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ORIGINAL RESEARCH

Implant Insertion Torque Load Analysis for Mandible using CBCT Images

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ABSTRACT

Introduction: Osteoporotic patients require particular attention to their implant site bone quality as an indication of prognosis and may require modified surgical technique Insertion Torque (IT).

Aim: It is the purpose of this study to test whether IT is significantly correlated with bone density or not, as assessed by the cone-beam computed tomography (CBCT) in a group of osteopenic and osteoporotic patients.

Materials and methods: A total of 30 patients were included in the study. The mandibular second premolar region was chosen as the site of investigation to prevent variability in surgical implant placement technique in different locations affecting bone mineral density (BMD). Partially, edentulous female patients between 51 and 60 years of age who were scheduled to receive implant placement were recruited for the study. CBCT (Master Series 3D Dental Imaging) was used for preoperative evaluation of the jaws for each patient. Materialise's Interactive Medical Image Control System (MIMICS) was used to process stacks of 2D images from CBCT. Finite element analysis were carried out on bone using Ansys software. Maximum displacement and maximum stress–strain patterns were compared in normal, osteoporotic, and osteopenic groups.

Results: The difference in mean bone density in all three groups were statistically significant ($p < 0.05$) (Table 1). FEA at 32, 36, 40 N in all 3 groups was statistically significant. (Table 2).

Conclusion: Within the limitations of the study, the amount of stress–strain that exhibits at 40 N load in normal bone will be almost the same stress–strain given at 32 N load in osteoporotic bone. Normal IT load analysis exhibits more stress/strain in osteoporotic patients when compared with other groups, showing that IT must be achieved to an optimum level to avoid further complication and failures.

Keywords: Ansys, Insertion torque, Load, MIMICS, Osteopenic bone, Osteoporotic bone, Stress–strain.

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INTRODUCTION

Clinical success in implant practice is influenced by both the volume (quantity) and the density (quality) of bone at the implant site. Bone quality and quantity differ from site to site and from patient to patient. Factors that are important to the success of dental implant treatment include material, biocompatibility, and design issues related to the dental implant; patient factors, such as general health, local tissue health, and quality and quantity of bone; and procedural issues, such as insertion torque (IT), timing of loading, healing duration, biomechanical loading, and prosthetic design. The quality of the host bone is among the most important factors in implants success, and implants placed in poor-quality bone are more likely to fail compared with those placed in optimal-quality bone even in a good clinical expertise.[1-3]

Although poor implant site bone quality is associated with greater risk of implant failure, the effect of compromised body bone mineral density (BMD) on a implant failure is not a definitive. A recent Cochrane evidence-based review opined that "no firm conclusions could be drawn regarding the effect of osteoporosis on resorption of edentulous jaw with or without implants." However the use of endosseous implants in osteoporosis patients is not contraindicated. Another review of 39 studies concluded that there is no evidence to show that the uses of dental implants in osteoporotic patients should be contraindicated; however, "a proper adjustment to the surgical technique and the longer healing period may be considered in order to achieve osteointegration."

Thus, it is evident that osteoporotic patients require particular attention to their implant-site bone quality as an indication of prognosis and may require modified surgical technique. An established method of assessing implant-site bone quality is by means of computed tomography (CT). Bone density, as expressed in hounsefield unit (HU), obtainable from CT, has been used to illustrate the quality of bone. Torque resistant to the cutting of bone during surgical preparation of implant site has also been used to present local bone quality and/or indicate primary implant stability; obviously, IT also depends on other factors, such as implant geometry, threat from surface morphology, cutting tool design, and efficiency.[4-9]

There is evidence to show that IT is related to local bone density. In a cadaver study, the peak IT of 24 self-tapping screw-shaped implants was significantly correlated to the bone density calculated from CT. Another study involving 56 implants placed in 13 patients showed a correlation between IT of self-tapping screw-shaped implants and HUs. Since osteoporotic patients require particular attention during implant placement, IT has been established as a simple and noninvasive method to assess local bone quality and primary implant stability.[10-13]

It is the purpose of this study to test whether IT is significantly correlated with bone density or not, as assessed by the CBCT in a group of osteopenic and osteoporotic patients.

