Hoop Strain in Dental Implants and the Influence of Different Cantilever Lengths, an In Vitro Pilot Study

By

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Final Dissertation Defense Approval Form

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Abstract

Purpose: The purpose of this study is to determine the hoop stress around dental implant in a circumferential and vertical pattern and to compare stress values to different cantilever length on a cross arch implant supported framework.

Material and Methods: A milled cross-arch metal framework supported by 4 implants imbedded in acrylic in addition to one separated implant in the middle. Five T-strain gauge rosette distributed on five dental implants recorded data as they were loaded by 50 and 100 N forces using MTS 810 loading machine. The loading sites were anterior implant, posterior implant, 0.5 Anterior Posterior ,(AP spread) ratio cantilever, 1.0, 1.5 and 2.0 ratio cantilever. Each one of those 7 sites were loaded 10 times for each of the 50 and 100 N generating 360 different reading for each of those groups. Three-way ANOVA was conducted (twice, one for vertical and one for hoop strain) for analysis of strain with factors of: Magnitude of force, extension of cantilever and position of the implants followed by Post hoc Tukey comparison between the groups.

Results: The anterior implant is under tension in vertical direction when forces are applied to the cantilever on the contralateral side. The most posterior implant is under less tension in the vertical direction but shows as much strains in the circumferential direction. Post hoc analysis shows cantilever over 1.0 ratio causes same high amount of stress to the system.

Conclusion: A ratio up of 0.5 AP spread for the cantilever is statistically acceptable. However, A ratio up to 1.0 AP spread for the cantilever exerts no more tension to the system than the load on the implants.

Keywords: hoop strain, dental implants, strain gauges, circumferential stress, and cantilever

Figures and Tables

List of Abbreviations

FE	Finite Element
FEA	Finite Element Analysis
FEM	Finite Element Method
A-P Spread	Anterior Posterior Spread

Chapter I: Introduction

1.1 Background of the problem

Dental implants are now a widely used and accepted modality of restorative dentistry[1]. The basis of successful dental implant treatment is the process defined by Brånemark as osseointegration. An understanding of the process of osseointegration has allowed development of clinical techniques that result in an implant stabilized in the bone.

After insertion of the implant, the bone heals in direct apposition to the implant. As a result, when occlusal forces "load" the implant-supported crown or prosthesis, the stress is transferred to the bone surrounding the implant.[2] Vertical loads are transferred along the long axis of the implant while the lateral component of masticatory forces is transferred to the crestal bone surrounding the top of the implant[3]. Currently, tissue engineered topographies along the collar of the implant are being developed to stimulate bone remodeling and modeling. These topographies can serve to stabilize the crestal bone and reduce the bone resorption (die-back) of the crestal bone that has been a problem.[4]

Even though the osseointegration process has been reported to have high success rate.[5] Some reported surgical failure rate as low as 1.5 %.[6] The long-term success of implant therapy is not just dependent on enhanced osseous stability[7]. More recently, there is greater attention being addressed to the implant-abutment interface.[3] The mechanical and biological stability derived from the implant design and surface topography engineering and the connective tissue and junctional epithelial soft tissue environment are critical to maintain the biologic environment in which the implant functions[8]. Chronic inflammation in this transmucosal region caused by the design, material or surface topography, can lead to a long-term tissue recession, peri-implantitis, and loss of the implant years after the completion of tooth replacement therapy.[2,4,9,10]

1.2 Statement of the Problem

A Pubmed search performed on December 11, 2015, at 15:04:52, showed 26354 articles found when the word dental stress was entered in the search category. As the key words; dental implant and hoop stress were entered, the search came back with only 2 results. When the strain gage was added to the previous search criteria, the search came back with zero results.

This shows this study is a pilot one that doesn't address hoop stress in the dental implant only in a 3D finite element study but it rather presents a physical analysis of actual 2-ways strain gages readings in a mechanical environment that mimics the actual one.

1.3 Research Purpose, Specific Aims and Hypothesis

The aims and objectives of the research are :

- To correlate vertical strain value in the implant with the hoop strains on both a single implant model and in a cantilever system
- To determine the type of reaction of implants according to the distance from the applied force
- To Utilize obtained data and conFigure an applicable clinical solution conFigureing the cantilever length without harming the complex.

The Hypotheses:

- The greater the length of the cantilever, the more the strain in the implant walls

- The greater the load on the cantilever, the greater the strain in walls of the implants
- Implants at different positions relative to the cantilever have different hoop strain

Null Hypotheses

- Cantilever lengths has no effect the strain in the implant walls.
- Loading cantilevers with greater loads has no effect on the strains of the wall of the implant.
- Implants at different positions relative to the cantilever have the same hoop strain.

1.4 Clinical significance of the Study

Cantilevered prostheses are a realistic clinical alternative for implant-supported prosthesis. They often reduce the cost of the treatment. The use of cantilevered prostheses permits a more rapid completion of the treatment and frequently avoids the need for more elaborate extensive surgical procedures.

However, because cantilevered prostheses are class III levers, the occlusal forces are magnified by the length of the lever arm. Thus the biomechanical loads on the abutment-implant interface, the abutment screw and the walls of the implant are magnified the greater the cantilevered arm.

While the effectiveness of this treatment modality is generally accepted, there is little quantitative information about the actual strain generated. Most clinicians approach this problem empirically using their intuitive clinical experience. However it would be significant for treatment planning design purposes to have quantitative information that could be related to modulus of elasticity (and the hoop stress) of the implant structures since this would allow a more objective treatment planning of the cantilevered prosthesis.

<u>*Chapter II : Literature Review*</u>

2.1 Implant Treatment History

Dental implant treatment has revolutionized oral rehabilitation in partially and fully edentulous patients. When the concept of osseointegration was introduced in 1977 by Per-Ingvar Brånemark[11] in relation to titanium endosseous implants, it became possible to achieve high success rates in association with this treatment modality, and multiple investigations have demonstrated an excellent long-term prognosis (Albrektsson et al. 1986, Jemt et al. 1989, Adell et al. 1990, Shearer 1995). Initially, dental implants were mainly used for anchorage of a removable full prosthesis in totally edentulous jaws (Adell et al. 1981)[11], but later on, also partially edentulous patients were treated successfully with either removable dentures or fixed bridges[12]. The indication for implant treatment has been gradually extended, and today an implant-retained single-crown is a well-established option for replacement of a missing tooth[13].

Dental implantology, which is dealing with the rehabilitation of the damaged chewing apparatus due to loss of the natural teeth, is currently the most intensively developing field of dentistry. Missing teeth can be replaced by dental implants (artificial roots), which are inserted into the root-bearing parts of the mandible or maxilla. The success and long- term prognosis of implant therapy depend primarily on proper diagnosis and treatment planning[12,13]. Today, there are ever increasing demands from patients with missing teeth for detail explanation of all expected possible steps during treatment including time, cost, number of procedures and finally the complexity level of their case if they choose to be implanted and restored.

2.2 Treatment Protocol

2.2.1 Treatment Protocol Sequence

According to the original implant treatment protocol (Brånemark 1985) (termed "gold standard" protocol in this thesis), it was recommended to wait at least 12 months following tooth extraction before insertion of implants. Furthermore, a two-stage approach was advocated which meant that the implant was placed in bone after flap elevation at one operation, the recipient site was covered with mucosa, and after approximately 3 months in the mandible and 6 months in the maxilla, a second-stage surgery was carried out[14]. At this operation, the implant was uncovered and an abutment connected to the fixture component. Hereafter, the impression for the final prosthetic restoration was taken.

The rationale of this treatment sequence was that the extraction socket should be allowed to heal completely before insertion of the implant[15]. Hereafter, the implant should be inserted in the jawbone and covered with mucosa, thereby preventing functional loading and ensuring osseointegration of the implant.

2.2.2 Treatment Protocol Stages

It is obvious that the above described treatment concept is associated with disadvantages such as being a time demanding procedure with several surgical stages that in- crease unpleasantness and costs to the patient. A prolonged treatment period and the high financial costs may also be considered as disadvantages from a socio-economic point of view. From a biological standpoint, a drawback in deferring the time of implant insertion following tooth extraction is that the alveolar bone begins to resorb soon after removal of the tooth, as a consequence of normal physiologic activity (Atwood & Coy 1971, Atwood 1971). This results in a reduction of the height and width of the alveolar ridge[16], which may interfere with the subsequent placement of an implant with a proper size and alignment[17].

It is noteworthy that the “gold standard” implant treatment protocol was not founded on scientific evidence[18]. E.g. a healing period of 3 to 6 months from fixture insertion to abutment operation and the following prosthetic treatment was empirically estimated on the basis of available knowledge on alveolar bone healing[19]. This treatment concept, however, was tested and survived for more than 25 years (Adell et al. 1981).

Within the last decades, the “gold standard” implant treatment protocol has been challenged by experiments, which aimed at shortening the treatment period and by reducing the number of surgical procedures. Various new surgical techniques have been investigated, such as a one-stage technique[20-22]. This technique implies that the implant penetrates the mucosa during healing (transmucosal implant)[23]. Hereafter two options exist, namely to wait a certain time before loading of the implant, or to load the implant immediately after placement.

Another approach is to reduce the time between a tooth extraction and implant insertion. One possibility is to insert the implant before complete healing of the extraction socket has occurred, optionally to insert the implant immediately after the tooth extraction procedure[24]. The ultimate goal would be to insert the implant immediately after extraction of the tooth and to place the prosthetic restoration on the day of implant surgery[25]. This concept has recently been suggested to be a realistic alternative to the conventional approach both in conjunction with single-tooth implants (Chaushu et al. 2001) and multiple implant restorations (Brånemark et al. 1999); however, there is still little clinical evidence that prognoses of the conventional protocol and this new "immediate" approach are comparable.[26] [27-29]

In order to estimate the appropriate time for implant insertion, understanding of the healing process at the recipient site after tooth extraction is really essential. Further- more, since bone remodeling is part of healing[30], it is also important to acquire knowledge of the contour changes occurring at the extraction site. It is believed that the stress transmitted into the bone during and after osseiointegration plays a major role in future success of the dental prosthesis.[31] These changes may adversely affect the quantity and architecture of the alveolar ridge and, thereby have an impact on the possibility to insert an implant, as well as influence the functional and esthetic outcome in prosthodontic treatment including implant-retained prosthetics. [32,33]

2.3 Stress and Strain

2.3.1 Finite Element Analysis

Stress and strain from occlusal loading and their effect around dental implant have been studied. [34] The stress and strain distribution in the bone surrounding dental implants are important factors in the long-term fixation and stability of the prosthesis.[35] It has been shown that strain can occur around the neck of the implants and may lead to bone resorption.[36] Studies have emphasized the importance of implant designs which can reduce the level of stress at the neck of the implants.[37] There are two ways to study and calculate the stress, either using finite element analysis or measuring the strain caused by the stress in an actual physical assembly. 'The Finite Element Analysis (FEA) is a numerical method for solving problems of engineering and mathematical physics.[38,39] Its useful for problems with complicated geometries, loadings, and material properties where analytical solutions cannot be obtained. Its usually referred to as Finite Element Analysis (FEA) or Finite Element Method (FEM)". [40]

A number of studies that have addressed the interface of the fixture to the abutment have utilized finite element analysis. [41-43] This computer-based technique is virtual in nature and totally dependent upon the data and information inputted to the computer system.[44]

These data often present an ideal situation that is not necessarily clinically relevant[45]. The ease and comfort the finite element provided for a lot of scientist and scholars yet to be defended by an actual modulation of the problem and solving it.[46]

2.3.2 Physical Assembly

The second way, testing of a physical assembly, results in a stress–strain curve. It is a graphical representation of the relationship between stress, derived from measuring the load applied on the sample, and strain, derived from measuring the deformation of the sample, i.e., elongation, compression, or distortion. The nature of the curve varies from material to material.[47]

2.4 Hoop Stress

2.4.1 Definition

Few people tried to define hoop stress in dental implant.[48] It is descried as "the conical, shank and socket connection between the implant fixture and the abutment has become a popular dental implant design feature.[49] The connection between these two elements is, in effect, a conical wedge that may exert lateral forces under load that may result in fracture of the coronal implant fixture walls known as hoop stress. The conical connection is held together by a connecting abutment screw that extends from the internal of the abutment into the coronal socket of the implant fixture".[48]

In addition to stresses on the crestal bone that result from forces that tend to displace the implant, another consideration that has received little attention is stresses from occlusal loading that results in distortion of the implant.

This phenomenon termed hoop stresses results from movement of the abutment relative to the implant body, causing distortion. It has been discussed in the engineering literature for containers that have an open end (Figure 1) .

Figure 1 Barrel with Hoop

2.4.2 Mathematical Formulas

Cylindrical stress is a mechanical stress defined for rotationally symmetric objects and results from forces acting circumferentially (perpendicular both to the axis and to the radius of the object). The classic equation for cylindrical stress is

$\sigma_c = F/tl$

Where: (σ_c) is the cylindrical stress, (F) is is the force exerted circumferentially on an area of the cylinder wall that has the following two lengths as sides:

(t) is the radial thickness of the cylinder

(l) is the axial length of the cylinder

However, hoop stress created by an internal pressure on a thin wall cylindrical pressure vessel is:

$\sigma_h = Pr/t$ (for a cylinder)

Where: (σ_h) is the hoop stress, (P) is the internal pressure, (t) is the wall thickness, (r) is the inside radius of the cylinder.[50]

Since the abutment interfaces with the top of the implant with an internal connection within the implant and the walls of the collar are quite thin, there is a possibility of distortion of the walls of the implant from occlusal forces. (Figure 2)

Figure 2 Illustration of dental implant

This may be an important factor either if the abutment moves relative to the implant or there is deep internal connection. Another situation in which the hoop stress merits consideration is when the crown-implant ratio is high. In this case the crown serves as a lever arm that potentially can distort the walls of the collar. Additionally, in situations where screw loosening occurs, additional stress may be placed on the walls of the implant from movement of the abutment. Little is known about the magnitude of hoop stresses associated with dental implants, although there are a number of clinical reports of the fracture of the implants.[51-53] It has also been suggested that the stress transmitted to the implant collar may have an effect on crestal bone resorption.[36]

When two components are tightened together by a screw they form a unit called a screw joint. The screw loosens only if outside forces applied to separate the parts are greater than the forces keeping them together. Forces that attempt to disengage the parts are called joint separating forces. The force keeping the parts together is called the clamping force. To achieve a secure assembly, screws should be tensioned to produce a clamping force greater than the external force tending to separate the joint.[54] Clamping load is usually proportional to tightening torque.[55] Applied torque develops a force within the screw called preload. Preload is the initial load in tension on the screw.[56] The preload in the screw results in a clamping force between the components.[57] The forces applied are believed to transfer some stress and eventually some strain to the screw. Consequently, the torque will be reduced and may cause screw loosening.[58]

2.5 Types of Bone Grafts

The use of osseointegrated implants opens the horizon to more treatment options. However, many times the clinician is limited by the anatomic presentation of structures and the availability of bone. In these circumstances, further treatment is required. Some of those treatment strategies are more aggressive and time consuming and include the sinus lift and bone grafts. [59-61]

There are few types of grafting when it comes to implant dentistry. The types of bone grafts are:

2.5.1 Autograft

Autologous or autogenous bone grafting involves utilizing bone obtained from same individual receiving the graft. Bone can be harvested from nonessential bones, such as from iliac crest, mandibular symphysis (chin area), and anterior mandibular ramus (coronoid process). When a block graft will be performed, autogeneous bone is the most preferred because there is less risk of graft rejection as the graft is originated from the patient's body.It would be osteoinductive and osteogenic, as well as osteoconductive. Disadvantage of autologous grafts is that additional surgical site is required, another potential location for postoperative pain and complications.[62]

2.5.2 Allografts

Allograft is derived from humans. The difference is that allograft is harvested from an individual other than the one receiving the graft. Allograft bone is taken from cadavers that have donated their bone so that it can be used for living people who are in need of it; it is typically sourced from a bone bank.[63]

2.5.3. Xenograft

Xenogratfs are bone grafts from a species other than human, such as bovine and are used as a calcified matrix.[64]

2.5.4 Alloplastic grafts

Alloplastic grafts may be made from hydroxyapatite, a naturally occurring mineral (main mineral component of bone), made from bioactive glass. Hydroxyapatite is a synthetic bone graft, which is the most used now due to its osteoconduction, hardness, and acceptability by bone. Some synthetic bone grafts are made of calcium carbonate, which start to decrease in usage because it is completely resorbable in short time and makes breaking of the bone easier. Finally used is the tricalcium phosphate in combination with hydroxyapatite and thus giving effect of both, osteoconduction and resorbability.[65]

The option of grafting the area with allograft material is safer the using an autogenously one. Those contagious substances should be absent in an ideal biocompatible bone grafting material. Carbonate, Calcium phosphate and Sulfate bone graft materials are typically biocompatible with no risk of being rejected by the host. Virus, Prion and bacterial contamination of bone grafting materials are not of our concern in autogenous or alloplastic bone grafts. The prevalence of HIV infection in freeze-dried bone and demineralized freeze-dried bone allografts has been reported to be 1 in 8,000,000 and 1 in 2.800.000 respectively. However, a lower success rate and more bone resorption after this procedure was reported. As a matter of fact, failure rate reached 71% in some reports.[66]

2.6 Autogenous Bone grafts Donor Sites

Autogenous bone grafts increase morbidity as they require surgeries of both donor and recipient sites.[67]

The use of autogenous bone graft with dental implants was originally discussed by Branemark. Multiple sites have different complications. Those sites that are usually used to harvest bone with their complications are :

