A CLINICAL, RADIOLOGICAL AND *IN VITRO* STRAIN INVESTIGATIONS OF MANDIBULAR IMPLANT OVERDENTURES

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FACULTY OF DENTISTRY
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A CLINICAL, RADIOLOGICAL AND *IN VITRO* STRAIN INVESTIGATIONS OF MANDIBULAR IMPLANT OVERDENTURES

ABSTRACT

Introduction: Conventional complete denture (CD) and two mandibular implant-overdenture (IOD) prostheses with non-balanced occlusal scheme can induce residual ridge resorption (RRR) and increase the risk of denture fracture. Nevertheless, the association between occlusal force distribution to other clinical and mechanical factors are not that clear. **Objectives:** To compare masticatory performance, occlusal force distribution, and patient-reported outcomes in patients wearing IOD and CD, and to investigate the effect of two mandibular implants and clinical parameters on maxillary and mandibular residual ridge resorption (RRR). Finite element analysis (FEA) was applied to investigate the *in vitro* strain distribution using loading simulation according to the clinically determined occlusal force distribution. The fracture risk was predicted based on tensile strain distribution at the implant attachment interface of IOD prostheses and compared with the frequency of clinical complications recorded for two attachment types, from the follow-up records of patients with IOD prostheses. **Methods**: Twenty-three patients in each of the IOD (age 66 ± 8 years) and CD (age 65 ± 10 years) groups were recalled 3-4 years after provision of the prostheses. Masticatory performance was determined based on the patients' ability to chew two-colored wax cubes and mixing ability index (MAI) derived. The percentages of occlusal force (OF%) distribution at anterior and posterior quadrants of the arch were recorded using a digital occlusal analyzer (T-scan III). The radiographic images of the dental panoramic radiograph were compared with the baseline for RRR determination using the bone area index measurement method. Patient-reported outcomes were analyzed using the shortened Malaysian version of Oral Health-related Quality of Life (OHIP-14) and denture satisfaction (DS) questionnaires. For FEA, maxillary and mandibular models were constructed from cone-beam computed tomographic data of a patient. The anterior and posterior vertical loads were simulated according to the OF% distribution obtained from the respective patient groups. Compressive and tensile strains were compared with the frequency of clinical complications recorded in IOD patients between the two implant attachment types. Results were statistically analyzed with a 95% confidence interval. **Results**: The mean MAI of the CD and IOD groups showed no significant difference (P=0.134), while significant difference was observed in the mean OF% (P=0.002). For patient-reported outcomes, the total scores of OHIP-14 (P=0.027) and DS (P=0.030) between groups showed significant differences. The IOD showed significantly less bone resorption compared to the CD groups in the maxillary anterior area (P=0.013). Multivariate regression analyses showed significant association between RRR and OF% at the anterior maxilla (P=0.000) and posterior mandible (P=0.023). The frequency of mechanical complications clinically observed with telescopic were significantly greater than with Locator attachments (P=0.005). The FEA results showed greater strain concentration on the denture impression surface at the attachment-acrylic interface of both telescopic- ($561\mu\varepsilon$) and Locator- retained ($323\mu\varepsilon$) IODs. **Conclusions**: Patients with mandibular IODs showed better OHIP-14 and DS, but with no significant difference in the masticatory performance compared to CD patients. Residual ridge resorption was significantly associated with the occlusal force distribution and the type of prostheses. A higher tensile strain produced by telescopic attachment compared to Locator attachment interface supported the clinical observation of greater complication with telescopic IODs.

Keywords: Implant-supported overdenture, masticatory performance, T-scan III system, bone resorption, finite element analysis.

A CLINICAL, RADIOLOGICAL AND IN VITRO STRAIN INVESTIGATIONS OF MANDIBULAR IMPLANT OVERDENTURES

ABSTRAK

Pengenalan: Skima oklusi yang tidak seimbang untuk denture penuh (gigi palsu) konvensional (CD) dan prostesis overdenture dengan dua implant mandibel (IOD) boleh menyebabkan resorpsi batas residu (RRR) dan boleh meningkatkan risiko dentur terfraktur. Walau bagaimanapun, pengagihan daya occlusal dan kaitannya dengan faktor klinikal dan mekanikal lain adalah tidak jelas. **Objektif:** Untuk membandingkan prestasi pengunyahan, pengagihan daya oklusi, dan hasil laporan pesakit yang memakai IOD dan CD, dan untuk mengkaji kesan dua implan di mandibel dan parameter klinikal sosio-demografi terhadap resorpsi batas residu mandibel dan maksila (RRR). Analisis elemen finit (FEA) telah digunakan untuk menyiasat pengagihan strain *in vitro* menggunakan simulasi daya occlusi klinikal yang telah dikenal pasti. Risiko fraktur diramalkan berdasarkan pengagihan strain tensil pada antaramuka atakmen implant dan prostesis IOD dan perbandingan dengan kekerapan komplikasi klinikal yang dicatatkan untuk dua jenis atakmen dengan melihat pada rekod susulan pesakit dengan prostesis IOD. **Kaedah:** Dua puluh tiga pesakit di setiap kumpulan IOD (umur 66 ± 8 tahun) dan CD (umur 65 ± 10 tahun) telah dipanggil semula 3-4 tahun selepas penyediaan prostesis. Prestasi pengunyahan ditentukan berdasarkan keupayaan pesakit mengunyah kiub lilin dua warna untuk mendapatkan indeks keupayaan pencampuran (MAI). Peratusan pengagihan daya oklusai (OF%) di kuadran anterior dan posterior rahang direkodkan menggunakan analyser oklusi digital (T-scan III). Imej dari radiografi panorama pergigian dibandingkan dengan garis dasar untuk penentuan RRR menggunakan kaedah pengukuran indeks kawasan tulang. Hasil yang dilaporkan oleh pesakit dianalisa menggunakan soal selidik yang berkaitan dengan Kualiti Kehidupan Kesihatan (OHIP-