MATERIALS AND METHODS

This study was conducted in the Department of Prosthodontics, Crown & Bridge, and Implantology, Tagore Dental College and Hospital, Chennai, India. Written informed consent was obtained from those who agreed to participate for performing radiographic examination (Note that radiographic exposure was not done only for study cases, but routinely done for implant patients and that database is utilized for the study.)

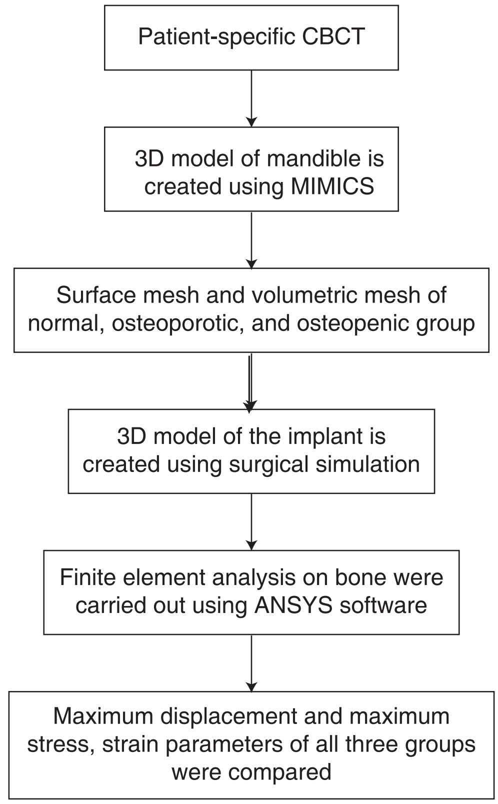
Patients

The mandibular premolar region was chosen as the site of investigation to prevent variability in surgical implant placement technique in patients between 50 and 60 years of age. Those who were scheduled to receive implants were recruited for the study. The osteopenic and osteoporotic status of each patient was determined by mineral density measurements with dual-energy X-ray absorptiometry (DEXA). Osteopenia and osteoporosis were defined as a bone density T-score between –1.0 and –2.5 standard deviations (SDs) below and ≤ 2.5 SDs below normal peak values respectively, for young adults. Implants size were standardized for all patients as 3.5 mm in diameter, 11 mm in length.

To be admitted to the study, the patient has to be ambulatory and without a history of hospitalization within 3 months of admission into the study. Patients had to have at least 7 mm of alveolar bone height in the premolar region and ability to give informed consent. Patients who were not sufficiently healthy for minor elective dental surgery or who suffered from uncontrolled diabetes mellitus or other metabolic diseases that affect nutritional status were excluded.

Schematic of the Study

Flow Chart 1: Sequential steps involved in analysis



Software used for Image Analysis

Materialise's Interactive Medical Image Control System Software

The process of converting anatomical data from images to 3D models is called as segmentation. In MIMICS, segmentation masks are used to highlight regions of interest. This information is then used to recreate a 3D model from the segmented structures (Flow Chart 1). Under segmentation, there are three tools in the main tool bar[14-17]:

Thresholding is the first action performed to create a segmentation mask. There are predefined settings for certain biological materials available in the thresholding toolbar. The entire bone region of the image was selected.

Region growing is used to separate masks into different parts as well as to get rid of floating pixels.

Calculate 3D is used to transform data from 2D images into a 3D model.

