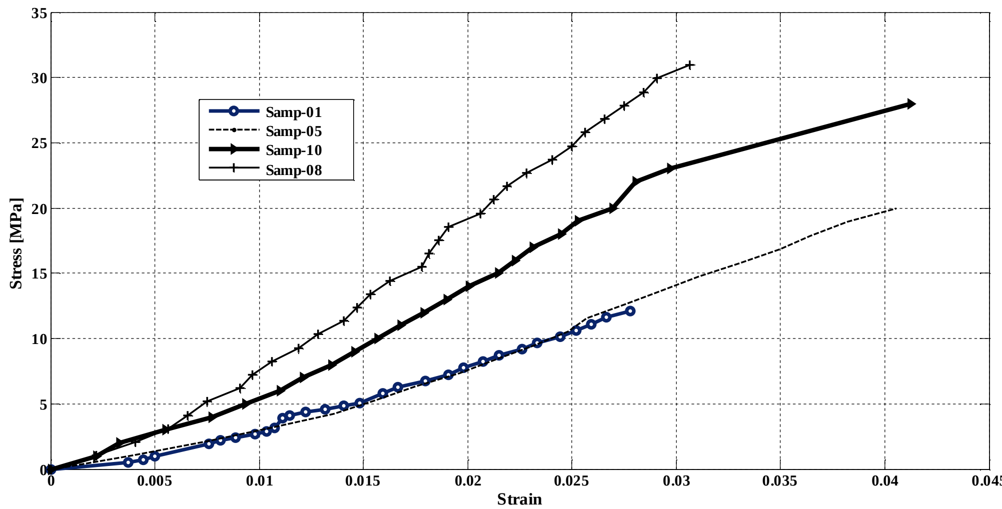

Fig. (8): The stress strain diagram for several samples

Tens of samples were tested to study the bone stress-strain behavior. The samples were obtained from different animals with different ages and sex. Some of these samples were selected to be displayed here in Fig. 9 and table 1. The stress-strain behavior showed that all the selected samples (for display) are quite brittle with different percentages. Results of several samples were excluded because of the divergence of their results. The divergence may be attributed to technical errors during the test, the animal age, sex and/or faulty preparation and storage techniques. However, the results, in Fig. 9, show the envelope of stress-strain behavior for most of the samples. The values of the fracture compression force, the modulus of elasticity and the ultimate stress (the yield stress) of the most consistent samples may be tabulated (table 1) as follows:-

Table 1: the fracture compression force, the modulus of elasticity and the ultimate stress (the yield stress) of some cortical and cancellous bone samples.

Sample ID	type	projected area mm^2	On set of fracture			
			Force [KN]	Stress [MPa]	strain	E [MPa]
Samp-02-01	Sponge	624	1.75	2.88	0.788	3.65
Samp-02-02	Sponge	552	0.75	1.358	0.011	123
Samp-03	Sponge	4620	2	0.4	0.0236	16.94
Samp-04-01	Sponge	682	2	2.93	0.088	33.29
Samp-05	Compact	475.45	9.5	19.98	0.0405	493.33
Samp-06	Compact	362.5	5.5	15.17	0.036	421.38
Samp-08	Compact	484.7	15	30.9	0.0306	1009.8
Samp-09	Compact	427.4	19.5	45.6	0.0351	1299.4
Samp-10	Compact	500.1	14	27.9	0.0412	677.18

Training model use:

After measurement of the bone mechanical properties and preparation of the training model, it was used for trial drilling (Figure 9), and the following was observed as compared to drilling in the Polyurethane plastic model while using the same drilling speed:

1. A better tactile experience during drilling was felt,
2. The transition from the cortical bone layer to the cancellous bone was felt during drilling as a sudden drop,
3. A water coolant was urgent to use otherwise a smell of bone burn was observed.