14, Versi pendek Malaysia) dan kepuasan penggunaan gigi palsu (DS). Bagi FEA, model maksila dan mandibel telah dibina daripada data tomografi beam kon. Beban menegak anterior dan posterior disimulasikan mengikut taburan OF% yang diperoleh dari kumpulan pesakit masing-masing. Strain mampatan dan tegangan berbanding dengan kekerapan komplikasi klinikal yang dicatatkan pada pesakit IOD antara kedua-dua jenis atakmen implan. Keputusan dianalisa secara statistik dengan interval keyakinan 95%. **Keputusan:** Purata MAI bagi kumpulan CD dan IOD tidak menunjukkan perbezaan yang signifikan (P = 0.134), manakala perbezaan yang signifikan diperolehi dalam purata OF% (P = 0.002). Bagi hasil yang dilaporkan oleh pesakit termasuk jumlah keseluruhan skor OHIP-14 (P = 0.027) dan DS (P = 0.030) terdapat perbezaan signifikan di antara kumpulan. Kumpulan IOD menunjukkan kurang resorpsi tulang berbanding dengan kumpulan CD yang signifikan pada kawasan anterior maksila (P = 0.013). Analisa regresi multivariat menunjukkan hubungan yang signifikan antara RRR dan OF% pada maxilla anterior (P = 0.000) dan posterior mandibel (P = 0.023). Kekerapan komplikasi mekanikal yang direkod secara klinikal dengan atakmen teleskopik lebih besar signifikannya berbanding atakmen lokator (P = 0.005). Keputusan FEA menunjukkan penumpuan strain yang lebih besar pada permukaan impresi dentur pada antaramuka kedua-dua denture IOD teleskopik- (561με) dan Locator (323με) IODs. **Kesimpulan:** Pesakit dengan IOD mandibel menunjukkan OHIP-14 dan DS yang lebih baik, tetapi tidak mempunyai kesan yang signifikan terhadap prestasi pengunyahan berbanding pesakit dengan denture penuhResopsi batas residu secara signifikan dikaitkan dengan pergagihan daya oklusi dan jenis prosthesis. Tekanan tegangan yang lebih tinggi yang dihasilkan pada antaramuka atakmen teleskopik berbanding atakmen Lokator, menyokong pemerhatian klinikal di mana komplikasi yang lebih besar dengan IOD atakmen teleskopik.

Kata kunci: Overdenture dua mandibel implan, prestasi mastikatori, T-scan III sistem, resorpsi tulang, analisa elemen finit.

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I wish to dedicate this work to my father’s soul (may he rest in peace).

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LIST OF SYMBOLS AND ABBREVIATIONS

ε	:	Strain
3D	:	3-Dimensional
CBCT	:	Cone-beam computed tomography
CD	:	Complete dentures
CT	:	Cross-sectional imaging
DPR	:	Dental panoramic radiograph
DS	:	Denture satisfaction
FEA	:	Finite element analysis
HRQoL	:	Health-related quality of life
IFD		Implant fixed denture
IOD	:	Implant overdentures
L-OHIP(M)	:	Long OHIP Malaysian version
MAI	:	Mixing ability index
OF	:	Occlusal force
OHIP	:	Oral Health Impact Profile
OHRQoL	:	Oral Health-Related Quality of Life

QoL	:	Quality of life
RRR	:	Residual ridge resorption
SF-36	:	General health-related quality of life 36-item
S-OHIP(M)	:	Short OHIP Malaysian version
STL	:	Standard triangle language
TMJ	:	Temporomandibular joint
WHO	:	World Health Organization

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CHAPTER 1: INTRODUCTION

1.1 Background of the study

Edentulism is regarded as a “major oral disease”, which results in frequent functional, psychologic, aesthetic, and economic complications. The extent of residual ridge resorption (RRR) in mandibular and maxillary residual alveolar ridges following tooth loss can vary among edentulous individuals (Atwood, 1971). Provision of removable complete denture (CD) prostheses has been the standard of care as it has been shown to be beneficial for the majority of patients who have lost all their teeth (Zarb & Bolender, 1997; Doundoulakis et al., 2003; Carlsson & Omar, 2010). The CDs derive support from the mucosa and the underlying residual alveolar bone, where the occlusal load is transmitted to the underlying bone tissues via the mucosa. An excessive level of the occlusal load increases the bone resorption rate (Jaul et al., 1980; Maruo et al., 2010; Fujiki et al., 2013; Ahmad et al., 2015), as the exerted force is beyond a limit that can balance bone formation and resorption. From a biomechanical viewpoint, well-distributed occlusal forces over maximal bearing area coverage of denture, minimizes the excessive concentration of stress, which may result in progression of RRR (Maeda & Wood, 1989).