Ansys Software

It used to convert the surface triangular mesh created by MIMICS into volumetric tetrahedral mesh. Then suitable static loads, such as 32, 36, and 40 N were applied to the meshed geometry. Finally, the resultant displacement von Mises stress and strain were visualized in graphical form of nodal solution; the corresponding numerical values were obtained.[18–20]

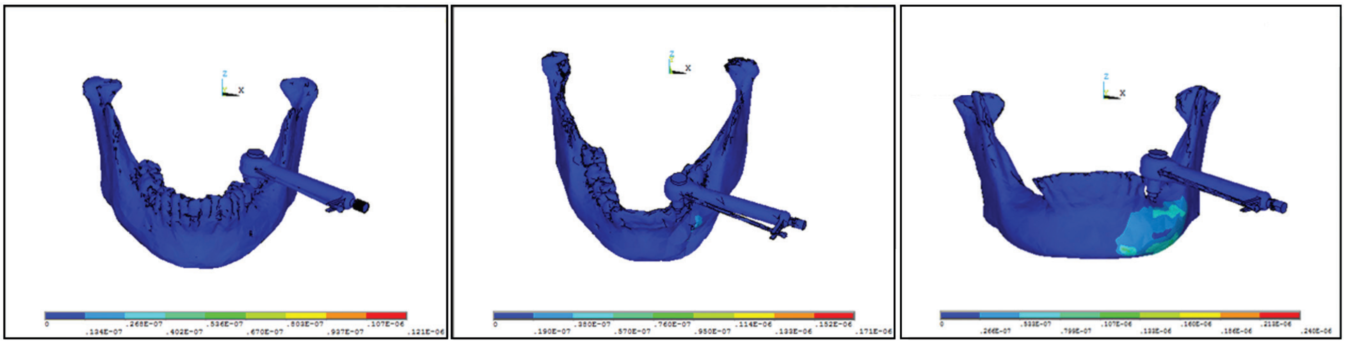


Fig. 1: Stress and strain changes observed at 32 N in normal, osteopenic, and osteoporotic type of bone

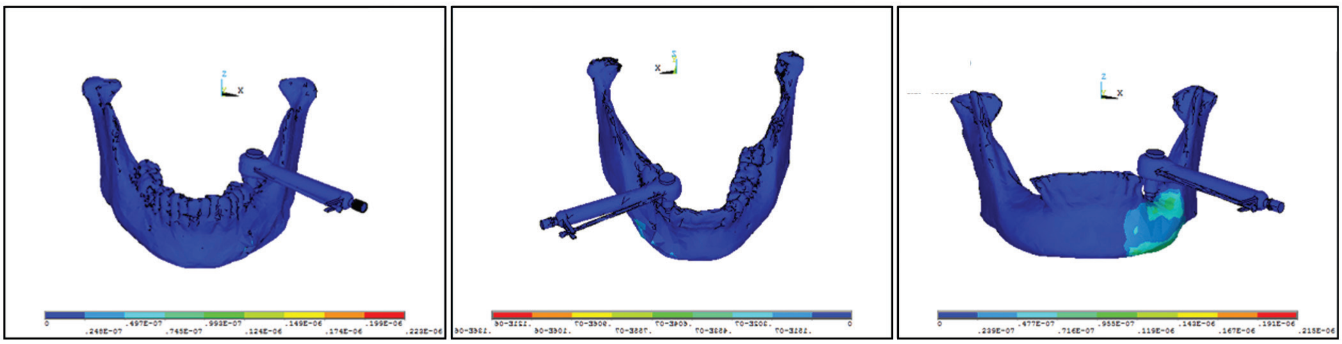


Fig. 2: Stress and strain changes observed at 36 N in normal, osteopenic, and osteoporotic type of bone