2.6.1 MAXILLARY TUBEROSITY BONE GRAFT

The major complication with maxillary tuberosity graft harvesting is oroantral communication. Grafts may be harvested with a chisel or rongeurs. The chisel edge should be kept slightly superficial to the maxilla to shave off pieces of tuberosity bone and prevent inadvertent sinus communication.[68]

2.6.3 MANDIBULAR SYMPHYSIS BONE GRAFT

A CT scan or panoramic radiograph is used to evaluate the available bone at this donor site. Lateral cephalometric radiograph can be useful to determine the anteroposterior dimension of the anterior mandible. A vestibular incision is made in the mucosa between the cuspid teeth. Limiting the distal extent of the incision will reduce the risk of mental nerve injury. The mandibular symphysis is associated with a higher incidence of postoperative complications. Incidence of temporary mental nerve paresthesia for symphysis graft patients is usually low. Ptosis of the chin has not occurred and can be prevented by avoiding complete harvesting of the mandible.[69,70]

2.6.4 MANDIBULAR RAMUS

The limits of the ramus area are dictated by clinical access. After graft preparation, the donor site is not augmented with bone substitutes because the inferior alveolar nerve may be exposed and irritated by the graft particles. The potential for damage to the inferior alveolar nerve, as opposed to its peripheral mental branches is of greater concern with the ramus graft technique. Patients may experience trismus following surgery and should be placed on postoperative glucocorticoids and NSAIDs medications to help reduce dysfunction.[69,70]

2.6.5 Tibia

There has been a low reported incidence of significant complications with this procedure. Complications may include hematoma formation, wound dehiscence, infection and fracture. The patient should avoid strenuous exercise for 4 to 6 weeks. Although quite rare most cases of tibia fracture are due to a bony access too low on the leg.[71]

2.6.6 ILIUM

The grafting of larger areas of bone deficiency often requires bone harvesting from the ilium. The crestal incision is made about 2cm below the anterior superior iliac spine and extending caudally 4 to 5 cm. Care is taken not to cut through the external oblique or gluteal muscles during this incision because this increases postoperative discomfort and slows ambulation. All bleeding from the marrow is controlled with small amounts of bone wax or collagen hemostatic. The patient is advised to avoid any lifting or twisting for the next 6 weeks to preclude hip fracture. The use of a pain pump with long acting local anesthetics has dramatically reduced the level of postoperative pain from the hip area.[72]

2.6.7 RIB GRAFT

The preferred donor ribs are the fourth and fifth ribs. The fifth rib is superior to the fourth in growing female patients. A major complication in rib harvesting is pleural perforation. In this case a chest tube catheter is inserted in to the area of pleural compromise to a length of approximately 1 to 2 cm; with the red rubber catheter in position, a purse string suture is placed to fix the tube which should be attached to a chest tube bottle. For small perforations the anesthesiologist provides positive pressure and maintains this position while a surgical knot is tightened. All patients having costochondral or rib harvests require a postoperative chest radiograph performed and clinical inspection for pneumothorax. If a pneumothorax is noted a chest tube may be placed.[73]

2.6.8 CRANIAL BONE

Cranial bone just superior and posterior to the temporal crest is generally quite thick and accidental full thickness harvest and or dural perforation is minimized. An incision is made beginning 1cm inferior to superior temporal line to avoid main arterial trunks of the superficial temporal and posterior auricular arteries thus reducing bleeding; the parietal bone, which is flat and also quite thick as compared with other areas of the cranium.[74]

The bone graft should have intimate contact with underlying host bone. Following harvest, the bone graft may be stored in sterile saline.[75] The graft is mortised into position and fixated to the ridge with screws.[76] Complete flap coverage and tension free closure is essential to the successful incorporation of the bone graft.[77] After the periosteal releasing incision is made, the flap is gently stretched to assess closure without tension. Although it is important that the flap margins are well approximated, the sutures should not be pulled too tightly or ischemia will occur. It is imperative that the graft is immobilized during healing postoperatively.[78] The patient should continue antibiotic therapy for at least 1 week.[79] Smoking has been associated with a high rate of wound dehiscence and graft failure.[80] Cholorhexidine rinsing is used for oral hygiene until the sutures are removed.

2.7 Sinus Left

The sinus lifts, on the other hand, require more healing time prior to the insertion or loading of the implant. In addition, complications of tearing of the Schneiderian membrane or an infection of the ethmoidal sinuses are always a risk.[81]

Sinus floor augmentation is one of the techniques that have been proposed for improving the long-term retention of dental implants. The procedure involves the creation of a submucoperiosteal pocket in the floor of the maxillary sinus for placement of a graft consisting of autogenous, allogenic, or alloplastic material. Currently, two main approaches to the procedure can be found in the literature. These include lateral window (external) and osteotome (internal) procedures. External technique allows for a greater amount of bone augmentation to the atrophic maxilla but requires a larger surgical access. However, internal technique is considered to be a less invasive alternative to the external method to increase the volume of bone in the posterior maxilla.

Complications of the sinus left predominantly consist of disturbed wound healing, hematoma, sequestration of bone, and transient maxillary sinusitis. The last complication was considered to be the major drawback of this procedure. Previous investigations have reported maxillary sinusitis up to 20% of patients after sinus left. Postoperative acute maxillary sinusitis may cause implant and graft failures. The reported cases of maxillary sinusitis developed after the lift procedures are all associated with the external techniques. On the contrary, internal procedure appears to be a safer method with rare complications.[82] Never the less, the complexity of the procedures discussed above and the time healing consumed have to be always in mind. These extensive treatments can be avoided by alternative methods; one of them is the cantilever option (Figure 3) .

Figure 3 Cantilever dental prosthesis

The use of a cantilever prosthesis on dental implants has been a controversial issue in the dental literature because of the stress distribution of axial loads and forces on the cantilever arm that may result in failure in the prostheses. The prognosis for the cantilever prosthesis includes the prosthesis, but as well maintenance of the marginal bone around implants supporting the cantilevered prosthesis.[83]

2.8 Anterior-Posterior Spread

In order to establish guidelines for the use of a cantilever, the Anterior-Posterior spread (A-P spread) has been defined. The A-P spread is the linear distance in the occlusal plane between the centers of the most anterior implant and the most posterior ones (Figure 4). The cantilever length is the distance from the distal point of the most posterior implant to the most distal point of the cantilever arm. The A-P spread over the Cantilever length is termed the Ratio.

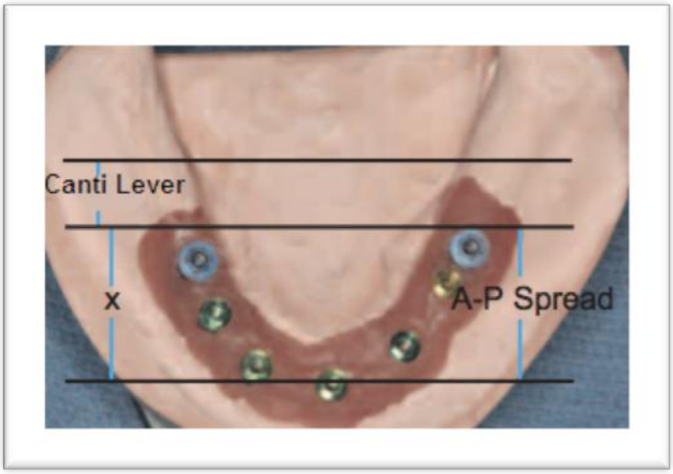

Figure 4 A-P Spread

The maximum cantilever length-anterior-posterior spread ratio is often used as a design factor for the cantilever length in completely implant-supported prostheses.[84] Cantilevers magnify forces and the greater the length the of cantilever, the greater the force on the implants. For this reason, proper biomechanical design is an essential factor in maintaining implant-supported prostheses.[85] Overloading may result in

(1) a gap at the prosthesis screw-prosthesis or abutment screw-abutment interface,[86] *(2)* fracture of the prosthesis or abutment screw,[87-89] *(3)* fracture or plastic deformation of prostheses,[89] *(4)* implant fracture,[11] *(5)* loss of osseointegration,[90] or *(6)* bone fracture.[91] Loosening of the prosthesis-retaining screw can occur at the lowest loads when compared to all other structural complications.[55]

Experimental methods that have studied those problems have included the use of strain-gaiged abutments designed like those used in vivo by Glantz et al[92] and Gunne et al [93] and photoelastic models.[94] Theoretical approaches have ranged from the simple to the relatively complex. Skalak studied cantilevered prosthesis and developed equations to quantify the loads on the implants and the cantilever.[85] He correlated on the position, distribution, and the numbers of the implants in a cross arch and their effect on rigid fixed prostheses. Skalak concluded that the loading was concentrated on implants nearest to the point where bite force was applied to the prosthesis. Monteith presented a computerized version of the 1983 Skalak model for use in case planning.[95] More complex computer models have ranged from 2D finite element (FE) idealizations to full 3D FE stress analysis with anisotropic material properties for the bone, and bonded versus nonbonded boundary conditions for the bone-implant interface[96-98]. The main assumptions underlying the analytic and computer studies are summarized and discussed recently in Brunski and Skalak.[99] Brunski however, studied implants and strain gages and measured them only in vertical direction.

2.8.1 A-P Spread Previous Suggestions

Some have suggested that the cantilevers length be varied according to the A-P spreads. Rangert suggested an A-P spread of 10 mm will allow a cantilever 20 mm.[100] Takayama suggested that the cantilever should be less than 2X the A-P spread.[101] English suggested that the cantilever length should be no longer than1.5X the A-P spread.[102]

The dental literature has been unclear about long-term success of fixed cantilevered prostheses supported by dental implants. However, while some authors have attempted to extrapolate from cantilevered prostheses supported by natural teeth, these are not directly applicable to implant cantilever FPD. In addition, the amount of stress transferred to the bone surrounding the dental implants and the long-term effect on the walls of the implants (hoop stresses) are yet to be analyzed.

There are no experimental studies on the relationship between the cantilever length and the stress on the implant for cantilever prostheses.

Thus the purpose of this research is to study, in an in vitro model simulation, the effects of a cantilevered prosthesis upon strain in the implant collar. These strains, previously referred to as hoop strains, will be examined under different experimental conditions. These strains will be compared to the module of elasticity of the material and thus suggest the point at which use of the cantilevered prostheses will distort the implant.

Chapter III. Material and Methods

3.1 Sample assembly:

3.1.1 Framework Virtual Design

A cantilevered frame work was virtually designed using CAD/CAM technology The specifications of the frame works were as following:

The distance horizontal between the 2 anterior implants was 30mm which is average distance between 2 mental foramen in the mandible.

The horizontal distance between the 2 posterior implants was 40mm, the average distance between 2 premolars horizontally.

The distance of the posterior 2 implants from the anterior ones was 15mm, the average distance between the 2 first premolars and the canines in the mandible, the AP spread.

The length of the cantilever was 30mm which is 2 X AP (the maximum that would be utilized clinically), (Figure. 5).

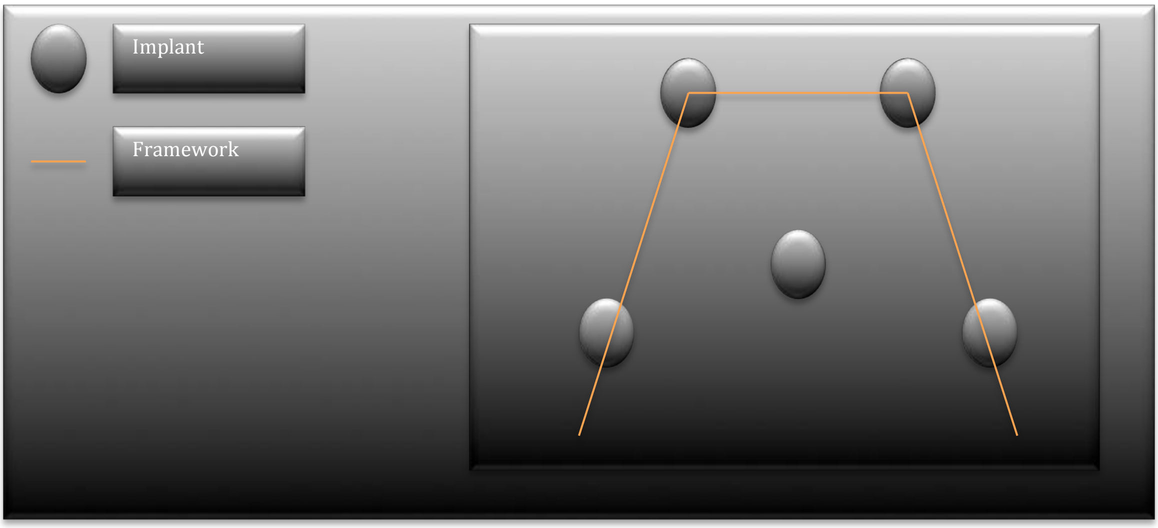

Figure 5 Illustration of the design

3.1.2 Framework Fabrication

The frame work was milled by using NobelBiocare milling system

- 4.0 Astra regular platform implants were attached to the framework.(Figure 6)

Figure 6 Astra Implant

- Each of the implants received a strain gage rosette (Micro-measurements & Sr-4 Vishay 2 grids) on the distal side of the implant on the collar (Figure 7) The attachment of the strain gage rosette to the strain implant is described below.

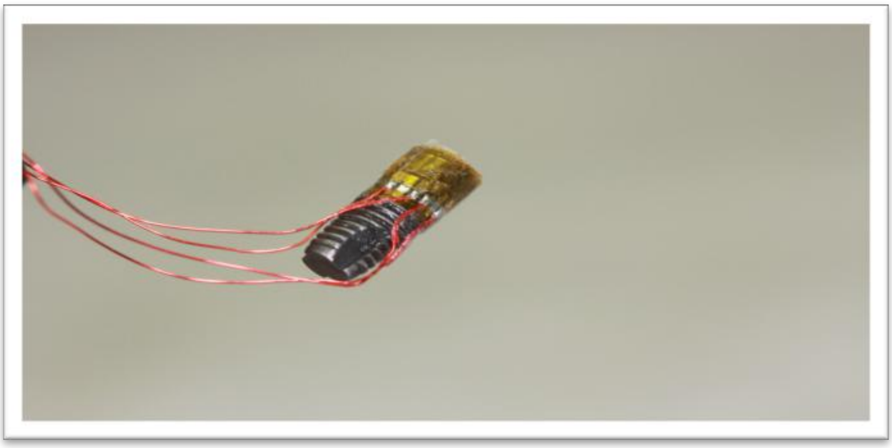

Figure 7 Implant attached to strain gage

- The 4 implants were attached to the framework. The fit of the implant was checked using a microscope to eliminate the presence of a gap between the framework and the implants.

- The framework with the attached implants was susspended within a rubber formeres using wooden dowls and wax
- An electronic level balancer software (iHandy level version 1.55) on IPhone version (4.2.1) was used to insure the framework was parallel to the floor. (Figure8)

Figure 8 iHandy softwear

- Polymethylmethacrylate monomer and polymer powder (hygienic repair resin © Coltène Whaledent Group)were mixed according to the manufacturer's recommendations and poured into the former up to the first thread level of the 4 implants. (Figure 9)

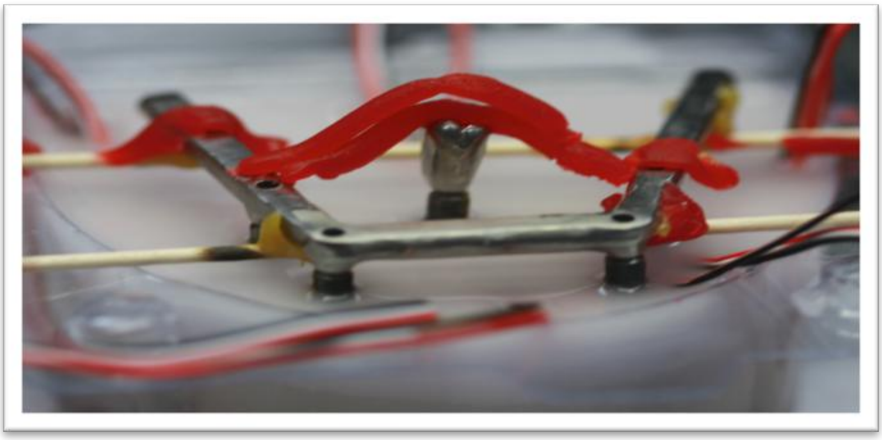

Figure 9 Framework in resin

- The fifth unattached implant was installed in the former at the same time before the resin polymerized. The fifth implant was paralleled to the other 4 implants in the frame work and was also imbedded up to the first thread.

- A standardized premolar crown was waxed and cast for the single implant / abutment unit. The crown will be screw retained.

• Prior to loading, the abutment screws were torqued according to the manufacturer's recommended tightness.

3.2 Strain gages:

- A strain gage is a device that responds to strain in an associated structure with a dimensional change that offers an alteration in electrical resistance to current flow. With increasing strain there is a lengthening of the gage and a corresponding increase in resistance and of course vice versa.

• A T-strain gage rosette (Micro-measurements & Sr-4 Vishay 2 grids) (Figure 10) was attached to the each of the 5 implants below the distal aspect of the implant's collar and connected to a Vishay Micro measurements System 5000 multichannel strain conditioner.