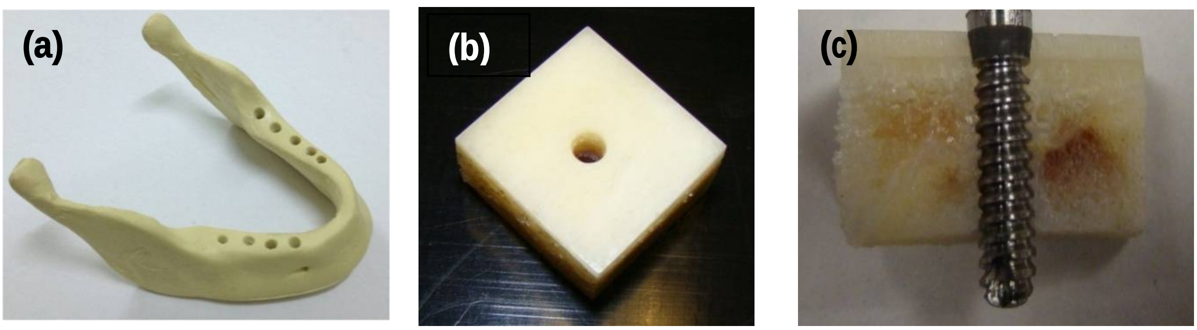

Fig. (9): drilling into the training models: (a) osteotomies drilled in the plastic polyurethane model, (b) osteotomy drilled in the composite bone model developed in this study, (c) cross section of the composite bone model with a dental implant model reinserted after cutting the bone model into two halves.

Discussion

High proportion of implant technical failures are due to errors in treatment planning or surgical technique can be explained by the low experience levels of the surgical trainees ascompared to experienced surgeons. [25] Plastic jaws, wood, and heads of animals like sheep and several other materials are used for training on placement of dental implants. However, none of these materials provide the same tactile sensation of surgical drilling in human jaws.

Study results could not be considered reliable unless validation of the model is conducted based on its modulus of elasticity to simulate the performance of human bone *invivo* in biomechanical studies of implant-supported prostheses. The modulus of elasticity of the mandibular bone may be affected by tooth loss and the resorption of the alveolar process, and its values varied from 47 to 2283 MPa in the different regions evaluated. These data are in accordance with those obtained with polyurethane by Neto et al [8] and with those of our study.

However, using ex-vivo animal tissues for the development of a specific test model with a determined hierarchy and properties for training on the drilling procedures provided a closer condition to the clinical situation and is thought to minimize the possibility of iatrogenic errors of inexperienced clinicians. Furthermore, the use of natural bone can permit conducting other characterization tests such as the determination of bone temperature during drilling with subsequent histological analysis of the results, the use of fracture mechanics to study micro-crack formation during the insertion of dental implants, and the use of strain gages to measure surface strains due to the dental implant insertion.

Finally, the time and effort of preparing the natural bone model must be weighed versus the ease of obtaining the readily available plastic jaws or animal heads that are far away from representing real bone conditions.

Summary, Conclusions and Future Work Recommendations

Summary

Compression and hysteresis analysis of animal bones were performed. The tests were carried out by the use of the material tester WP300 compression manufactured by GUNT. Several samples were utilized from different locations and with different structures. Cortical, sponge types were utilized for this purpose. Some tests are recorded as fail. Some others showed consistency and few shows inconsistency. However, only the results of consist samples were considered.

The main objective of this study was not to compare the performance of the bone model versus the polyurethane rather than to develop and characterize the model itself. The training model developed from bovine femur cortical and cancellous bone simulated the macroscopic anatomy of the mandible and provided more lifelike conditions during the drilling and insertion of dental implant models as compared to plastic jaws made up of polyurethane.

Conclusions

The experimental results may yield to the following conclusions.

1- For the cortical bone type: it is quit brittle material with a mean ultimate stress of 22.75 MPa and with modulus of elasticity of 654MPa.
2- For the cortical bone type: the energy absorbed during one loading-unloading cycle is about 40% of the paid energy.
3- For the cortical bone type: the mean hardness HB=30.
4- For the cortical bone type: it is a ductile material with a mean ultimate stress of 2.4MPa and the mean hardness HB=82.

Recommendations for future work

Increases in the number of patients receiving dental implants as part of overall treatment plans indicates that further research into implant training is required to enhance patient outcomes and quality assurance.

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Conflict of Interest

Authors state that no conflicts **of Interest** exist.

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