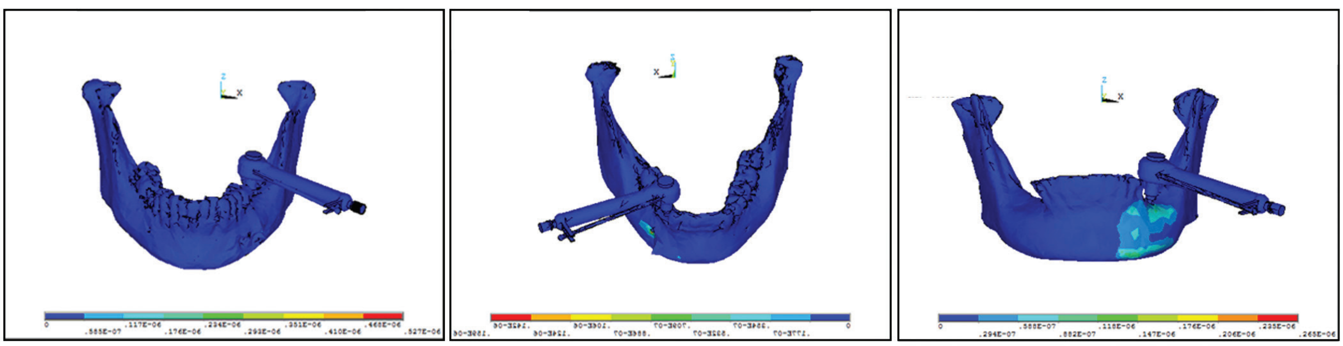


Fig. 3: Stress and strain changes observed at 40 N in normal, osteopenic, and osteoporotic type of bone

STATISTICAL ANALYSIS

All data were collected and analyzed using SPSS 16.0 for Windows. Student's t-test and one-way analysis of variance (ANOVA) were calculated between groups to determine the difference in bone mineral densities.

The level of significance at 5% (0.05) and power at 90% were considered.

RESULTS

A total of 30 females participated in the study. The mean age of subjects were 56.4 ± 2.2 years. The mean bone density for groups I–III was 60364.36, 51789.65, and 40468.62 mm^3 respectively (Table 1). The difference in mean bone density in all three groups were statistically significant ($p < 0.05$) (Table 2).

Table 1: Mean bone density for various groups

Parameter	*Mean*	*Standard deviation*
Group I (Normal)	60,364.36	245.69
Group II (Osteopenic)	51,789.65	227.57
Group III (Osteoporotic)	40,468.62	201.16

Finite Element Analysis of Normal Mandible

In normal mandible, after applying the defined loading condition, the measured value of displacement (mm), von Mises stress (Pa), and strain changes were visualized in graphical form of nodal solution. The obtained numerical values are tabulated in Table 2. The maximum stress (Pa) within the bone at 32 (Fig. 1), 36 (Fig. 2), and 40 (Fig. 3) N was found to be 112.54, 164.15, and 164.31 respectively, and maximum strain under this stress was found to be 0.121E-06, 0.179E-06, and 0.185E-06. The

Table 2: Correlation of IT values at different loading in three types of bones

Case study	*Vector sum of displacement (DMX)*	*Strain SMN, SMX*	*Stress SMN, SMX*
Normal mandible at 32 N	0.131E-06	0.121E-06	11,254
Osteopenic mandible at 32 N	0.371E-06	0.171E-06	16,289
Osteoporotic mandible at 32 N	0.463E-06	0.240E-06	19,835
Normal mandible at 36 N	0.192E-06	0.179E-06	16,415
Osteopenic mandible at 36 N	0.435E-06	0.223E-06	19,808
Osteoporotic mandible at 36 N	0.592E-05	0.251E-06	20,135
Normal mandible at 40 N	0.356E-06	0.185E-06	16,431
Osteopenic mandible at 40 N	0.521E-06	0.265E-06	21,597
Osteoporotic mandible at 40 N	0.677E-06	0.527E-06	30,630

DMX: Maximum displacement; SMN: Minimum value; SMX: Maximum value

vector sum of displacement due to this stress was 0.131, 0.192, and 0.365 respectively.

Finite Element Analysis of Osteoporotic Mandible

In osteoporotic mandible, after applying the defined loading condition, the measured value of displacement (mm), von Mises stress (Pa), and strain changes were visualized in graphical form of nodal solution. The obtained numerical values are tabulated in Table 2. The maximum stress (Pa) within the bone at 32 (Fig. 1), 36 (Fig. 2), and 40 (Fig. 3) N was found to be 198.35, 201.35, and 306.30, maximum strain under this stress was found to be 0.240E-06, 0.251E-06, and 0.527E-06. The vector sum of displacement due to this stress was 0.463E-06, 0.592E-06, and 0.677E-06.