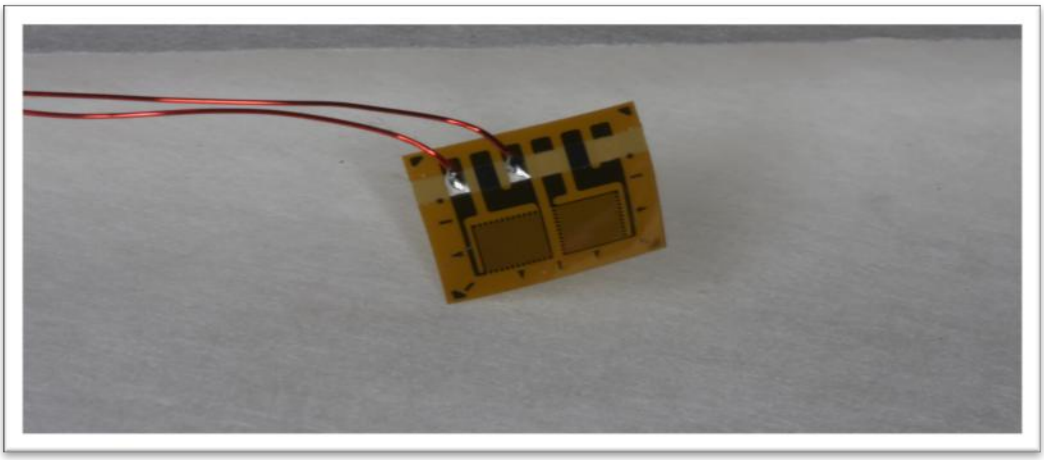

Figure 10 Strain gage rosette

In order to attach the strain gage, the collar was treated with sand paper (3M, 9003NA Aluminum Oxide Sandpaper, 9-Inch x 11-Inch, Coarse) (Figure 11) followed by application of a neutralizer (Vishay, M-Prep Neutralizer 5A).

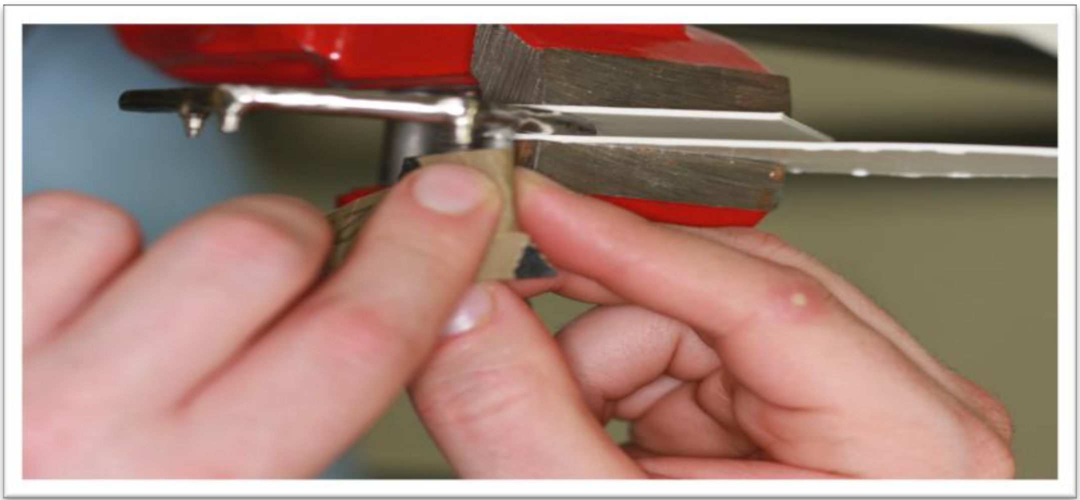

Figure 11 Implant collar treatment

The strain gage was then seated face down on a piece of adhesive tape (3M 109 Wallsaver Removable Mounting Tape) and then adhesive(M-BOND 200 Vishay) is applied on the back of the strain gage and then it was attached to the implant. (Figure12)

Figure 12 Adhesive application

After 15 min setting time at room temperature, polymerization was complete and the tape was removed. The strain gage was then tested again using an external gage reader unit (Vishay P3500) for responsiveness (Figure 13).

Figure 13 Gages attached to reader unit

- Each implant will receive a strain gage with two grids of which one measures vertical strains and the other one measures circumferential strains. The gages were numbered, Odd numbers will refer to circumferential strain gages and even numbers represent the vertical gages. (Figure 14 a, Table 14 b)

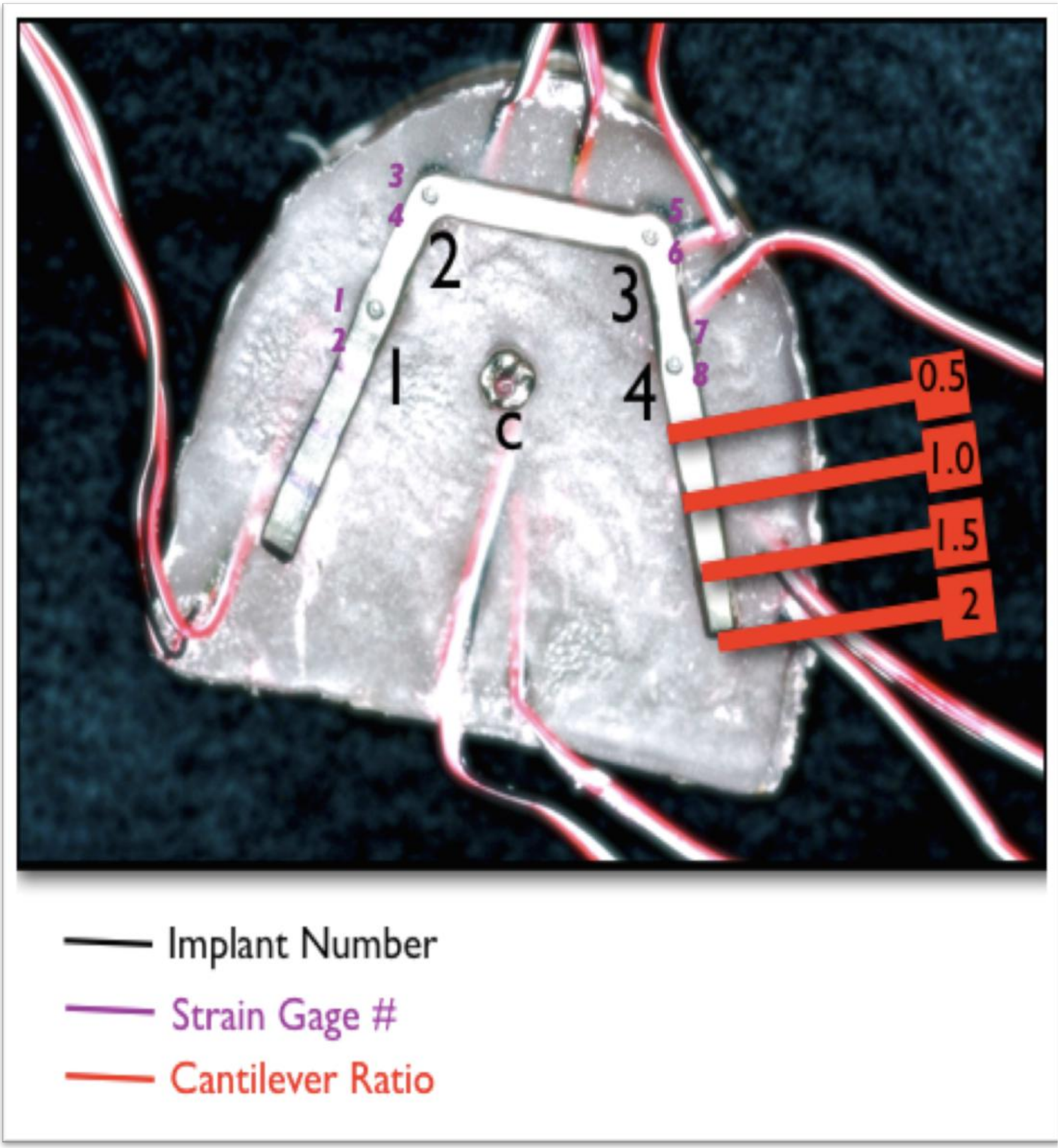

Figure 14 a, Model Numbering

Table 14 b, Implants Numbering

Implant Position	Gages Number	Gages Type
1	1	Circumferential
	2	Vertical
2	3	Circumferential
	4	Vertical
3	5	Circumferential
	6	Vertical
4	7	Circumferential
	8	Vertical

Prior to the experimental protocol, the strain gages were normalized after attachment, to zero strain.

3.3 Experimental protocol

- Forces were loaded axially on the framework and the single implant using MTS 810 loading system, (Figure 15) . All loading

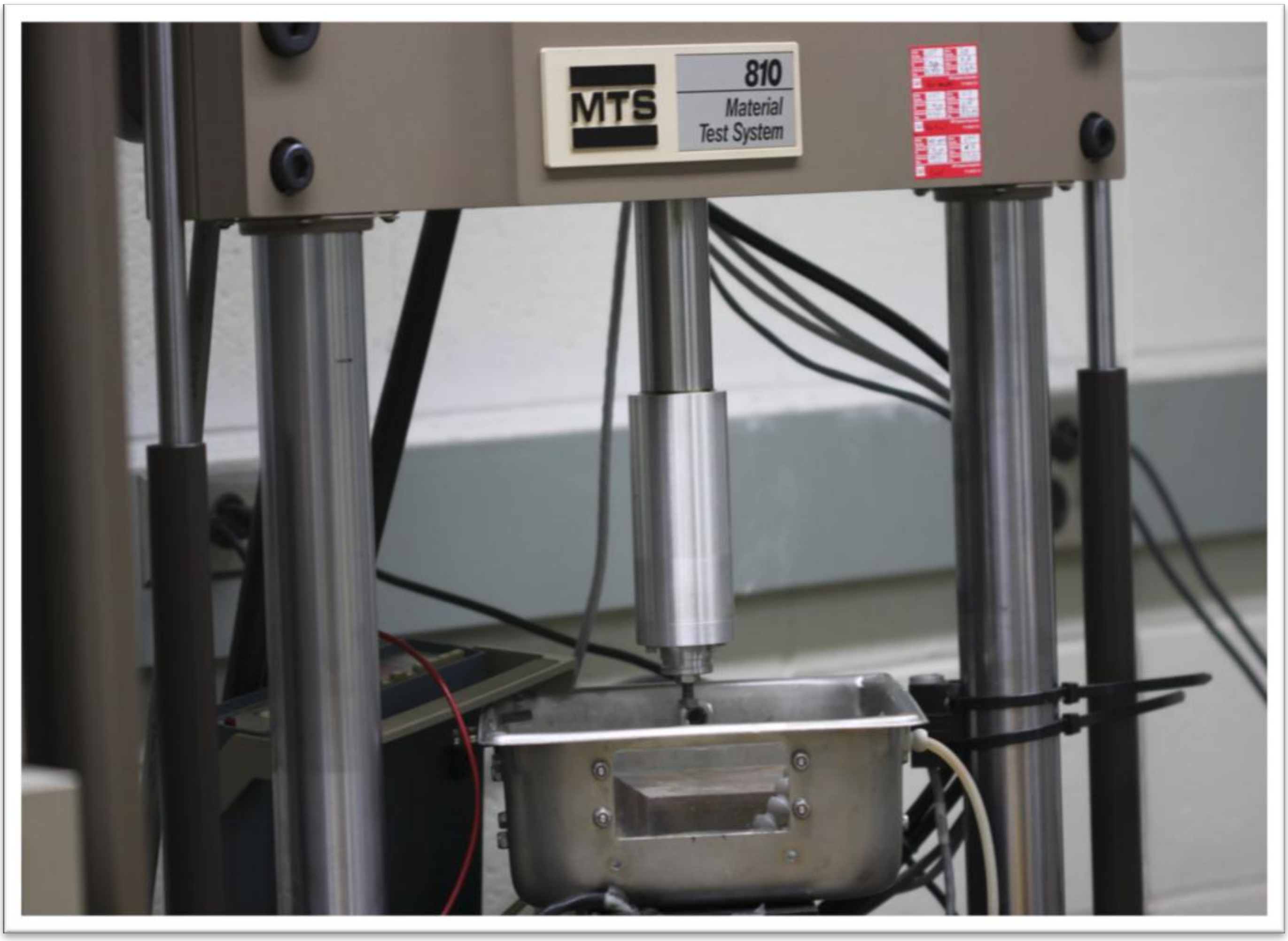

Figure 15 MTS810 loading system

were axial, perpendicular to the occlusal plane. The loads applied were:

  - 50N, 100N
  - Each load was applied 10 times (10 cycles):

    - Over the center of the single implant
    - Over the center of the anterior implant unilaterally (#3)
    - Over the center of the posterior implant unilaterally (#4)

  - The cantilever was loaded as such:
    - On the cantilever 7.5 mm distal to the most distal implant, ratio of 0.5
    - On the cantilever 15 mm distal to the most distal implant, ratio of 1.0
    - On the cantilever 22.5 mm distal to the most distal implant, ratio of 1.5
    - On the cantilever 30 mm distal to the most distal implant, ratio of 2.0

• The data was forwarded through an adapter (Figure 16) that

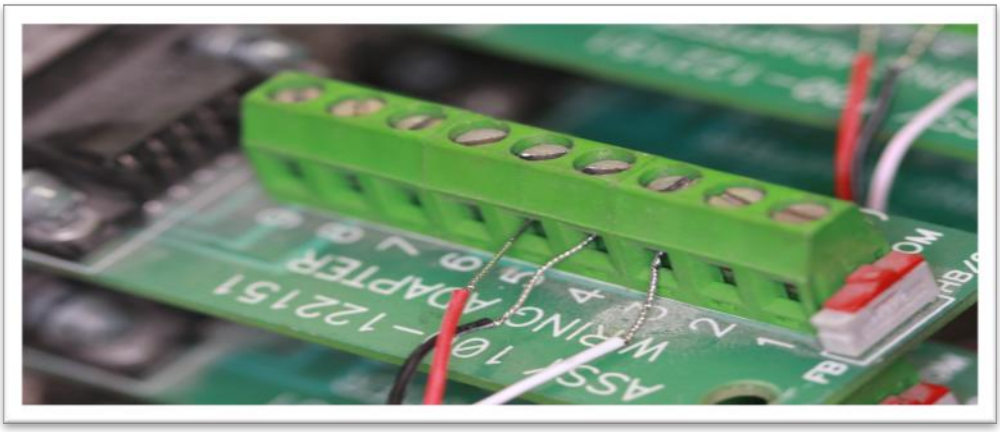

Figure 16 Data adapter

seamlessly transfer it into the strain conditioner (Figure 17) and inputted into a computer with Strain Smart 5000 Software (V 4.31) (Figure18)and then converted to a Microsoft Excel for Mac 2015 (version 15.11.2).

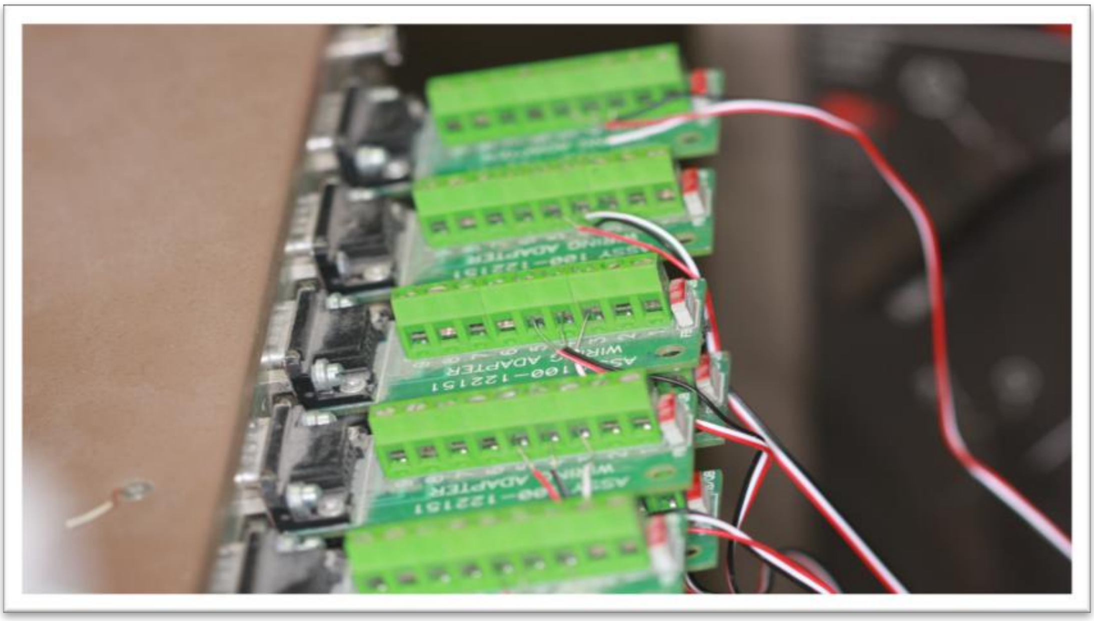

Figure 17 Strain conditioner

- Ten readings, were obtained from each trial, 2 on the single implant and 8 readings were obtained from each of the 4 implants attached to the framework.