In relation to the occlusal force, it has been argued that the type of occlusal scheme for a CD with nearly equal force distribution on both sides of the arch enhances the tissue seat of the denture during mastication (Kerstein et al., 2013). Conventional CD and mandibular-implant overdenture (IOD) prostheses were shown to become less stable with asymmetrical occlusal forces. This pattern of symmetry in force distribution between the left and right side of the arch in natural dentition has also been demonstrated (Maness & Podoloff, 1989). Koos et al. (2012) also found a significantly higher force distribution on the molar and premolar teeth compared to anterior teeth. Analysis of the dynamic occlusal forces using computerized techniques such as the T-scan system has allowed these occlusal parameters to be quantified with the occlusal load on multiple points in the dentition to be measured in time sequence from initial to the maximum intercuspation position (Maness, 1987b; Cartagena et al., 1997). The excessive occlusal forces with unequal distribution recorded from the T-scan occlusal movie facilitates occlusal adjustment with the help of articulating paper. Equally-distributed left and right occlusal forces result in improved denture stability (Olivieri et al., 1998).

In regards to the patients' treatment outcome with CD prostheses, it was observed that the individual complaints were mostly related to denture wearing (Allen & McMillan, 2003). In particular, more complaints were observed in mandibular dentures due to lack of retention and stability, especially in severely-resorbed ridges (Tallgren, 1972; Huumonen et al., 2012). Ill-fitting dentures disturb the patient’s capability to eat satisfactorily, talk clearly, and smile spontaneously (Sheiham & Croog, 1981). Therefore, an investigation utilizing standard epidemiological strategies to examine the multidimensional characters of oral health status on clinical, social, and psychological indicators is expected to give an experimental premise to dental health planning and assessment (Reisine, 1988).

Fracture of acrylic dentures were previously, a very common complication (Beyli & Von Fraunhofer, 1981; Darbar et al., 1994; Takamiya et al., 2012), which accounted for more than half of the incidence of total causes of denture repair (Vallittu et al., 1993; Narva et al., 2001). The fractured denture can be easily repaired, however additional visits to the dentist and waiting for laboratory processes can cause inconvenience and embarrassment for the patient who has to be without the denture while it is being repaired (Gonda et al., 2010). Despite the improvement in the materials and technique used in CD construction, the continual ridge resorption could lead to an ill-fitting denture, particularly in patients who wear them over an extended length of time without being relined or rebased. Lack of denture adaptation could make the dentures more susceptible to deformation and fracture. It has been shown that stress concentration at the midline area of the maxillary conventional CDs was relatively higher compared to the mandibular CDs (Prombonas & Vlissidis, 2006). Denture fracture occurs mostly during mastication with occlusal biting forces significantly lower than the static failure strength of the denture base (Vallittu et al., 1993). However, repeated mastication loads lead to significant deterioration of the mechanical properties and fatigue of the denture material in the long term (Vallittu et al., 1994; Narva et al., 2005). Moreover, natural wetness of the oral environment could intensify formation of microcracks due to the fatigue of the acrylic denture material, which further propagate and result in denture fracture (Vallittu et al., 1994).

In implant prostheses, the force distribution is expected to be different from that of implant removable prostheses (Fontijn-Tekamp et al., 2000). A number of longitudinal clinical reports have shown that IODs required a high level of prosthetic maintenance (Goodacre et al., 2003; Andreiotelli et al., 2010). With the incorporation of attachments on the fitting surface of the overdenture prostheses, the strain concentration around these attachments may lead to increased fracture risk of these prostheses (Gonda et al., 2007; Takahashi et al., 2015). The fracture risk of IOD prostheses is approximately 78% (Walton & MacEntee, 1993), while the opposing conventional maxillary dentures show approximately 38% frequency of fracture incidence (Walton & MacEntee, 1994).

There are various types and designs of implant attachment systems in the market, with varied retention features (Alsabeeha et al., 2009). Several clinical complications were observed with magnet attachment as compared to the ball attachment such as less retention and plaque accumulation (Smith GA, 1983; Naert et al., 1998; Cune, 2005). However, the ball attachment was observed to have a higher recurrence rate of technical complications compared to the telescopic or Locator attachments (Krennmair et al., 2011). The telescopic attachment consists of a telescopic crown abutment, and a corresponding secondary outer coping (Langer et al., 2000), which functions based on a friction grip between the inner and outer crowns. On the other hand, the Locator attachment occupies less space in the denture base due to its shorter height (Evtimovska et al., 2009), making it preferable in cases of limited inter-occlusal arch space (Pasciuta et al., 2005).