Finite Element Analysis of Osteopenic Mandible

In osteopenic mandible, after applying the defined loading condition, the measured value of displacement (mm), von Mises Stress (Pa), and strain changes were visualized in graphical form of nodal solution. The obtained numerical values are tabulated in Table 2. The maximum stress (Pa) within the bone was found to be 162.89, 198.08, and 215.97 and maximum strain under this stress was found to be 0.171E-06, 0.223E-06, and 0.265E-06. The vector sum of displacement due to this stress was 0.371E-06, 0.435E-06, and 0.521E-06.

DISCUSSION

Another challenge is in diagnosing osteoporosis in the jaw bone since it is believed that a 40% decrease in bone mineral density needs to occur before radiographic analysis reveals osteoporosis. Moreover, the inner surface of the trabecular bone resorbs, making the diagnosis further challenging. In studies where the patients are on medications, such as electronic health record (EHR) or bisphosphonates, the bio-availability, dosage, and mode of administration are influential factors often not mentioned in the study. Although osteoporosis is assumed to have a negative impact on osteointegration, clinical studies fail to show a definite association between this disease and the occurrence of implant failure. Some authors suggest that osteoporosis decreases the cancellous bone volume, resulting in less bone-to-implant contact, and eventually, influencing the prognosis of dental implants. It is also mentioned that osteoporosis challenges implant insertion and therefore, activation of CB2 receptors contributes to bone maintenance and a more reliable osteointegration. Further, some authors suggest that osteoporosis increases some pro-inflammatory cytokines, and decreases factors which contribute to more stable bone formation. Moreover, it is not only the systemic condition itself, but also the medications taken to control that condition may have adverse effects on implant success. However, there is still controversy in the literature in regard to implants being contraindicated in osteoporotic patients.[1-5,21-24]

August et al[25] suggest that osteoporosis affects osteointegration by directly affecting bone quality in the maxilla. In the mandible, however, this is not the case; the relevant literature is more in agreement with the results that August et al[25] obtained from mandible. The reason might be that more assessed implants were placed in mandible; however, this cannot be confirmed since most of the studies assessed did not mention which jaw the implants were placed in. Koka et al[26] (Table 3) also conclude that osteoporosis and bisphosphonate use have no effect on implant success and mention that this is logical since the space between the implant and the intact bone that should be filled with new bone is so small that it does not get affected by an osteoporotic condition.

It was found that osteoporosis (measured by hip BMD) and osteopenia had no significant impact on the success/failure of dental implants. Moreover, the bone marrow transplant scores and implant location were not influential on implant survival. In other words, 10-year survival rates of dental implants in osteoporotic and osteopenic patients was a promising 92.5% and, therefore, osteoporosis is not a contraindication for implant placement.

The answer to whether osteoporosis results in more failure in dental implants is a crucial one in modern dentistry, with a considerable increase in the average life expectancy and an aging population. In this context, the resultant effects of this condition on jaw bones are of particular interest. Patients are living longer, with more number of teeth in their oral cavities increasing the demand for implant placement in the aging population.