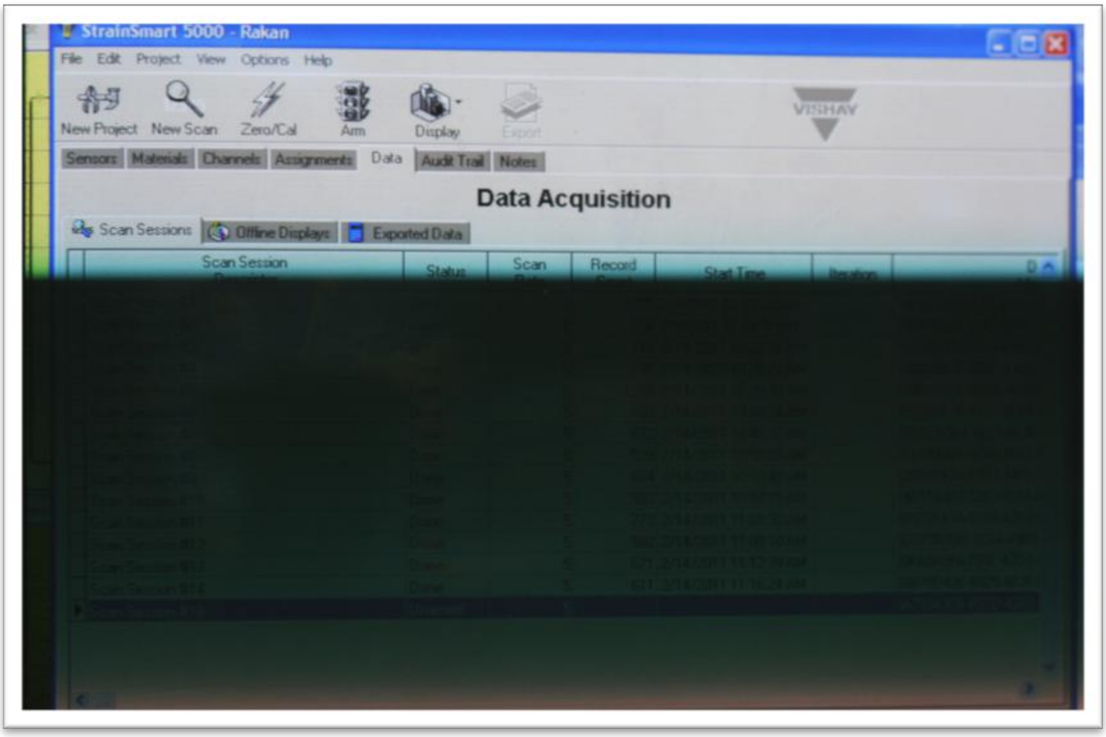

Figure 18 StrainSmart software 5000

Chapter IV. Statistical Analysis

The data were analyzed with SPSS version 18 in Microsoft Windows XP. The α value was set to 0.05 for all the statistical tests.

•Three-way ANOVA's were done separately for each dependent variable, the first was vertical strain and the second was circumferential with independent factors of:

- Magnitude of force
- Cantilever length
- Position of the implants

• Post hoc tests used Tukey's test to compare groups.

Initially at the beginning of the experiment, all the strain gages were tested for responsiveness.

The following table shows the statistical analysis of all the elements for the axial (vertical) strain gages. (Table 19)

Univariate Analysis of Axial Variance (Table 19)

Between-Subjects Factors		
		N
Length	.0	60
	7.5	60
	15.0	60
	22.5	60
	30.0	60
Position	1	100
	3	100
	4	100
Load	50	150
	100	150

Descriptive Statistics							
Dependent Variable:Axial (vertical)							
Length		Position	Load	Mean		Std. Deviation	N
dimension1	.0	dimension2	1	50	-.100	.3162	10
				100	-.800	.4216	10
				Total	-.450	.5104	20
			3	50	4.900	1.3703	10
				100	13.400	.6992	10
				Total	9.150	4.4871	20
			4	50	-.900	.5676	10
				100	.300	.4830	10
				Total	-.300	.8013	20
			Total	50	1.300	2.7436	30
				100	4.300	6.5818	30
				Total	2.800	5.2232	60
	7.5	dimension2	1	50	.100	.3162	10
				100	-.500	.5270	10
				Total	-.200	.5231	20
			3	50	21.600	4.9933	10
				100	37.000	.9428	10
				Total	29.300	8.6396	20
			4	50	.800	.6325	10
				100	-.200	.4216	10
				Total	.300	.7327	20
			Total	50	7.500	10.5266	30

				100	12.100	17.9200	30
				Total	9.800	14.7543	60
	15.0	dimension2	1	50	-.100	.3162	10
				100	-.100	.3162	10
				Total	-.100	.3078	20
			3	50	38.000	11.8603	10
				100	76.300	2.0028	10
				Total	57.150	21.3203	20
			4	50	-.200	.4216	10
				100	-.340	.4719	10
				Total	-.270	.4414	20
			Total	50	12.567	19.4505	30
				100	25.287	36.7070	30
				Total	18.927	29.8224	60
	22.5	dimension2	1	50	-.100	.3162	10
				100	-.200	.4216	10
				Total	-.150	.3663	20
			3	50	56.600	2.1705	10
				100	80.100	1.9692	10
				Total	68.350	12.2228	20
			4	50	-.700	.4830	10
				100	-.600	.6992	10
				Total	-.650	.5871	20
			Total	50	18.600	27.3592	30
				100	26.433	38.6154	30

				Total	22.517	33.4134	60
	30.0	dimension2	1	50	-.100	.3162	10
				100	-1.100	.3162	10
				Total	-.600	.5982	20
			3	50	70.700	3.6225	10
				100	101.400	.5164	10
				Total	86.050	15.9488	20
			4	50	.300	.4830	10
				100	-.500	.5270	10
				Total	-.100	.6407	20
			Total	50	23.633	33.9121	30
				100	33.267	49.0038	30
				Total	28.450	42.0619	60
	Total	dimension2	1	50	-.060	.3136	50
				100	-.540	.5425	50
				Total	-.300	.5025	100
			3	50	38.360	24.5197	50
				100	61.640	32.1963	50
				Total	50.000	30.7814	100
			4	50	-.140	.8084	50
				100	-.268	.5988	50
				Total	-.204	.7107	100
			Total	50	12.720	22.9973	150
				100	20.277	34.6742	150
				Total	16.499	29.6145	300

Tests of Between-Subjects Effects					
Dependent Variable:Axial (vertical)					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	260437.855[a]	29	8980.616	1354.237	.000
Intercept	81661.801	1	81661.801	12314.235	.000
Length	25048.289	4	6262.072	944.292	.000
Position	168351.361	2	84175.681	12693.316	.000
Load	4283.497	1	4283.497	645.932	.000
Length * Position	50658.158	8	6332.270	954.878	.000
Length * Load	908.313	4	227.078	34.242	.000
Position * Load	9271.633	2	4635.817	699.060	.000
Length * Position * Load	1916.606	8	239.576	36.127	.000
Error	1790.504	270	6.631		
Total	343890.160	300			
Corrected Total	262228.359	299			
a. R Squared = .993 (Adjusted R Squared = .992)					

Estimated Marginal Means

1. Length

Dependent Variable:Axial (vertical)

Length		Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
dimension1	.0	2.800	.332	2.145	3.455
	7.5	9.800	.332	9.145	10.455
	15.0	18.927	.332	18.272	19.581
	22.5	22.517	.332	21.862	23.171
	30.0	28.450	.332	27.795	29.105

2. Position

Dependent Variable:Axial (vertical)

Position		Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
dimension1	1	-.300	.258	-.807	.207
	3	50.000	.258	49.493	50.507
	4	-.204	.258	-.711	.303

3. Load				
Dependent Variable:Axial (vertical)				
Load	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
50	12.720	.210	12.306	13.134
100	20.277	.210	19.863	20.691

4. Length * Position							
Dependent Variable:Axial (vertical)							
Length		Position		Mean	Std. Error	95% Confidence Interval	
						Lower Bound	Upper Bound
dimension1	.0	dimension2	1	-.450	.576	-1.584	.684
			3	9.150	.576	8.016	10.284
			4	-.300	.576	-1.434	.834
	7.5	dimension2	1	-.200	.576	-1.334	.934
			3	29.300	.576	28.166	30.434
			4	.300	.576	-.834	1.434
	15.0	dimension2	1	-.100	.576	-1.234	1.034
			3	57.150	.576	56.016	58.284
			4	-.270	.576	-1.404	.864
	22.5	dim	1	-.150	.576	-1.284	.984
			3	68.350	.576	67.216	69.484

		ension2	4	-.650	.576	-1.784	.484
	30.0	dimension2	1	-.600	.576	-1.734	.534
			3	86.050	.576	84.916	87.184
			4	-.100	.576	-1.234	1.034

5. Length * Load						
Dependent Variable:Axial (vertical)						
Length		Load	Mean	Std. Error	95% Confidence Interval	
					Lower Bound	Upper Bound
dimension1	.0	50	1.300	.470	.374	2.226
		100	4.300	.470	3.374	5.226
	7.5	50	7.500	.470	6.574	8.426
		100	12.100	.470	11.174	13.026
	15.0	50	12.567	.470	11.641	13.492
		100	25.287	.470	24.361	26.212
	22.5	50	18.600	.470	17.674	19.526
		100	26.433	.470	25.508	27.359
	30.0	50	23.633	.470	22.708	24.559
		100	33.267	.470	32.341	34.192

6. Position * Load						
Dependent Variable:Axial (vertical)						
Position		Load	Mean	Std. Error	95% Confidence Interval	
					Lower Bound	Upper Bound
dimension1	1	50	-.060	.364	-.777	.657
		100	-.540	.364	-1.257	.177
	3	50	38.360	.364	37.643	39.077
		100	61.640	.364	60.923	62.357
	4	50	-.140	.364	-.857	.577
		100	-.268	.364	-.985	.449

7. Length * Position * Load								
Dependent Variable:Axial (vertical)								
Length		Position		Load	Mean	Std. Error	95% Confidence Interval	
							Lower Bound	Upper Bound
dimension1	.0	dimension2	1	50	-.100	.814	-1.703	1.503
				100	-.800	.814	-2.403	.803
			3	50	4.900	.814	3.297	6.503
				100	13.400	.814	11.797	15.003
			4	50	-.900	.814	-2.503	.703
				100	.300	.814	-1.303	1.903
	7.5	d	1	50	.100	.814	-1.503	1.703

		imension2		100	-.500	.814	-2.103	1.103
			3	50	21.600	.814	19.997	23.203
				100	37.000	.814	35.397	38.603
			4	50	.800	.814	-.803	2.403
				100	-.200	.814	-1.803	1.403
	15.0	dimension2	1	50	-.100	.814	-1.703	1.503
				100	-.100	.814	-1.703	1.503
			3	50	38.000	.814	36.397	39.603
				100	76.300	.814	74.697	77.903
			4	50	-.200	.814	-1.803	1.403
				100	-.340	.814	-1.943	1.263
	22.5	dimension2	1	50	-.100	.814	-1.703	1.503
				100	-.200	.814	-1.803	1.403
			3	50	56.600	.814	54.997	58.203
				100	80.100	.814	78.497	81.703
			4	50	-.700	.814	-2.303	.903
				100	-.600	.814	-2.203	1.003
	30.0	dimension2	1	50	-.100	.814	-1.703	1.503
				100	-1.100	.814	-2.703	.503
			3	50	70.700	.814	69.097	72.303
				100	101.400	.814	99.797	103.003
			4	50	.300	.814	-1.303	1.903
				100	-.500	.814	-2.103	1.103

Post Hoc Tests

Length

Multiple Comparisons								
Axial (vertical) Tukey HSD								
(I) Length		(J) Length		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
dimension2	.0	dimension3	7.5	-7.000*	.4702	.000	-8.291	-5.709
			15.0	-16.127*	.4702	.000	-17.418	-14.835
			22.5	-19.717*	.4702	.000	-21.008	-18.425
			30.0	-25.650*	.4702	.000	-26.941	-24.359
	7.5	dimension3	.0	7.000*	.4702	.000	5.709	8.291
			15.0	-9.127*	.4702	.000	-10.418	-7.835
			22.5	-12.717*	.4702	.000	-14.008	-11.425
			30.0	-18.650*	.4702	.000	-19.941	-17.359

	15.0	dimension3	.0	16.127*	.4702	.000	14.835	17.418
			7.5	9.127*	.4702	.000	7.835	10.418
			22.5	-3.590*	.4702	.000	-4.881	-2.299
			30.0	-9.523*	.4702	.000	-10.815	-8.232
	22.5	dimension3	.0	19.717*	.4702	.000	18.425	21.008
			7.5	12.717*	.4702	.000	11.425	14.008
			15.0	3.590*	.4702	.000	2.299	4.881
			30.0	-5.933*	.4702	.000	-7.225	-4.642
	30.0	dimension3	.0	25.650*	.4702	.000	24.359	26.941
			7.5	18.650*	.4702	.000	17.359	19.941
			15.0	9.523*	.4702	.000	8.232	10.815
			22.5	5.933*	.4702	.000	4.642	7.225

Based on observed means.

The error term is Mean Square(Error) = 6.631.

*. The mean difference is significant at the .05 level.

Homogeneous Subsets

Axial (vertical)							
Tukey HSD[a,b]							
Length		N	Subset				
			1	2	3	4	5
dimension1	.0	60	2.800				
	7.5	60		9.800			
	15.0	60			18.927		
	22.5	60				22.517	
	30.0	60					28.450
	Sig.		1.000	1.000	1.000	1.000	1.000
Means for groups in homogeneous subsets are displayed. Based on observed means. The error term is Mean Square(Error) = 6.631.							
a. Uses Harmonic Mean Sample Size = 60.000.							
b. Alpha = .05.							

Position

Multiple Comparisons								
Axial (vertical) Tukey HSD								
(I) Position		(J) Position		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
dimension2	1	dimension3	3	-50.300*	.3642	.000	-51.158	-49.442
			4	-.096	.3642	.962	-.954	.762
	3	dimension3	1	50.300*	.3642	.000	49.442	51.158
			4	50.204*	.3642	.000	49.346	51.062
	4	dimension3	1	.096	.3642	.962	-.762	.954
			3	-50.204*	.3642	.000	-51.062	-49.346
Based on observed means. The error term is Mean Square(Error) = 6.631.								
*. The mean difference is significant at the .05 level.								

Homogeneous Subsets

Axial (vertical)				
Tukey HSD[a,b]				
Position		N	Subset	
			1	2
dimension1	1	100	-.300	
	4	100	-.204	
	3	100		50.000
	Sig.		.962	1.000
Means for groups in homogeneous subsets are displayed. Based on observed means. The error term is Mean Square(Error) = 6.631.				
a. Uses Harmonic Mean Sample Size = 100.000.				
b. Alpha = .05.				

The following table shows the statistical analysis of all the elements for the circumferential strain gages. (Table 20)

Univariate Analysis of Circumferential Variance (Table20)

Between-Subjects Factors		
		N
Length	.0	80
	7.5	80
	15.0	80
	22.5	80
	30.0	80
Position	1	100
	2	100
	3	100
	4	100
Load	50	200
	100	200

Descriptive Statistics							
Dependent Variable:Curcum (HS)							
Length		Position		Load	Mean	Std. Deviation	N
dimension1	.0	dimension2	1	50	-.100	.3162	10
				100	-.100	.3162	10
				Total	-.100	.3078	20
			2	50	-.400	.5164	10
				100	2.200	.4216	10
				Total	.900	1.4105	20
			3	50	-4.500	.7071	10
				100	5.200	.4216	10
				Total	.350	5.0082	20
			4	50	-415.600	4.8580	10
				100	57.200	1.7512	10
				Total	-179.200	242.5673	20
			Total	50	-105.150	181.5459	40
				100	16.125	24.1089	40
				Total	-44.512	142.4122	80
	7.5	dimension2	1	50	-.300	.4830	10
				100	-.400	.5164	10
				Total	-.350	.4894	20
			2	50	.200	.4216	10
				100	.000	.0000	10
				Total	.100	.3078	20

			3	50	-.400	.5164	10
				100	-.300	.6749	10
				Total	-.350	.5871	20
			4	50	36.200	8.5739	10
				100	100.700	2.1108	10
				Total	68.450	33.6413	20
			Total	50	8.925	16.4775	40
				100	25.000	44.2759	40
				Total	16.963	34.1647	80
	15.0	dimension2	1	50	1.000	.0000	10
				100	.500	.5270	10
				Total	.750	.4443	20
			2	50	.600	.5164	10
				100	1.400	.6992	10
				Total	1.000	.7255	20
			3	50	.000	.6667	10
				100	1.600	1.0750	10
				Total	.800	1.1965	20
			4	50	68.600	22.2920	10
				100	114.060	3.3520	10
				Total	91.330	28.0099	20
			Total	50	17.550	31.7167	40
				100	29.390	49.5394	40
				Total	23.470	41.7569	80
	22.	di	1	50	.600	.5164	10

	5	m en si on 2		100	1.200	.4216	10
				Total	.900	.5525	20
			2	50	1.000	.6667	10
				100	2.300	.4830	10
				Total	1.650	.8751	20
			3	50	-1.700	.9487	10
				100	-.500	.5270	10
				Total	-1.100	.9679	20
			4	50	87.300	2.9833	10
				100	106.200	2.2998	10
				Total	96.750	10.0361	20
			Total	50	21.800	38.3441	40
				100	27.300	46.1593	40
				Total	24.550	42.2533	80
	30. 0	di m en si on 2	1	50	.000	.0000	10
				100	2.200	.4216	10
				Total	1.100	1.1653	20
			2	50	1.900	.3162	10
				100	3.400	.5164	10
				Total	2.650	.8751	20
			3	50	.700	.8233	10
				100	8.300	.9487	10
				Total	4.500	3.9934	20
			4	50	88.600	4.0879	10
				100	85.900	2.8848	10