1.2 Problem statement

Bilateral balanced occlusion is the preferred occlusal scheme for CD, which effectively eliminates the unbalanced side to side torque of the prostheses. The T-scan occlusal analysis system is an effective tool to monitor the restorative occlusal adjustments and evaluate the equality of force distribution (Kerstein et al., 2013). Furthermore, T-scan systems offer a chance for viewing the occlusal forces into different zones (anterior and posterior) across the dental arch in maximum intercuspation (Cartagena et al., 1997; Kumagai et al., 1999). However, studies investigating occlusion of IODs or even comparing with conventional CD using the T-scan III occlusal system are scarce in the literature.

The presence of interforamina implants in the anterior portion of the mandible could inhibit ridge resorption with bone apposition reported in the severely-resorbed mandible (Sennerby et al., 1988; Davis et al., 1999). Two-implants have been recommended for mandibular IOD and the first choice of treatment for edentulous mandible (Feine et al., 2002; Thomason et al., 2012). However, information in the literature comparing mandibular bone resorption between conventional CD and IOD wearers showed a high variability of the results. Kordatzis et al. (2003) showed lesser mandibular RRR in the latter while Tymstra et al. (2011) could not find a significant difference between the groups. With regards to the antagonistic edentulous maxilla, mandibular IOD seemed to induce bone resorption in the anterior more than the posterior maxilla (Kreisler et al., 2003). Ahmad et al. (2015) related an uneven hydrostatic pressure distribution underneath the mandibular denture base distal to the implants and hence greater resorption in IOD, while the antagonist maxillary ridge was not investigated. They used unilateral maximal bite force measurement of one single tooth instead of multiple teeth. Since CD and IOD did not remain stable when asymmetrical forces were applied, the assessment of occlusal load distribution along the whole arch could be more relevant.

In regard to the patient-reported outcomes, patients wearing IOD experienced a greater bite force and higher satisfaction scores than conventional CD wearers (Geckili et al., 2012a). However, few studies have focused on bite force in relation to patients' Oral Health-Related Quality of Life and denture satisfaction among patients rehabilitated with IODs or CDs (Lassila et al., 1985; Cune et al., 2005; Rismanchian et al., 2009; Geckili et al., 2012a; Geckili et al., 2012b). Furthermore, most bite force measurements have been performed using strain gauge devices, which could not be used routinely for clinical assessment (Throckmorton et al., 2009). This is mainly due to the thickness of the utilized measurement devices (Lassila et al., 1985; Rismanchian et al., 2009) as well as their inability in performing measurement on both sides, which could result in the displacement of the denture on the other side.

The strain distribution within the denture is often evaluated by applying a certain amount of occlusal load at a specific location. However, this approach mostly fails to accurately reproduce the clinical force applied intraorally on the denture (Cheng et al., 2010; Gonda et al., 2010) due to the different magnitudes of occlusal forces at the anterior and posterior quadrants in complete edentulous situations. Therefore, determining the actual distribution of occlusal load generated clinically in various quadrants could assist in achieving a more accurate simulation of the denture function. Most of the previous studies have utilized strain gauges to investigate the denture fracture (Regli & Kydd, 1953; Regli & Gaskill, 1954; Wain, 1957; Lambrecht & Kydd, 1962; Johnson, 1965; Obeid et al., 1982; Stafford & Glantz, 1991; Prombonas & Vlissidis, 2006; Cilingir et al., 2013). However, strain gauges could only measure the surface strain and require a sealed dry area to prevent short circuits of the gauge during measurements (Darbar et al., 1994). Because of these limitations, Finite element analysis (FEA) has been recommended for *in vitro* strain analyses (Darbar et al., 1994; Prombonas & Vlissidis, 2006). Nevertheless, unrealistic force application compared to the clinical situation is considered as one of the limitations associated with FEA, as it is simulated based on unilateral maximal bite force measurement on one single tooth instead of multiple teeth. In addition, recent *in vitro* studies of the CD fracture behavior using strain gauges (Prombonas & Vlissidis, 2006; Cilingir et al., 2013) or FEA method (Cheng et al., 2010) have often investigated the strain distribution within the denture by applying a certain amount of occlusal loads without determining the load distribution across the arch.

1.3 Null Hypothesis

1. There are no significant differences in masticatory performance, occlusal force distribution, and patient-reported outcomes between mandibular IOD and conventional CD patients.
2. Mandibular and maxillary ridge resorption is not associated with the prostheses type, occlusal force distribution, and patients' socio-demographic factors.

3. There are no significant differences in the clinical complications between telescopic and Locator attachments-retained mandibular IOD prostheses.
4. There are no differences in the *in vitro* strain distribution between maxillary and mandibular CDs and maxillary CD opposing mandibular IOD with different attachment systems.
5. There is no difference in the *in vitro* strain distribution between telescopic and Locator attachment-retained mandibular IOD prostheses.