Table 3: Summary of previously documented evidences

Title	*Author*	*Type of study*	*Population*	*Result*	*Conclusion*
Effect of osteoporotic status on the survival of titanium dental implants	Holahan et al (2008)[28]	Retrospective cohort study	> 50 years 746 female USA	III year survival rate of 32.5 arch location and BMD score did not have a statistically significant effect on implant survival rate	A diagnosis of osteoporosis or osteopenia is not a contraindication to dental implant therapy
Relationship between systemic BMD and local bone quality as effectors of dental implant survival	Holahan et al (2011)[29]	Retrospective cohort study	50 years or older 645 female USA	No correlation exist between systemic BMD and jaw bone quality	Implants placed in good-quality bone as assessed subjectively by the surgeon have significantly better survival characteristics than implants placed in moderate/poor-quality bone.
Survival of dental implant among post-menopausal female dental school patients taking oral bisphosphonates	Famili et al (2011)[27]	Retrospective cohort study	>50 years 122 female 55 pts on BP USA	98.7% success rates with one implant failure. No evidence of osteonecrosis	Oral BP did not significantly affect implant success rates Implant placement in osteoporotic patients taking BP did not result in osteonecrosis of the jaw
Influence of estrogen status on endosseous implant osseointegration	August et al (2001)[25]	Retrospective cohort study	168F-PMP-w/o Estrogen replacement therapy 75 F-PMP-w Estrogen replacement therapy 114:F-PRM 59 M<50 years 110 M >50 years	Maxilla ERT causes loss of implant failure Mandible no change in failure	Suggests ERT in osteoporotic patients in need of a maxillary implant
Survival of dental implant in post-menopausal bisphosphonate users	Koka et al (2010)[26]	Retrospective cohort study	139 PMP female 55 BP users 82 non-BP users USA	Survival rate BP users-99.17% Non-BP users-98.19%	Dental implants placed in post-menopausal women have the same survival potential regardless of whether patient have a history of bisphosphonate use
OUR present study reveals	2015		30 female patients	IT values are statistically significant	IT load analysis exhibits more stress/strain in osteoporotic patients when compared with other groups, showing that IT must be achieved to an optimum level to avoid further complication and failures.

On the contrary, osteoporosis is the most common metabolic bone disease affecting 25% of women between the ages of 50 and 65 and, therefore, dealing with osteoporotic patients in need of dental implants is highly demanded.[27] It is stated by Holahan et al[28,29] that osteoporosis is not a contraindication for dental implant placement (Table 3).

It is noteworthy that age itself is not a contributing factor to dental implant failure; however, concomitant factors together with aging, such as uncontrolled metabolic diseases (osteoporosis, diabetes, etc.) might affect the outcome of implant therapy in both surgical and healing stages.[30-35] Challenges in searching and extracting strong evidence in the literature is partly because the terms implant failure, success, and even bone quality are not well defined and numerous definitions and criteria have been used for the very same term and therefore, the comparability of the studies is questionable. Moreover, there is no gold standard in assessing bone quality. Other limitation arises because many studies have too few subjects; for example, the only study that assesses the osteoporotic status based on BMD score has merely 30 subjects.

The present study revealed that IT was significantly correlated to implant-site bone density, as represented by BMD values obtained from CBCT images in a group of osteopenic and osteoporotic patients. The results of our study agrees with previous findings for implant patients in general regarding the correlation between IT and bone dentistry. Insertion torque is a readily available and quantitative value obtained by the dental surgeon as a part of normal implant placement procedure. Insertion torque also directly measures the bone area of interest. In addition, it obviates the need for radiation exposure and circumvents issues, such as overlap and distortion of traditional radiographs that affect the accuracy of bone quality assessment.

Implications for Practice

As opposed to the previous belief that implant therapy was considered to be a contraindication in osteoporotic patients whether they were on treatment or not, the results obtained in this review show that implants can be considered in such patients. The significance of this finding is mainly due to the fact that the aging population in need of dental implants can now benefit from this life-changing treatment. In short, a practicing dentist can consider implant therapy as means of replacing lost teeth in the aforementioned patients, provided a careful assessment of the medical history has been conducted. But it is mandatory to critically analyze and alter our IT loads for osteoporotic patients as the results of our study emphasize.

Implications for Research

Further research in this area is recommended by means of stronger study designs, with more control on confounding factors, and to give scope and idea to find out what amount of force (In newtons-IT) can be given to any patient by using CBCT and software, which will give perfect assessment for clinician for dental implant placement.

CONCLUSION

Within the limitations of the study, the amount of stress–strain that exhibits at 40 N load in normal bone will be almost the same stress–strain given at 32 N load in osteoporotic bone. Normal IT load analysis exhibits more stress/strain in osteoporotic patients when compared with other groups, showing that IT must be achieved to an optimum level to avoid further complication and failures.

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