				Total	87.250	3.7116	20
			Total	50	22.800	38.5322	40
				100	24.950	35.7441	40
				Total	23.875	36.9442	80
	Tot al	di m en si on 2	1	50	.240	.5911	50
				100	.680	1.0388	50
				Total	.460	.8695	100
			2	50	.660	.9172	50
				100	1.860	1.2291	50
				Total	1.260	1.2360	100
			3	50	-1.180	1.9866	50
				100	2.860	3.5168	50
				Total	.840	3.4923	100
			4	50	-26.980	197.4992	50
				100	92.812	20.3944	50
				Total	32.916	152.1039	100
			Total	50	-6.815	98.7038	200
				100	24.553	40.8362	200
				Total	8.869	77.0540	400

Tests of Between-Subjects Effects					
Dependent Variable:Curcum (HS)					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2.363E6	39	60590.643	3662.158	.000
Intercept	31463.664	1	31463.664	1901.695	.000
Length	287948.183	4	71987.046	4350.967	.000
Position	77133.121	3	25711.040	1554.000	.000
Load	98395.142	1	98395.142	5947.099	.000
Length * Position	846434.260	12	70536.188	4263.276	.000
Length * Load	204426.645	4	51106.661	3088.937	.000
Position * Load	260806.819	3	86935.606	5254.473	.000
Length * Position * Load	587890.902	12	48990.908	2961.058	.000
Error	5956.224	360	16.545		
Total	2400454.960	400			
Corrected Total	2368991.296	399			
a. R Squared = .997 (Adjusted R Squared = .997)					

Estimated Marginal Means

1. Length					
Dependent Variable:Curcum (HS)					
Length		Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
dimension1	.0	-44.512	.455	-45.407	-43.618
	7.5	16.962	.455	16.068	17.857
	15.0	23.470	.455	22.576	24.364
	22.5	24.550	.455	23.656	25.444
	30.0	23.875	.455	22.981	24.769

2. Position					
Dependent Variable:Curcum (HS)					
Position		Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
	2	1.260	.407	.460	2.060
	3	.840	.407	.040	1.640

	4	32.916	.407	32.116	33.716

3. Load				
Dependent Variable:Curcum (HS)				
Load	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
50	-6.815	.288	-7.381	-6.249
100	24.553	.288	23.987	25.119

4. Length * Position							
Dependent Variable:Curcum (HS)							
Length		Position		Mean	Std. Error	95% Confidence Interval	
						Lower Bound	Upper Bound
dimension1	.0	dimension2	1	-.100	.910	-1.889	1.689
			2	.900	.910	-.889	2.689
			3	.350	.910	-1.439	2.139
			4	-179.200	.910	-180.989	-177.411
	7.5	dim	1	-.350	.910	-2.139	1.439
			2	.100	.910	-1.689	1.889

		ension2	3	-.350	.910	-2.139	1.439
			4	68.450	.910	66.661	70.239
	15.0	dimension2	1	.750	.910	-1.039	2.539
			2	1.000	.910	-.789	2.789
			3	.800	.910	-.989	2.589
			4	91.330	.910	89.541	93.119
	22.5	dimension2	1	.900	.910	-.889	2.689
			2	1.650	.910	-.139	3.439
			3	-1.100	.910	-2.889	.689
			4	96.750	.910	94.961	98.539
	30.0	dimension2	1	1.100	.910	-.689	2.889
			2	2.650	.910	.861	4.439
			3	4.500	.910	2.711	6.289
			4	87.250	.910	85.461	89.039

5. Length * Load						
Dependent Variable:Curcum (HS)						
Length		Load	Mean	Std. Error	95% Confidence Interval	
					Lower Bound	Upper Bound
dimension1	.0	50	-105.150	.643	-106.415	-103.885
		100	16.125	.643	14.860	17.390
	7.5	50	8.925	.643	7.660	10.190
		100	25.000	.643	23.735	26.265
	15.0	50	17.550	.643	16.285	18.815
		100	29.390	.643	28.125	30.655
	22.5	50	21.800	.643	20.535	23.065
		100	27.300	.643	26.035	28.565
	30.0	50	22.800	.643	21.535	24.065
		100	24.950	.643	23.685	26.215

6. Position * Load						
Dependent Variable:Curcum (HS)						
Position		Load	Mean	Std. Error	95% Confidence Interval	
					Lower Bound	Upper Bound
dimension1	1	50	.240	.575	-.891	1.371
		100	.680	.575	-.451	1.811
	2	50	.660	.575	-.471	1.791
		100	1.860	.575	.729	2.991
	3	50	-1.180	.575	-2.311	-.049
		100	2.860	.575	1.729	3.991
	4	50	-26.980	.575	-28.111	-25.849
		100	92.812	.575	91.681	93.943

7. Length * Position * Load								
Dependent Variable:Curcum (HS)								
Length		Position		Load	Mean	Std. Error	95% Confidence Interval	
							Lower Bound	Upper Bound
dimension1	.0	dimension2	1	50	-.100	1.286	-2.630	2.430
				100	-.100	1.286	-2.630	2.430
			2	50	-.400	1.286	-2.930	2.130
				100	2.200	1.286	-.330	4.730
			3	50	-4.500	1.286	-7.030	-1.970
				100	5.200	1.286	2.670	7.730
			4	50	-415.600	1.286	-418.130	-413.070
				100	57.200	1.286	54.670	59.730
	7.5	dimension2	1	50	-.300	1.286	-2.830	2.230
				100	-.400	1.286	-2.930	2.130
			2	50	.200	1.286	-2.330	2.730
				100	-8.171E-14	1.286	-2.530	2.530
			3	50	-.400	1.286	-2.930	2.130
				100	-.300	1.286	-2.830	2.230
			4	50	36.200	1.286	33.670	38.730
				100	100.700	1.286	98.170	103.230
	15.0	dimen	1	50	1.000	1.286	-1.530	3.530
				100	.500	1.286	-2.030	3.030
			2	50	.600	1.286	-1.930	3.130

		sion2		100	1.400	1.286	-1.130	3.930
			3	50	-3.553E-14	1.286	-2.530	2.530
				100	1.600	1.286	-.930	4.130
			4	50	68.600	1.286	66.070	71.130
				100	114.060	1.286	111.530	116.590
	22.5	dimension2	1	50	.600	1.286	-1.930	3.130
				100	1.200	1.286	-1.330	3.730
			2	50	1.000	1.286	-1.530	3.530
				100	2.300	1.286	-.230	4.830
			3	50	-1.700	1.286	-4.230	.830
				100	-.500	1.286	-3.030	2.030
			4	50	87.300	1.286	84.770	89.830
				100	106.200	1.286	103.670	108.730
	30.0	dimension2	1	50	-2.753E-14	1.286	-2.530	2.530
				100	2.200	1.286	-.330	4.730
			2	50	1.900	1.286	-.630	4.430
				100	3.400	1.286	.870	5.930
			3	50	.700	1.286	-1.830	3.230
				100	8.300	1.286	5.770	10.830
			4	50	88.600	1.286	86.070	91.130
				100	85.900	1.286	83.370	88.430

Post Hoc Tests

Length

Multiple Comparisons							
Curcum (HS) Tukey HSD							
(I) Length		(J) Length	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
dimension2	.0	dimension3 7.5	-61.475*	.6431	.000	-63.238	-59.712
		15.0	-67.983*	.6431	.000	-69.746	-66.219
		22.5	-69.063*	.6431	.000	-70.826	-67.299
		30.0	-68.387*	.6431	.000	-70.151	-66.624
	7.5	dimension3 .0	61.475*	.6431	.000	59.712	63.238
		15.0	-6.508*	.6431	.000	-8.271	-4.744
		22.5	-7.588*	.6431	.000	-9.351	-5.824
		30.0	-6.912*	.6431	.000	-8.676	-5.149
	15.0	dimen .0	67.983*	.6431	.000	66.219	69.746
		7.5	6.508*	.6431	.000	4.744	8.271
		22.5	-1.080	.6431	.448	-2.843	.683

		sion3	30.0	-.405	.6431	.970	-2.168	1.358
	22.5	dimension3	.0	69.063*	.6431	.000	67.299	70.826
			7.5	7.588*	.6431	.000	5.824	9.351
			15.0	1.080	.6431	.448	-.683	2.843
			30.0	.675	.6431	.832	-1.088	2.438
	30.0	dimension3	.0	68.387*	.6431	.000	66.624	70.151
			7.5	6.912*	.6431	.000	5.149	8.676
			15.0	.405	.6431	.970	-1.358	2.168
			22.5	-.675	.6431	.832	-2.438	1.088

Based on observed means.

The error term is Mean Square(Error) = 16.545.

*. The mean difference is significant at the .05 level.

Homogeneous Subsets

Curcum (HS)					
Tukey HSD[a,b]					
Length		N	Subset		
			1	2	3
dimension1	.0	80	-44.512		
	7.5	80		16.963	
	15.0	80			23.470
	30.0	80			23.875
	22.5	80			24.550
	Sig.		1.000	1.000	.448

Means for groups in homogeneous subsets are displayed.

Based on observed means.

The error term is Mean Square(Error) = 16.545.

a. Uses Harmonic Mean Sample Size = 80.000.

b. Alpha = .05.

Position

Multiple Comparisons								
Curcum (HS) Tukey HSD								
(I) Position		(J) Position		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
dimension2	1	dimension3	2	-.800	.5752	.506	-2.285	.685
			3	-.380	.5752	.912	-1.865	1.105
			4	-32.456*	.5752	.000	-33.941	-30.971
	2	dimension3	1	.800	.5752	.506	-.685	2.285
			3	.420	.5752	.885	-1.065	1.905
			4	-31.656*	.5752	.000	-33.141	-30.171
	3	dimension	1	.380	.5752	.912	-1.105	1.865
			2	-.420	.5752	.885	-1.905	1.065
			4	-32.076*	.5752	.000	-33.561	-30.591

		3						
	4	dimension3	1	32.456*	.5752	.000	30.971	33.941
			2	31.656*	.5752	.000	30.171	33.141
			3	32.076*	.5752	.000	30.591	33.561

Based on observed means.

The error term is Mean Square(Error) = 16.545.

*. The mean difference is significant at the .05 level.

Homogeneous Subsets

Curcum (HS)				
Tukey HSD[a,b]				
Position		N	Subset	
			1	2
dimension1	1	100	.460	
	3	100	.840	
	2	100	1.260	
	4	100		32.916
	Sig.		.506	1.000

Means for groups in homogeneous subsets are displayed.

Based on observed means.

The error term is Mean Square(Error) = 16.545.

a. Uses Harmonic Mean Sample Size = 100.000.

b. Alpha = .05.

Chapter V. Results

Data were obtained from all the Strain gages except number 4, the axial gage on the implant at position 2, as it deemed not functional. The data from this gage were treated as zeros for the purpose of the statistical analysis. The total number of each group is shown in table 21,22

Table 11Between subjects Circumferential

Between-Subjects Factors (Circumferential)		
		N
Length	.0	80
	7.5	80
	15.0	80
	22.5	80
	30.0	80
Position	1	100
	2	100
	3	100
	4	100
Load	50	200
	100	200

Table 22 Between subjects Axial

Between-Subjects Factors (Axial)		
		N
Length	.0	60
	7.5	60
	15.0	60
	22.5	60
	30.0	60
Position	1	100
	3	100
	4	100
Load	50	150
	100	150

Table 23a (ANOVA results- axial)

Tests of Between-Subjects Effects

Dependent Variable: Axial

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	260437.855[a]	29	8980.616	1354.237	.000
Intercept	81661.801	1	81661.801	12314.235	.000
Length	25048.289	4	6262.072	944.292	.000
Position	168351.361	2	84175.681	12693.316	.000
Load	4283.497	1	4283.497	645.932	.000
Length * Position	50658.158	8	6332.270	954.878	.000
Length * Load	908.313	4	227.078	34.242	.000
Position * Load	9271.633	2	4635.817	699.060	.000
Length * Position * Load	1916.606	8	239.576	36.127	.000
Error	1790.504	270	6.631		
Total	343890.160	300			
Corrected Total	262228.359	299			

All the data were organized in Microsoft Excel 2010:Mac and tables were arranged for the statistical analysis. The dependent variable was the micro strain recorded. The independent variables were load, position, and location of load. An interaction between each variable was set as well. The α value was set to 0.05 and the confidence level was set to 95%. The results from ANOVA showed no statistical significant difference(tables 22, 23). Thus, the null hypotheses were rejected . The results from Post Hoc test, Tukey HSD, are shown in tables 24,25

Table 23 (ANOVA results- Circumferential)

Tests of Between-Subjects Effects					
Dependent Variable: Circumferential					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2.363E6	39	60590.643	3662.158	.000
Intercept	31463.664	1	31463.664	1901.695	.000
Length	287948.183	4	71987.046	4350.967	.000
Position	77133.121	3	25711.040	1554.000	.000
Load	98395.142	1	98395.142	5947.099	.000
Length * Position	846434.260	12	70536.188	4263.276	.000
Length * Load	204426.645	4	51106.661	3088.937	.000
Position * Load	260806.819	3	86935.606	5254.473	.000
Length * Position * Load	587890.902	12	48990.908	2961.058	.000
Error	5956.224	360	16.545		
Total	2400454.960	400			
Corrected Total	2368991.296	399			

Table 24 Tukey Post hoc-curcumferential

Circum.		N	Mean	SD	P. Value	Turkey Post Hoc
Cantilever	0	80	-44.512	.455	< .0001	C
	7.5	80	16.962	.455		B
	15	80	23.470	.455		A
	22.5	80	24.550	.455		A
	30	80	23.875	.455		A
Load	50	200	-6.815	.288	< .0001	
	100	200	24.553	.288		
Implant Position	1	100	.460	-.340	< .0001	B
	2	100	1.260	.460		B
	3	100	.840	.040		B
	4	100	32.916	32.116		A
Cant * pos* load					< .0001	

Table 25 Tukey Post hoc-axial

Axial		N	Mean	SD	P. Value	Turkey Post Hoc
Cantilever	0	80	2.800	.332	< .0001	E
	7.5	80	9.800	.332		D
	15	80	18.927	.332		C
	22.5	80	22.517	.332		B
	30	80	28.450	.332		A
Load	50	200	12.720	.210	< .0001	
	100	200	20.277	.210		
Implant Position	1	100	-.300	.258	< .0001	B
	3	100	50.00	.258		A
	4	100	-.204	.258		B
Cant * pos* load					< .0001	

The strain gage readings on the side where the forces were applied were significantly higher than the ones on the contralateral side. Implants number 1 and 2 showed minimal activity compared with implants number 3 and 4 for both 50 N (Figure 26) and 100 N (Figure 27) applied forces.