1.4 Aim of the study

The current study aimed to determine the masticatory performance and the occlusal force distribution association with residual ridge resorption and patient-reported outcomes and to investigate prostheses strain distribution using FEA in patients with mandibular implant-overdentures and conventional complete denture prostheses.

1.5 Objectives

1.5.1 Clinical study

1. To compare the masticatory performance, occlusal force distribution and patient-reported outcomes in edentulous patients with mandibular IOD and conventional CD prostheses.
2. To determine factors associated with maxillary and mandibular residual ridge resorption in edentulous patients with mandibular IOD and conventional CD prostheses.

3. To compare the clinical complications between telescopic and Locator attachments-retained mandibular IOD prostheses.

1.5.2 Finite element analysis study

1. To investigate the *in vitro* strain distribution in maxillary opposing mandibular CDs and maxillary CD opposing mandibular IOD with different attachment systems.
2. To investigate the *in vitro* strain distribution between telescopic and Locator attachment-retained mandibular IOD prostheses.

1.6 Rationale of the study

The provision of mandibular IODs supported by two implants has been shown as a successful alternative treatment for conventional mandibular CDs. However, ridge resorption, prostheses fracture, and high maintenance could affect patient-reported outcomes.

The significance of this study was the utilization of the computerized T-scan III occlusal analysis to determine the occlusal force distribution. The dental panoramic radiograph images were also used to measure bone resorption in IOD patients. The control group consisted of CD patients who had been wearing their prostheses for about the same length of time as IOD patients.

Another intention was to investigate the strain concentration areas within mandibular CD and IOD and the opposing maxillary CDs. The use of FEA could predict possible areas of fracture in various prostheses and among IOD prostheses retained by different attachment types. Moreover, the findings of strain pattern and distribution for different attachments of IOD prostheses could help in the clinical decision making, as far as the choice of attachment is concerned.

1.7 Study structure

A brief summary of the study design including various project activities is presented in Figure 1.1.

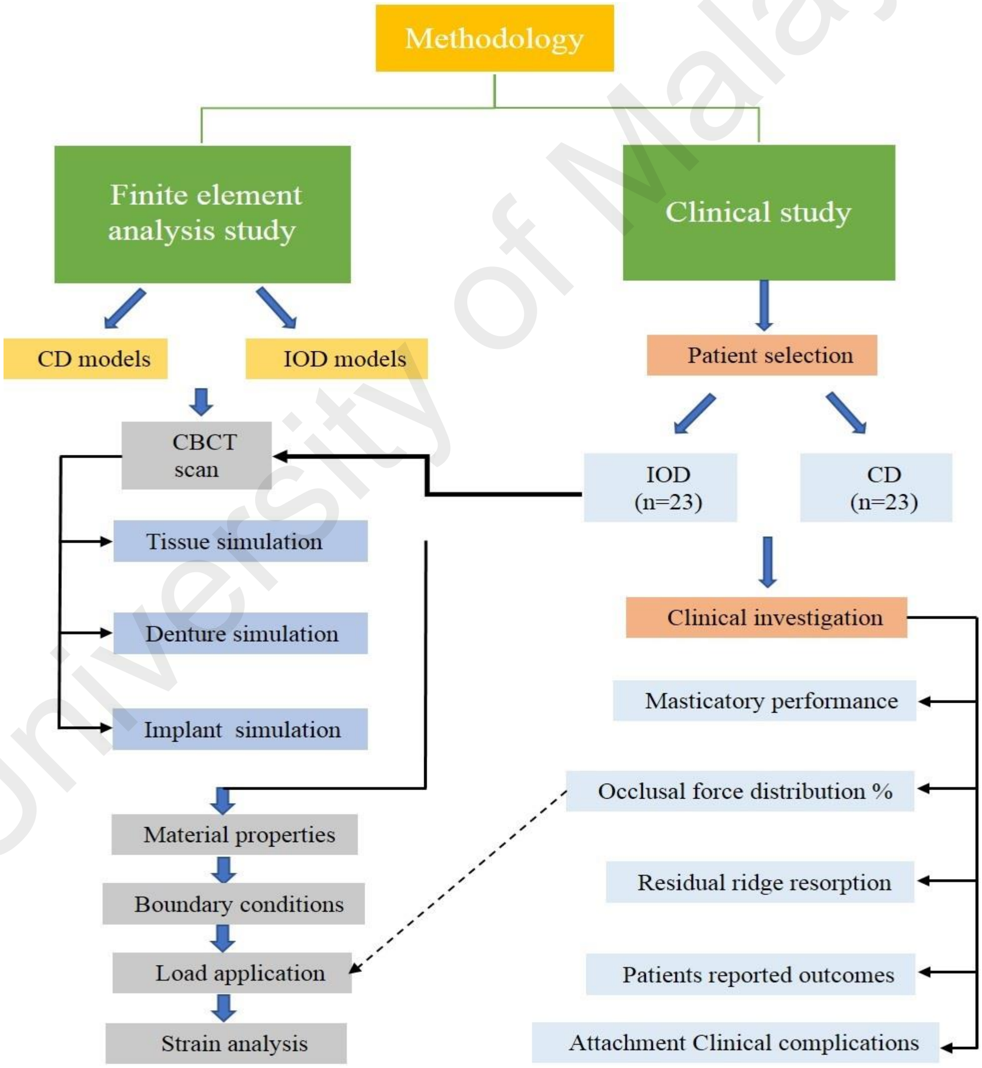

Figure 1.1: Flow chart of the clinical and *in vitro* FEA investigation.

CHAPTER 2: LITERATURE REVIEW

2.1 Complete edentulism

Complete tooth loss or edentulism is a “debilitating disease and irreversible condition and is described as the final marker of disease burden for oral health” (Cunha-Cruz et al., 2007; Emami et al., 2013). It is a public health problem affecting older adults, and it has been associated with socio-economic status and general well being (Cunha-Cruz et al., 2007).

Edentulism disturbs diet intake due to masticatory dysfunction (Sheiham & Steele, 2001), which can directly lead to functional limitations, as well as physical, psychological, and social disability and handicap (Locker, 1988). Therefore the occurrence of edentulism should be monitored in different countries as an indicator of population health and functioning (Thomson, 2012). Understanding the significance of edentulism and its general effect on elderly population health can assist policymakers and public health researchers in this area (Peltzer et al., 2014).

A systematic review and meta-analysis by Kassebaum et al. (2014) showed that the prevalence of complete tooth loss has declined between 1990 to 2010. However, the burden of complete tooth loss remains (Locker & Millar, 2005).

Complete edentulism is a worldwide health problem, mostly in the older age groups (Felton, 2009). The overall rate of edentulism in Canada in the year 2010 was estimated at 6.4% and among adults of age between 60–79 years old, it was 21.7% (Cooney, 2010). In Ireland, the Netherlands, Iceland, Brazil, and Turkey the rate of edentulism among adults between 65–74 years old was 48.3%, 65.4%, 54.7%, 71.5%, and 48.0%

respectively (Madléna et al., 2008; Felton, 2009; Ribeiro et al., 2011; Doğan & Gökalp, 2012), and it was 14% in Sweden for 55–84 years old (Österberg et al., 2010).

The rate of edentulism has a tendency to alter among various locales, even inside a nation. For example in Canada, there was a wide variation amongst provinces, from Quebec (14%) to Northwest Territories (5%), due to related factors such as access to fluoridated water and smoking (Locker & Millar, 2005).

According to the Oral Health Division (2011) survey, it was reported that the rate of edentulism in the Malaysian population had declined from 54% in 1974 to 32% in 2010. However, the rate of edentulism could vary among different areas, wherein a study conducted in Kelantan, the prevalence of edentulism was found to be 56%, and it was associated with older age individuals (Shamdol et al., 2008).

2.2 Edentulism risk factors

2.2.1 Age

Deficient basic dental care for senior residents possibly leads to poor nutrition, dental pain, medical complications and tooth loss (Wick, 2010). Tooth loss has been reliably associated with increasing age (Islas-Granillo et al., 2016). As the vascularity of the alveolar bone declines, bone resorption increase and reduces the capacity to repair damage (Boskey, 2013). Additionally, the number of residual teeth diminishes with aging because of the higher prevalence of periodontitis which increases with an older population (Renvert et al., 2013).

2.2.2 Gender

Male and female genders were equally affected by tooth loss in some studies (Nelsen et al., 2001; Takenaka et al., 2001; Humphrey & Bocaege, 2008; Bolhofner & Baker, 2012), and the association between gender and tooth loss could not be established (Russell et al., 2013).

2.2.3 Smoking

Smoking has been recognized as a risk factor and can lead to tooth loss due to peripheral vascular disease and chronic periodontal disease. In a study of 33,777 matured Canadians aged 65 years or more, 48% of smokers were edentulous (Millar & Locker, 2007). Similarly, Xie & Ainamo (1999) examined the relationship of different factors associated with tooth loss in senior citizens living at home in Helsinki, Finland. They found that the individuals who smoked were two times more likely to be totally edentulous after adjusting the age and gender factors.

2.2.4 Asthma

In addition to smoking, Xie & Ainamo (1999) found that asthmatic patients were ten times more likely to be edentulous in the maxillary arch than non-asthmatics. The authors hypothesized that patients with inhaled corticosteroids could have encountered systemic effects causing suppression of bone development, and eventually bone and tooth loss of the maxillary bone. In another investigation of 177 edentulous subjects aged 76 years, Xie et al. (1997a) found that elderly patients suffering from asthma were six times more likely to encounter severe reduction of the mandibular ridge compared to non-asthmatic patients.

2.2.5 Diabetes

It has been estimated that by the year 2035 there would be about 600 million people suffering from diabetes (Iversen et al., 2016). A cross-sectional study of 370 patients revealed that edentulous older men had four times more risk for developing non-insulin dependent diabetes mellitus, regardless of age or race than those with partial or complete dentitions (Cleary & Hutton, 1995). Also, diabetes was found to be positively associated with edentulism among adults aged 35 years and older in Mexico (Medina-Solís et al., 2006).