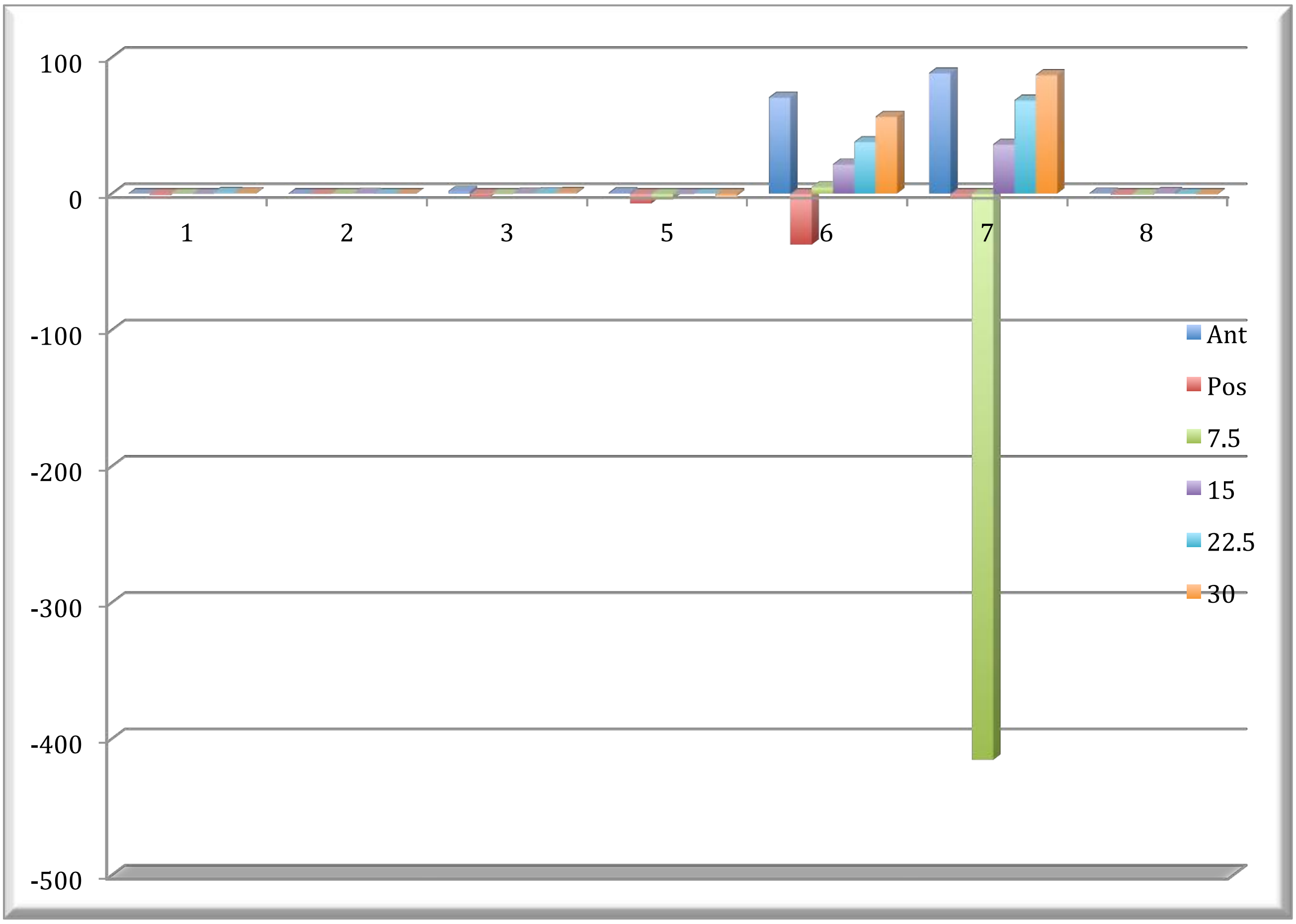

Figure 26 strain gage readings on implants when 50 N applied

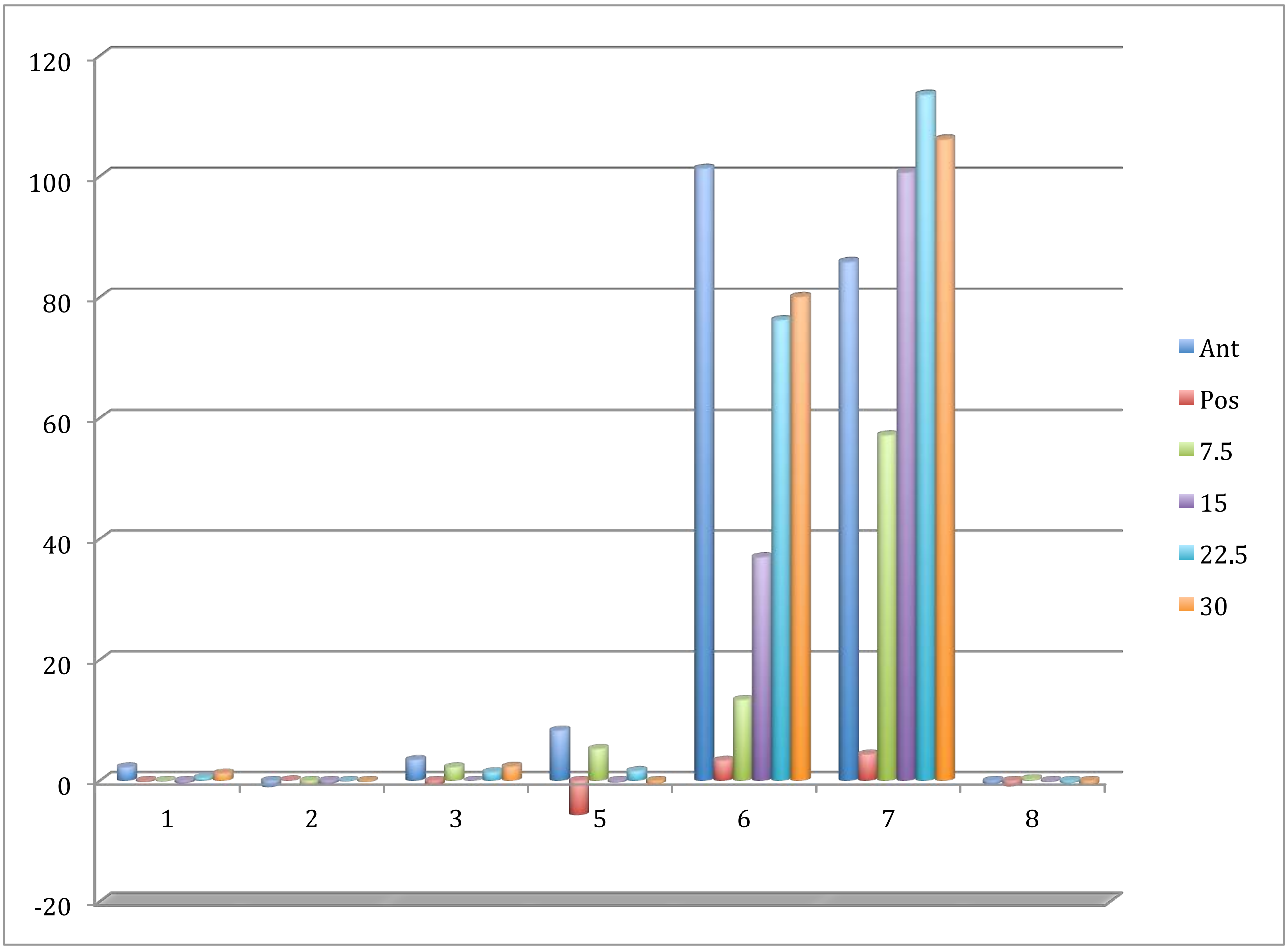

Figure 27 strain gage readings on implants when 100 N applied

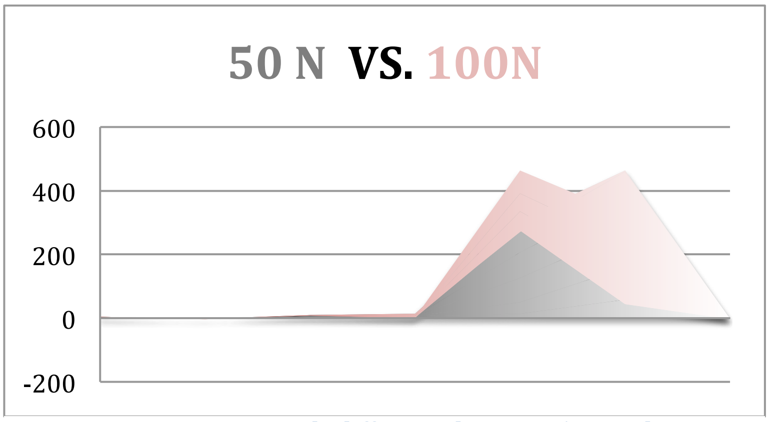

Figure 28 Magnitude difference between 50 N and 100 N

The magnitude of the data when 50 N forces were applied on all points showed a lower reading than when the 100 N was applied (Figure28)

When implants were loaded, direct loading over implants showed (Averages):

A. When loading implant number 3 directly, as 50N is applied, implant number 3 showed a reading of -7.2 με on the circumferential strain gage and -37.5 με on the vertical strain gage (Table 29, Figure 30). As 100N is applied, it showed -5.7 με on the circumferential strain gage and 3.3 με on the vertical strain gage (Table 31, Figure 32).

Table 29 strain gages readings on implants 3,4 when 50 N applied directly on implant 3

			Implant number 3		Implant number 4	
[01] Strain	[02] Strain	[03] Strain	[05] Strain	[06] Strain	[07] Strain	[08] Strain
-1	0	-2	-8	-38	-3	-1
-1	0	-2	-8	-39	-4	-1
-1	0	-2	-8	-38	-4	-1
-2	0	-2	-6	-36	-3	-1
-1	0	-2	-6	-36	-4	-1
-2	-1	-2	-8	-38	-3	0
-1	0	-2	-7	-38	-3	-1
-1	-1	-2	-7	-37	-3	-2
-1	0	-2	-7	-38	-4	-1
-1	0	-2	-7	-37	-3	-1
-1.2	-0.2	-2	-7.2	-37.5	-3.4	-1

Average

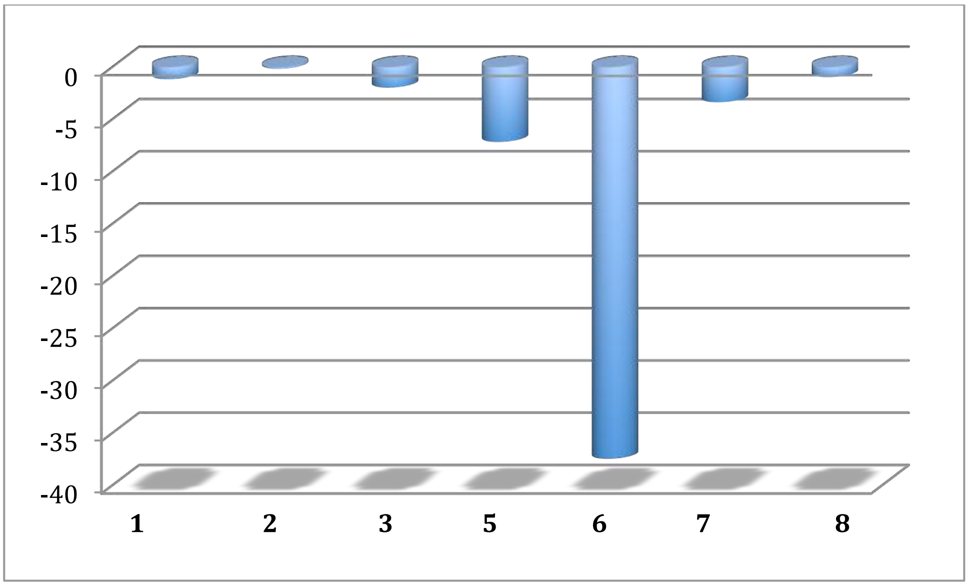

Figure 30 strain gages when 50 N applied on implant 3

B. When loading implant number 3 directly, as 50N is applied, implant number 4 showed a reading of -3.4 με on the circumferential strain gage and -1.0 με on the vertical strain gage (Table 29, Figure 30). As 100N is applied, it showed 4.3 με on the circumferential strain gage and -1.0 με on the vertical strain gage (Table 31, Figure 32).

Table 31 strain gages readings on implants 3,4 when 50 N applied directly on implant 3

			Implant number 3		Implant number 4	
[01] Strain	[02] Strain	[03] Strain	[05] Strain	[06] Strain	[07] Strain	[08] Strain
0	0	2	-6	3	5	0
0	0	-1	-5	6	5	-1
0	0	-1	-5	6	5	0
-1	1	-2	-6	2	4	-2
0	0	-1	-6	2	4	-1
0	0	-1	-6	2	4	-2
-1	0	-1	-5	2	4	-1
0	0	-1	-7	3	4	-1
0	0	-1	-6	3	4	-2
0	0	0	-5	4	4	0
-0.2	0.1	-0.7	-5.7	3.3	4.3	-1

Average

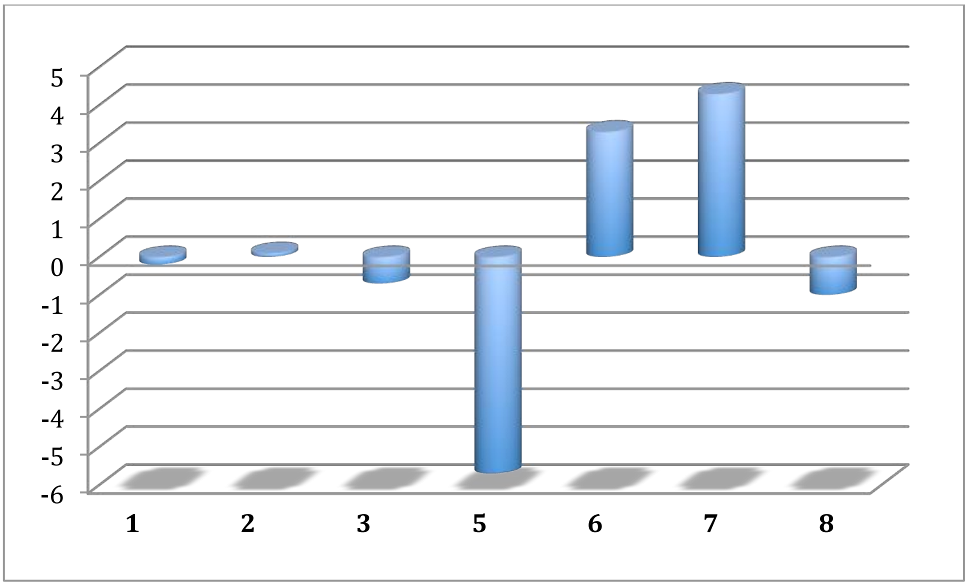

Figure 32 strain gages when 100 N applied on implant 3

C. When loading implant number 4 directly, as 50N is applied, implant number 3 showed a reading of -4.5 με on the circumferential strain gage and 4.9 με on the vertical strain gage(Figure 33). As 100N is applied, it showed 5.2 με on the circumferential strain gage and 13.4 με on the vertical strain gage(Figure 34). Those numeric results and the rest of the descriptive following results are listed in table 39. However Figureative charts will follow the descriptive paragraphs.

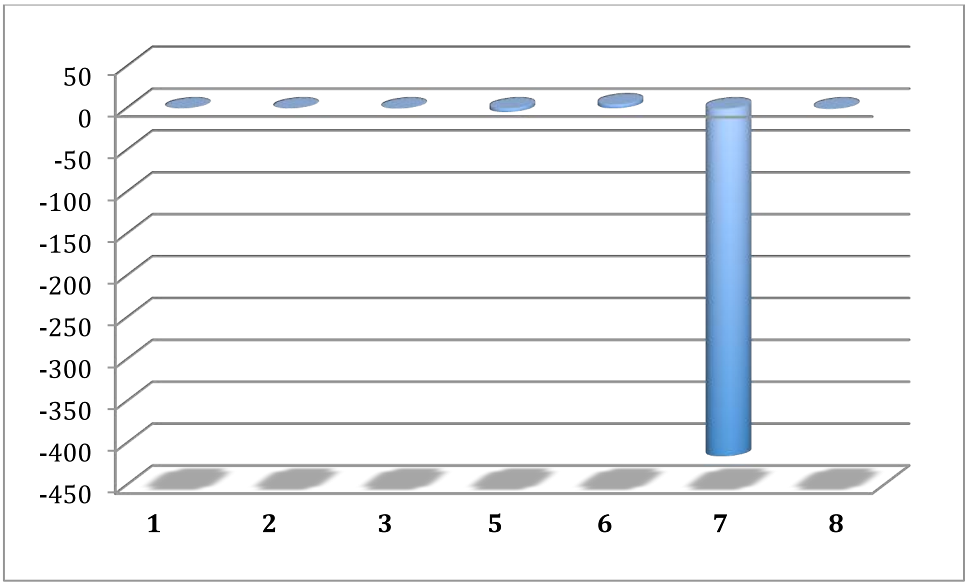

Figure 33 Strain gages when 50 N applied in implant 4

D. When loading implant number 4 directly, as 50N is applied, implant number 4 showed a reading of -415.6 με on the circumferential strain gage and 0.9 με on the vertical strain gage(Figure 33). As 100N is applied, it showed 57.2 με on the circumferential strain gage and 0.3 με on the vertical strain gage(Figure 34).

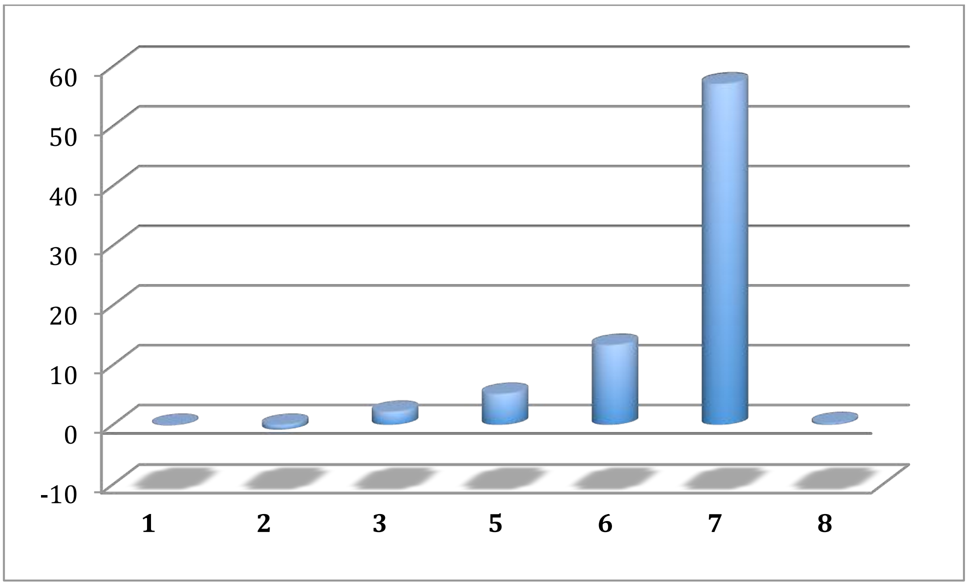

Figure 34 Strain gages when 100 N applied on implant 4

Never the less, as the cantilever were loaded, it showed that:

A. When loading on 7.5mm on the cantilever directly, as 50N is applied, implant number 3 showed a reading of -0.4 με on the circumferential strain gage and 21.6 με on the vertical strain gage. As 100N is applied, it showed -0.3 με on the circumferential strain gage and 37 με on the vertical strain gage(Figure 35).

B. When loading on 7.5mm on the cantilever directly, as 50N is applied, implant number 4 showed a reading of 36.2 με on the circumferential strain gage and 0.8 με on the vertical strain gage. As 100N is applied, it showed 100.7 με on the circumferential strain gage and-0.2 με on the vertical strain gage(Figure35).