2.2.6 Rheumatoid arthritis

Rheumatoid arthritis is a chronic inflammatory disease characterized by joint swelling, joint tenderness, and destruction of synovial joints (Felton, 2009). Some clinical studies have proposed a probable association between rheumatoid arthritis and tooth loss (Mercado et al., 2001; Al-Shammari et al., 2005). While there was no positive association found in other studies (Laurell et al., 1989; Yavuzyilmaz et al., 1992). de Pablo et al. (2008) found edentulism in rheumatoid patients (56%) to be twice as common as in non-rheumatoid patients (34%).

2.2.7 Obesity

Obesity is considered as a progressively serious health problem, due to its association with diabetes (Andreyeva et al., 2007). A review by Österberg et al. (2010) found a positive association between obesity and edentulism in the age group of 55–84 years and the association was stronger in women than in men.

2.2.8 Lower education and income

People with higher salary possibly have more access to educational information and measures that promote preventative health care, better dietary behaviors, and living environments, and they gain a more prominent measure of oral hygiene products (Mendes et al., 2012). Peoples in the lower occupational classes were thought to be at higher possibility of health risk behaviors (Fukuda et al., 2005). Also, the prevalence of dental caries in low-income individuals has been previously noted as a potential risk factor of edentulism (Krustrup & Petersen, 2007).

2.3 Rehabilitation of edentulous patients

2.3.1 Complete denture prostheses

Complete denture rehabilitation method remains an important part of dental education and practice (Zarb & Bolender, 1997). The most basic form of oral rehabilitation for edentulous patients has been with CD, due to relatively affordable cost, has acceptable aesthetics, and function, and is easy to clean (Doundoulakis et al., 2003). Until the establishment of dental implants supporting IOD prostheses, the only accessible treatment for edentulous patients was CDs (Carlsson & Omar, 2010).

Nevertheless, not all CD wearers are able to adapt to their dentures, even if the dentures fulfill all conventional prosthodontic criteria. A retrospective study by Laurina & Soboleva (2006) was conducted to determine possible causes of patients' complains about new CDs. The authors found that most of the patients frequently complained of denture looseness, aesthetics, impaired masticatory function, and accumulation of food under the denture.

Uram-Tuculescu et al. (2015) clinically investigated the differences in masticatory muscle function using electromyographic (EMG) device during chewing of agar-based food model between dentate patients and patients treated with conventional CD, IOD, and implant fixed denture (IFD). The results showed a higher masticatory muscle activity for denture wearers compared to the dentate subjects, due to extra mechanical efforts during oral food processing to accommodate the use of dentures for preparing a bolus for swallowing.

Similarly, a meta-analysis systematic review by Gracht et al. (2017). A higher chewing values were observed in IFD or IOD groups compared to CD group, indicating improved bite force and masticatory performance in the former groups.

2.3.2 Osseointegrated dental implants

Osseointegration is defined as "the apparent direct attachment or connection of osseous tissue to an inert, alloplastic material without intervening fibrous connective tissue" (The Glossary of Prosthodontic terms, 2017). Brånemark (1983) presented the osseointegration term to describe this modality for stable fixation of titanium implants to bone tissue. He described the chambers fabricated from metal titanium could become permanently incorporated into living bone, and the bone fused with the titanium oxide layer of the implant could not be separated (Brånemark, 1959).

Osseointegrated implants survival success rate of 87.5% was observed for individuals in a 3 years longitudinal study conducted by Cox & Zarb (1987). Friberg & Jemt (2015) investigated the implant/prosthesis survival rates, marginal bone loss, and clinical complications in patients who received implants in one or two-surgery stages for 5 years of follow-up. During the observation period, it was observed that out of 259 patients only eight patients were observed with complete implant/prosthesis failures or bone loss.

It was also important for the implant not to be excessively loaded, as these loads could interfere with osseointegration (Porter Jr et al., 2002). For the average tooth, the periodontal ligament acts as an intermediate cushion to buffer the occlusal forces, while in the osseointegrated dental implant, occlusal forces were transmitted immediately to the surrounding bones (Weinberg, 1993).

2.3.3 Implant fixed prostheses

The use of 5-6 intreforaminal implants to support fixed prostheses for edentulous patients has been introduced by Brånemark (1977) and Feine & Carlsson (2003). The failure and survival rates of different modalities of implant prostheses have been reviewed and the results indicated higher survival rates for IFD dental prostheses compared to other types of implant prostheses (Muddugangadhar et al., 2015).

Implants lack the stress release associated with a periodontal ligament and hence they are exposed to greater harmful loading effect on the restorative materials and the crestal bone (Curtis et al., 2000). Dental implants are also thought to be predisposed to occlusal overloading, which could explain for peri-implant bone loss and implant prostheses failure (Kim et al., 2005).

Therefore it has been recommended that in order to minimize the incidence of complications, reliable implant components and the restorative materials for IFDs prostheses should be used in a well-structured maintenance system after treatment (Pjetursson et al., 2012).