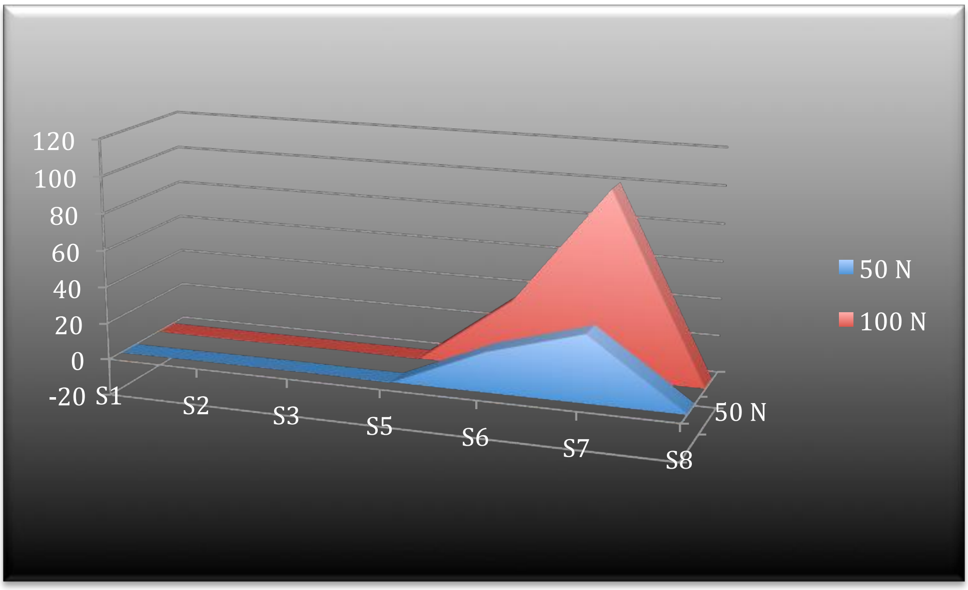

Figure 35 Strain gages subjected to 50,100 N when applied on 7.5 mm cantilever

C. When loading on 15 mm on the cantilever directly, as 50N is applied, implant number 3 showed a reading of 0 με on the circumferential strain gage and 38 με on the vertical strain gage. As 100N is applied, it showed 1.6 με on the circumferential strain gage and 76.3 με on the vertical strain gage(Figure36).

D. When loading on 15 mm on the cantilever directly, as 50N is applied, implant number 4 showed a reading of 68.6 με on the circumferential strain gage and -0.2 με on the vertical strain gage. As 100N is applied, it showed 113.6 με on the circumferential strain gage and -0.4 με on the vertical strain gage(Figure 36).

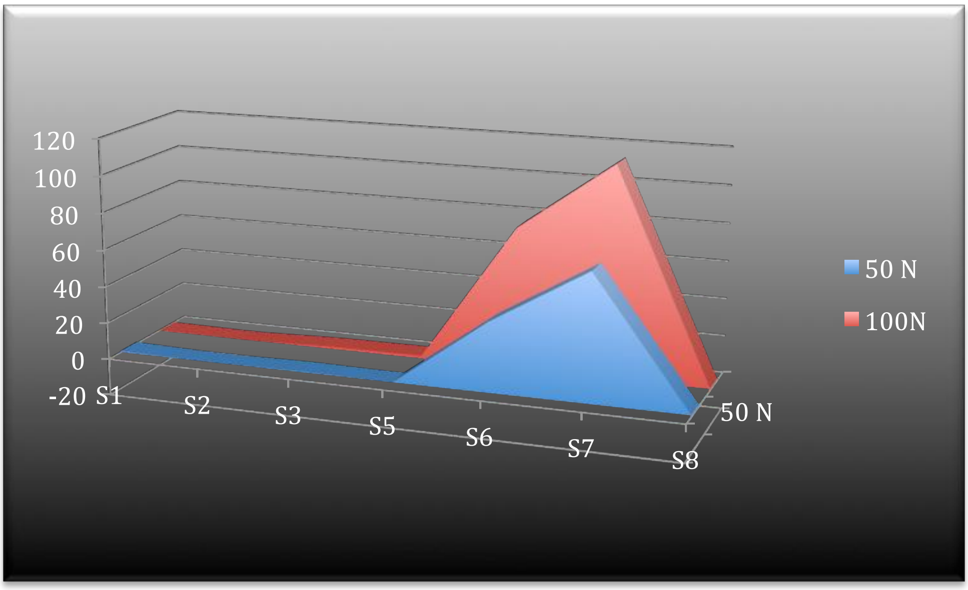

Figure 36 Strain gages subjected to 50,100 N when applied on 15 mm cantilever

E. When loading on 22.5 mm on the cantilever directly, as 50N is applied, implant number 3 showed a reading of -

1.7 με on the circumferential strain gage and 56.6 με on the vertical strain gage. As 100N is applied, it showed -0.5 με on the circumferential strain gage and 80.1 με on the vertical strain gage(Figure 37).

F. When loading on 22.5 mm on the cantilever directly, as 50N is applied, implant number 4 showed a reading of 87.3 με on the circumferential strain gage and -0.7 με on the vertical strain gage. As 100N is applied, it showed 106.2 με on the circumferential strain gage and -0.7 με on the vertical strain gage(Figure 37).

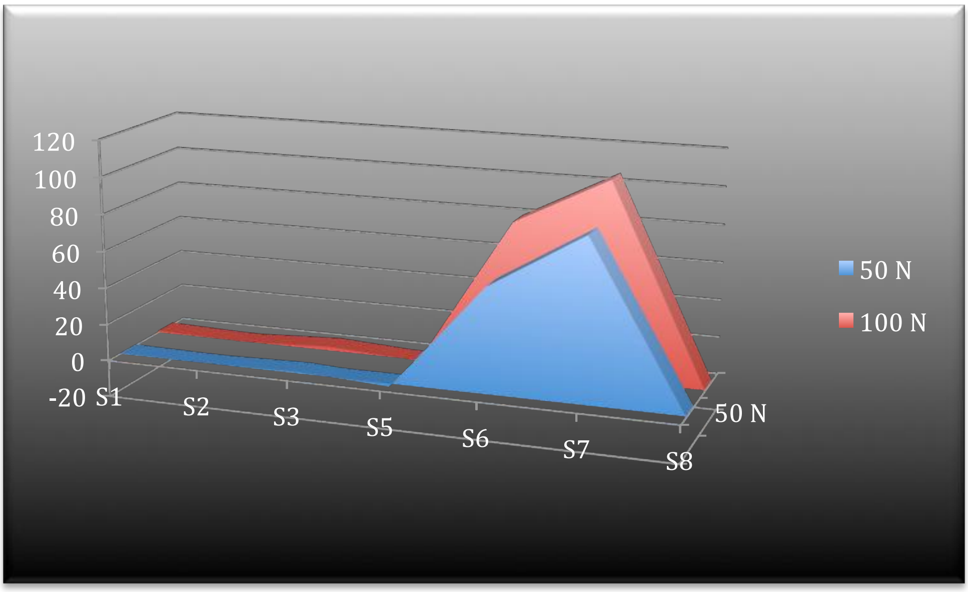

Figure 37 Strain gages subjected to 50,100 N when applied on 22.5 mm cantilever

G. When loading on 30 mm on the cantilever directly, as 50N is applied, implant number 3 showed a reading of 0.7 με on the circumferential strain gage and 70.7 με on the vertical strain gage. As 100N is applied, it showed 8.3 με on the circumferential strain gage and 101.4 με on the vertical strain gage(Figure 38).

H. When loading on 30 mm on the cantilever directly, as 50N is applied, implant number 4 showed a reading of 88.6 με on the circumferential strain gage and 0.3 με on the vertical strain gage. As 100N is applied, it showed 85.9 με on the circumferential strain gage and-0.5 με on the vertical strain gage(Figure 38).

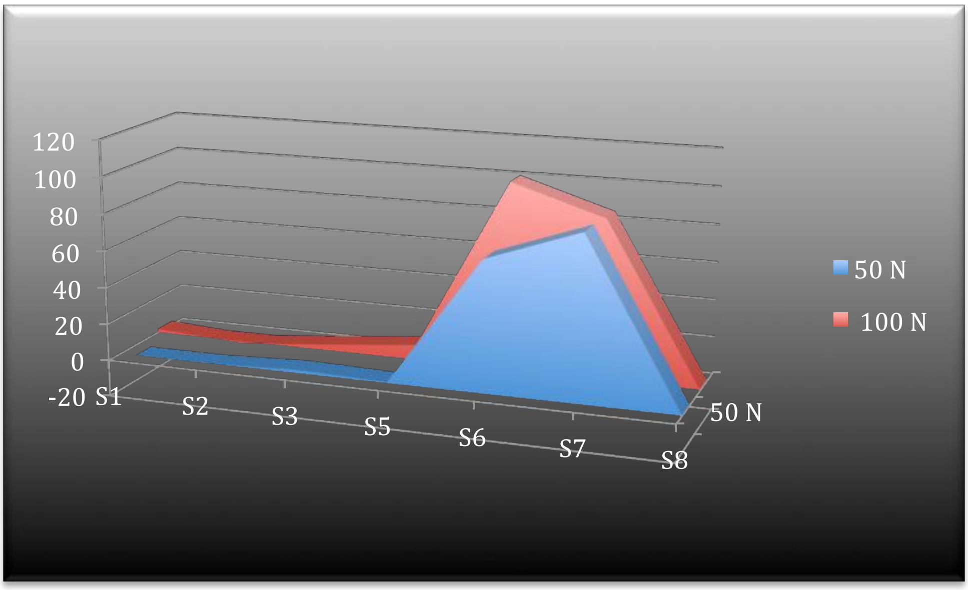

Figure 38 strain gages subjected to 50,100 N when applied on 30mm Cantilever

All the above results are listed down in table 39

Table 39 Summery of Measurements

Loading Point / Implant/ Force	Implant 3	Implant 4	7.5 mm	15 mm	22.5 mm	30 mm
Implant 3 C on 50N	-7.2*	-4.5	-0.4	0	-1.7	0.7
Implant 3 V on 50N	-37.5	4.9	21.6	38	56.6	70.7
Implant 3C on 100N	-5.7	5.2	-0.3	1.6	-0.5	8.3
Implant 3 V on 100N	3.3	13.4	37	76.3	80.1	101.4
Implant 4 C on 50N	-3.4	-415.6	36.2	68.6	87.3	88.6
Implant 4 V on 50N	-1.0	-0.9	0.8	-0.2	-0.7	0.3
Implant 4 C on 100N	4.3	57.2	100.7	113.6	106.2	85.9
Implant 4 V on 100N	-1	0.3	-0.2	-0.4	-0.7	-0.5

***** All measurements in με

V is vertical strain gage

C is circumferential strain gage

The readings from the strain gages on the contra lateral implants strain gages are listed in the appendix.

Chapter VI. Discussion and Study Limitations

An Observation was made during the analysis reflected different behaviors of three different strain gages. Demonstrated below are three plots illustrating different experimental behaviors of strain gages presented in microstrains. On the Circumferential strain gage, the data plot shows a curve that goes all the way up and down to the point of the origin. This is interpreted, as elastic deformation in the implant., of which in this case, is minimal, if any at all .(Figure 40)

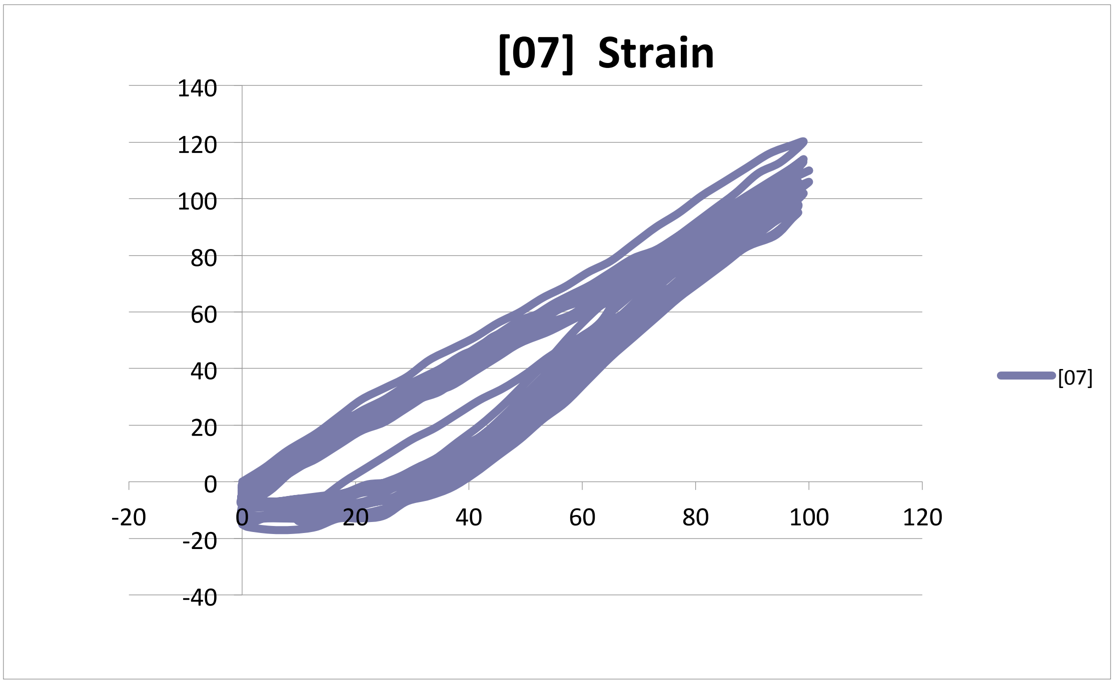

Figure 40 Minimal Plastic deformation

However, When the point of origin of the curve is different from the point of return, this is interpted as a plastic deformity the in wall of the implant. (Figure41)

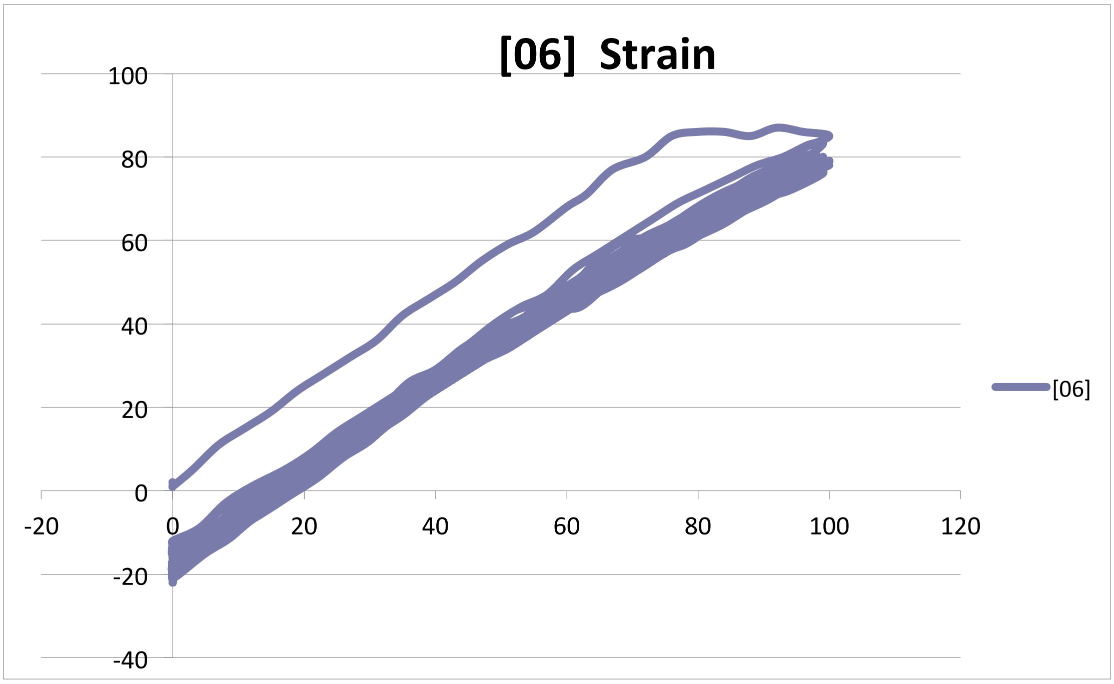

Figure 41 Plastic deformation in the wall of the implant

However, in one of the trials, where 50 N was applied on implant number 4, the abutment settled into the implant because it had not been properly torqued, (Figure42).

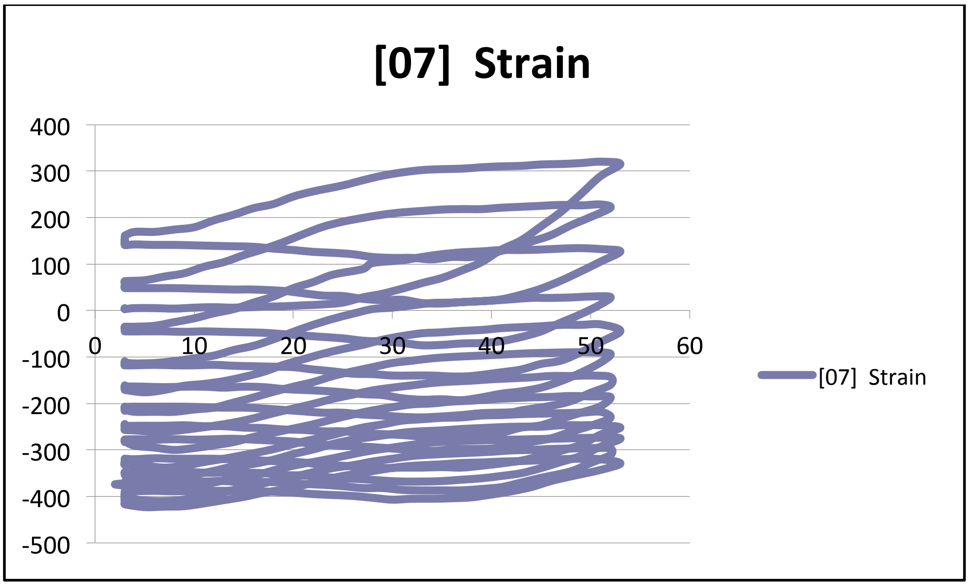

Figure 42 Settling effect of the strain gage

As the study demonstrated, there are criteria's that can utilize to help the clinician establish guidelines that allow determination the cantilever lengths. There were number of observation in this study that provided data useful in determining cantilever length. First is the fact that forces of the cantilever are not transmitted to the contra lateral side of the prosthesis. Second is that implants within the structure of the prostheses appear to be supported by the prosthesis it self which partially absorbs the forces from the cantilever section. It is a distal abutment adjacent to the cantilever was which appears to receive loads that ultimately threaten its integrity. In the study the implant close to cantilever, implant number 4 demonstrated greater microstrains in the circumferential direction. However, implant number 3, which is supported by the prosthesis mesially and distally, demonstrated greater deformation vertically.

From the work of Brunski it appears that a fulcrum exist at the distal aspect on the terminal abutment. In Implant number 3, the vertical strain gage demonstrated positive strain readings. This would suggest that this aspect of the prosthesis was subjected to tensile forces since it was in the opposite side of the fulcrum from the loaded cantilever. On the other hand, implant number 4 demonstrated tensions in the circumferential direction and very little compression in the vertical direction. This results from the fact that the fulcrum point from loading the prosthesis is at the distal aspect from the implant. However, it is very difficult in this complex system to separate out the vertical and circumferential strains because of the nature of mandibualr movement and occlusal contacts.

From the theoretical point of view, the effect of both vertical

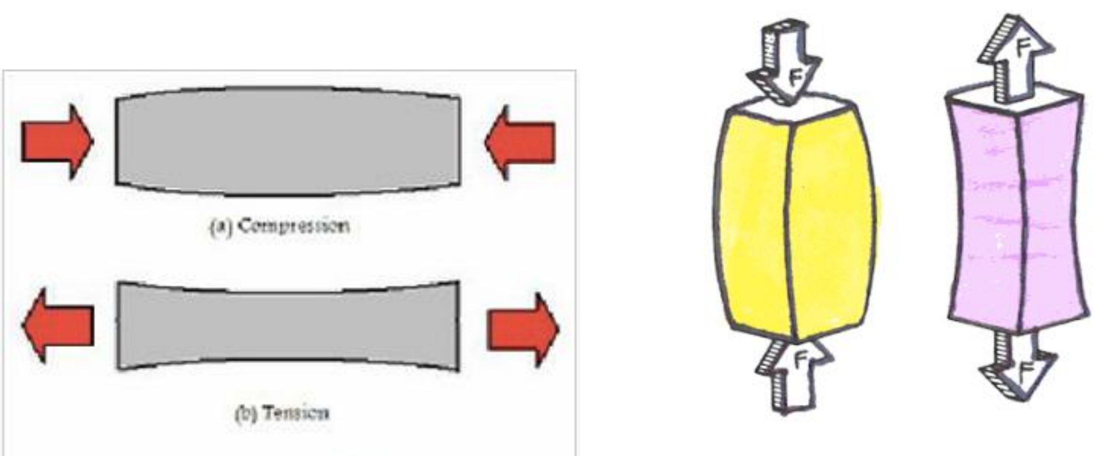

Figure 43 Tension and compression effect in different directions

and circumferential strains work side to side and can't be isolated from each other's. The tension on the vertical direction result in elongation in a cross section and the compression results in shortening it. The compression in a circumferential direction results in decreasing the radius and tension results in increasing the radius. As a result, the more the tension happens in a vertical direction results in more compression in the circumferential and vise versa. (Figure 43)

The ability to analyze the data in this study suffers from certain limitations. In a cross section of a compressed cylindrical body (which will get shorter) the linear wall is pushed out to accommodate for the compression and will form a curve to contain the change. The measurement of that curve is longer than the initial

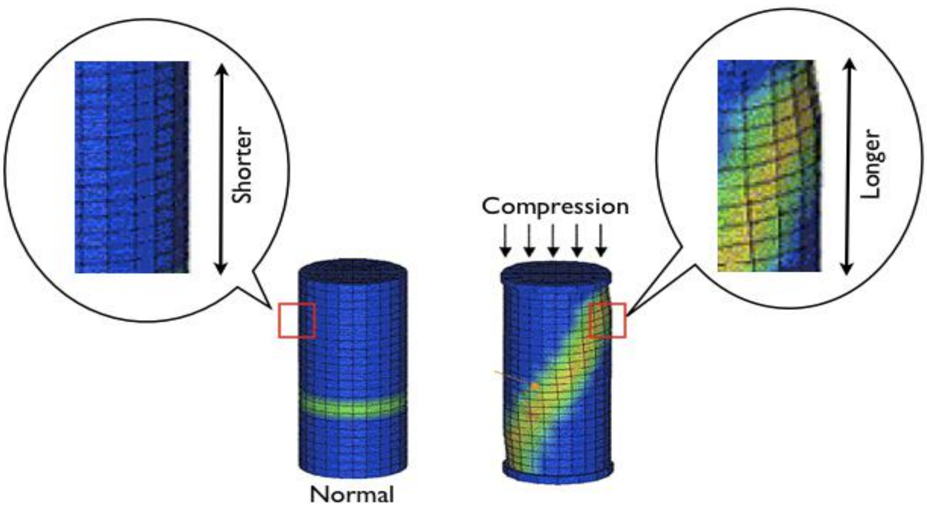

Figure 44 effect of elongation on compressed (bulged) cylindrical wall straight linear wall and hence it measures increasing in the vertical (tension) although the overall effect is compression. This happens at the level of the neck of the implant where the strain gages are attached in this study. (Figure 44). In this study, implant number 4 shows positive reading in circumferential strain gage (bulging in the wall) while the vertical strain gages is showing positive readings as well. The explanation of this maybe that although the whole implant is undergone into tension already (shorter), we are measuring only the neck part of the implant which is showing increasing in the length vertically.

Skalak and Brunski[103] studied the influences of loading cantilever on dental implants abutments. Their study design is deferent from this study. Their experimental design differs from the current study in the type of implants utilized as well as the their distribution. Never the less, Skalak concluded a cantilever length of 1.8 of the AP spread would be mathematically acceptable. Skalak model utilized higher loads than the current study. The results in this study disagree with Skalak who reported the most tension occurs in the implant closest to the forces, as the most tensile forces this study showed occurred on implant number 3 on a vertical strain gage.[99]

Brunski installed strain gages on the implants and recorded their readings. He however, only studied strains in vertical direction.[99] There is no published study on measuring the stress around implants using strain gages in a circumferential fashion.

The magnitude of the tensile forces on implant 3 vertically was very close to the forces observed in implant 4 circumferentially. It looks like those 2 strain gages (the vertical on 3 & the circumferential in 4) start at the same time and they follow the same curve on a plot showing the same elastic deformation. (Figure34)

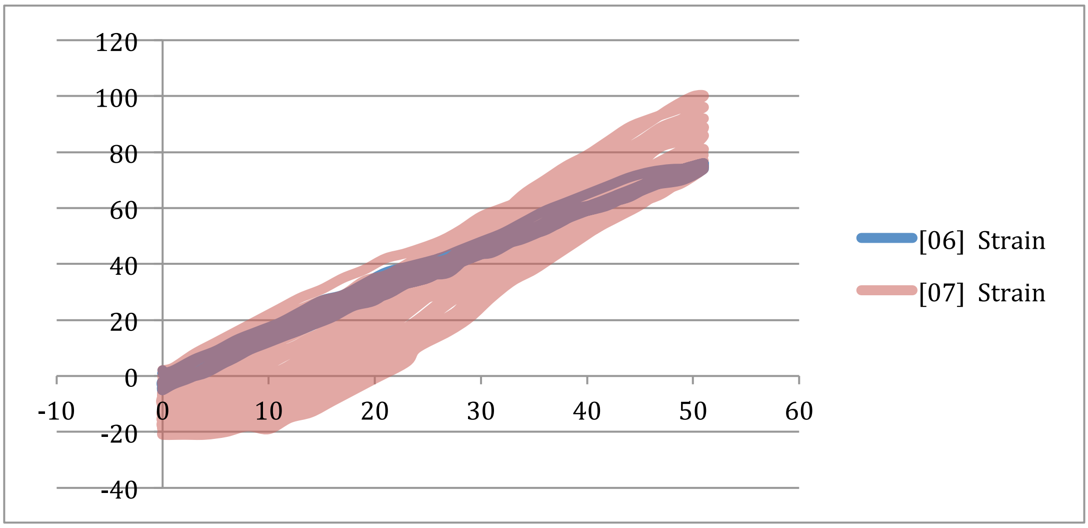

Figure 45 proximity of the level of the elastic deformity in implants 3,4

This observation shows that the most distal implant is subjected to mainly circumferential forces and not as much vertical forces. Since the strain gages in this study were installed on the distal side of the implant collar. This strongly suggests that implant 4 tends to tilt towards the distal and this resulted in increases in the circumferential strain. On implant 3, similar readings were obtained from the vertical strain gage. Perhaps the differences in the strain maybe related to the prosthesis. Implant 3 is splinted from both sides; mesially and distally. While implant 4 is only supported from its mesial aspect. There for, implant 3 is restrained in lateral movement while implant 4 has more tendencies to moves laterally. However the observation requires further investigation.

The data from strain gages when loading the 7.5 mm (0.5 AP ratio) cantilever showed only elastic deformation in the stress/strain curve. This suggests that the implant can support this cantilever

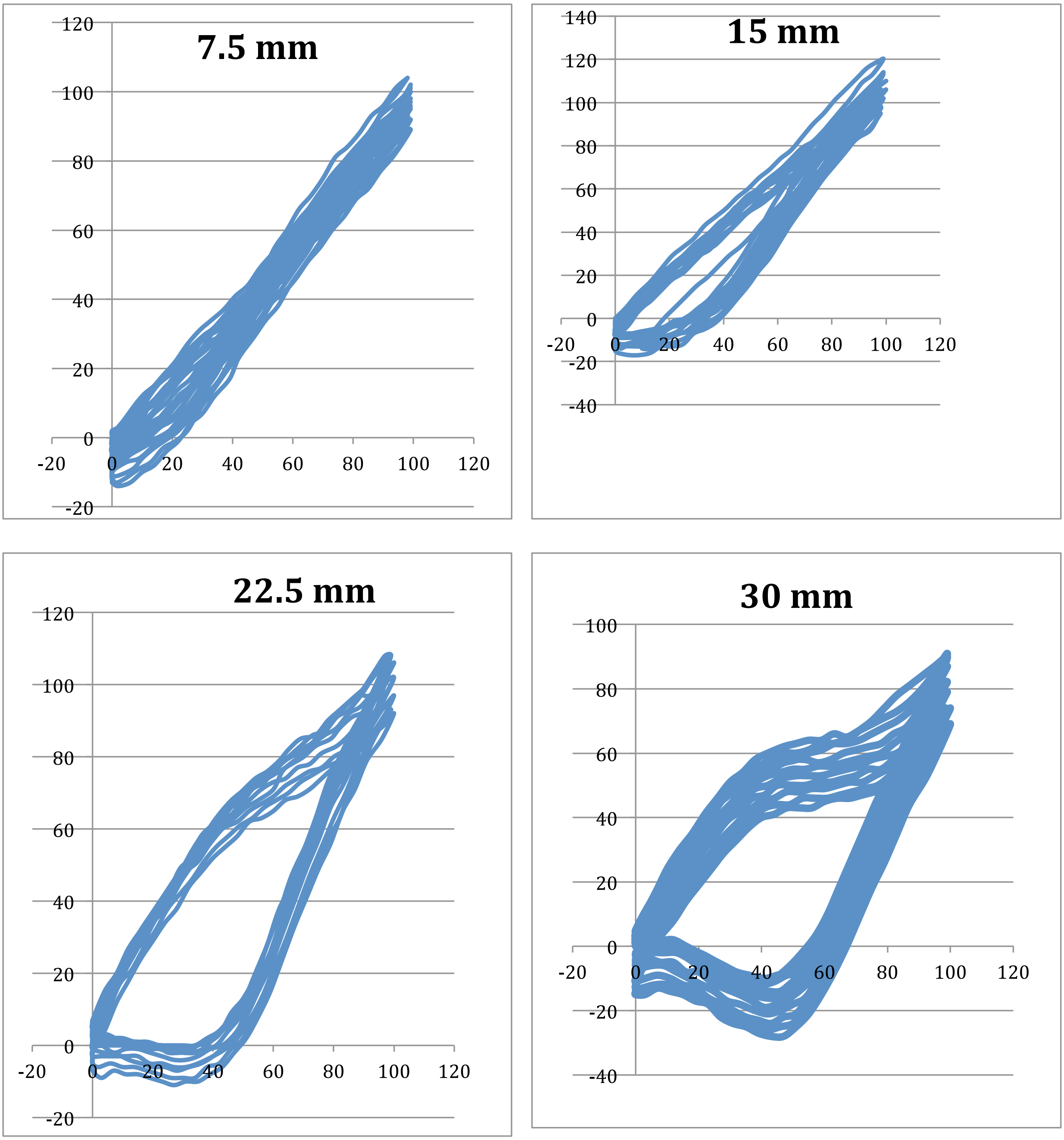

Figure 46 Curve behavior on different cantilever lengths

length. Similar observation was made in regards to loading the 15 mm (1.0 ratio). However, loading further points on the cantilever demonstrated a different curve (Figure 45).

Although the curves from loading 22.5 mm and 30 mm cantilevers return to their points of origin. Never the less, the strains at both these cantilever lengths exceeded the proportional limits and may result in permanent deformation of the wall of the implant. This phenomena was observed in this experiment where only 10 cyclic loadings were applied to the system. It maybe a concern that clinically where prosthesis are subjected to regular loading for extended period of time the effects on the implants result in either deformation or fracture on the implant. This suggests that loading the cantilever up to 0.5 and 1.0 ratio of the AP spread shows the same effect on loading implants directly and wouldn't harm the mechanical system (this applies in patients with no Para-functional habits that exerts more forces). Yet Tukey analysis suggested insignificant differences between the implants groups and 7.5 group only. (Table 24)

When comparing the strain gages plotted charts to a stress/strain curve (Figure46). The curves get into a point just right

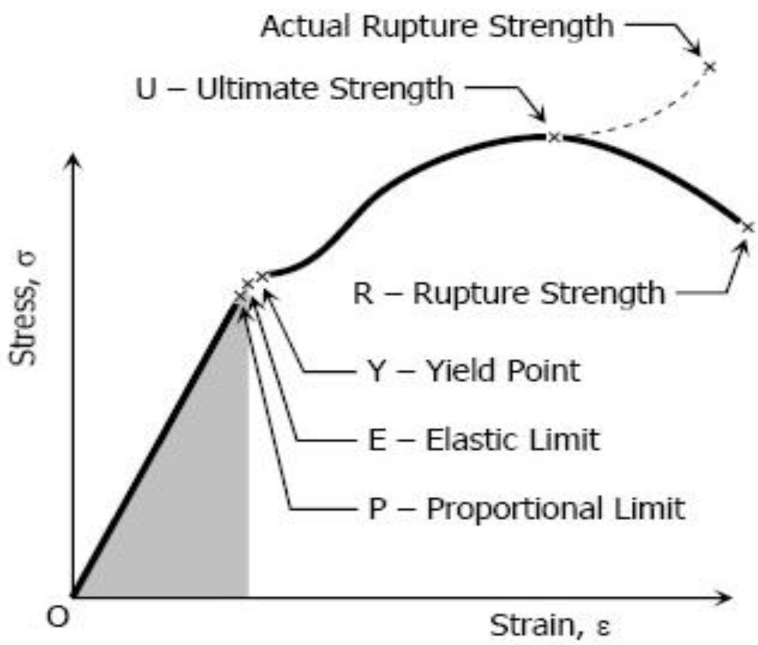

Figure 47 Stress-Strain curve

before the rapture strength point and come back to the origin as the load decreases. It would be interesting to load the system in a further study to failure and study the nature of the curve and the responses when a failure occurs and compare the point of origin of the curve. Getting strain gages on the other side of the implant and plot the curve on the mesial side of the implant as the curve on the distal side is being monitored. The expected data would show a mirror image of the 2 curves and it might suggest each side of the wall is pulling back the material from going beyond a certain limit into failure.

Chapter VII Summery, Suggested Future Research

Within the limitation of the study, it is concluded that:

- In a cross arch prosthesis type, the strains are more prominent on the unilateral side of which the loads are applied.
- The anterior implant (implant number 3) is under tension in vertical direction when forces are applied to the cantilever. The most posterior implant (implant number 4) is under less tension in the vertical direction but shows as much strains in the circumferential direction.
- A ratio up to 1.0 AP spread for the cantilever exerts no more tension to the system than the load on the implants. A ratio up of 0.5 AP spread for the cantilever is statistically acceptable. Further cantilever lengths show high tension in both vertical and circumferential directions and results in more tension to the system and more plastic deformation to the implants walls.

This pilot study opens the horizon for a lot of further studies that. A further future study would be to load the cantilever to failure and study the tension transmitted to bar (prosthesis) and to compare different implant systems with different hoop designs and describe the biomechanics when subjected to different higher loads. Another study would include the torque value in the screws and the strain the abutments and how would they correlate with the hoop strain. To study the biological effect of the hoop strain on the bone remodeling process and the strain transferred to the bone. A model with strain gages and photo-elastic analysis would be highly suggested for such a study.

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