2.3.4 Implant-supported prostheses

The McGill consensus in the year 2002 on overdentures stated that: there is now overwhelming evidence that a two-IOD should become the first choice of treatment for the edentulous mandible, based on available scientific evidence (Feine et al., 2002).

In 2009, the York consensus statement was further support evidence demonstrating that patients' satisfaction and quality of life with implant-supported mandibular dentures. Much of these evidences came from randomized controlled trials" (Thomason et al., 2009). Due to their relatively lower cost and lower complication rate than fixed prostheses, mandibular IODs have been popular (Feine & Carlsson, 2003; Carlsson et al., 2004).

2.3.5 Number of implants used with implant-supported overdenture prostheses

Maxillary overdentures supported by four to six implants splinted with a bar (Slot et al., 2010; Carlsson, 2014), have revealed effective functional results than two implants. However, maxillary IODs on two implants were commonly found less effective than the mandibular two-IODs (Mericske-Stern, 2003).

Merickske-Stern (1990) in a retrospective study on 67 patients who were provided with mandibular two-IOD, has observed that two implants may sufficiently be used for IOD retention, without the need of multiple implants or to implants splinted with a bar.

Regarding the peri-implant tissue condition, Batenburg et al. (1998) conducted a prospective one year study to investigate patients with mandibular overdenture prostheses, retained by two and four implants. They concluded that no difference was observed in the peri-implant health between the groups and made a recommendation that treatment with two implants should be sufficient to retain IOD in the mandible.

A recent randomized clinical trial on 20 participants with edentulous mandibular ridges, who were randomly assigned into two groups; four implants installed in lateral-canine and premolar regions, and two implants in lateral-canine regions. The authors concluded however that increasing the number of implants from two to four in mandibular IODs had no significant influence on implant stability (Wafa'a et al., 2017). Therefore, following the McGill consensus two mandibular implants can be considered a viable treatment option for edentulous mandible.

2.3.6 Attachments used with implant-supported overdenture prostheses

According to the Glossary of Oral and Maxillofacial Implants (Hjørting-Hansen et al., 2007), an attachment system is "a design of a particular type of retentive mechanism employing compatible matrix and patrix corresponding components. Matrix refers to the receptacle component of the attachment system, and patrix refers to the portion that has a frictional fit and engages the matrix".

A wide variety of commercially-available attachment systems is used as retentive components in implant overdentures. The retentive design can be splinted or unsplinted using different attachments designs (Alsabeeha et al., 2009). The anatomy of the edentulous arch with desired retention level, hygiene, maintenance capability, implants parallelism, and cost considerations are important factors in choosing the appropriate overdenture attachment type (Alsiyabi et al., 2005; Gulizio et al., 2005).

The attachment types can be classified into ball, Locator, magnet, bar, and telescopic attachments. Plaque accumulation has been shown to be significantly higher in magnet attachment than for ball attachment, because of frequent exchange of magnets, or wear and corrosion of them (Naert et al., 1998). Besides, the use of magnet attachment provides less retention as compared to the other attachment systems (Smith GA, 1983; Cune, 2005).

Between bar and ball attachments in the mandibular two-IODs it was observed that the biological complications were not significantly different, however, a greater number of technical complications per patient was recorded with bar than ball attachments (Gotfredsen & Holm, 2000). Bar attachment requires the skill of technician in the fabrication. At the same time, the splinted design of the bar could compromise hygiene. A comparison between ball to telescopic attachments, however, was less favorable where ball attachments showed higher recurrence of technical complications over five years (Krennmair et al., 2011). Denture reinforcement when using ball attachments has been suggested to increase fracture resistance of the base (ELsyad et al., 2016). From the biological aspect, the soft tissue response around abutments in patients who use ball attachments was less favorable compared to other unsplinted design of attachments (Kleis et al., 2010).

2.3.6.1 Telescopic attachments

Telescopic crowns as retentive elements for overdenture prostheses, also known as double-crowns, consist of an inner or primary telescopic coping, cemented to an abutment, and the corresponding detachable outer or secondary telescopic crown (Langer et al., 2000). This type of retainer provides excellent retention resulting from frictional fit between the crown and the sleeve (Keller & Haase, 1991). The use of cemented, rigid telescopic crowns was suggested to avoid disadvantages of screw-retained superstructures, such as difficult access to the screw positions (Hoffmann et al., 2006). Moreover, telescopic-retained restorations can be easily removed or inserted and are considered as an effective treatment modality for geriatric patients (Heckmann et al., 2004).

2.3.6.2 Locator attachments

The Locator attachment system is a system with a self-aligning feature and has dual retention (inner and outer), which has been on the market since 2000. The Locator design comprises; a patrix (male) which is the replaceable nylon attached to the denture base of the overdenture, and a matrix (female)) which is fixed as an overdenture abutment (Kleis et al., 2010).

The nylon retentive element comes in different colors, to indicate different retentive strength (Chung et al., 2004). Additional features are extended range attachments, which can be used to correct implant angulation up to 20° (Evtimovska et al., 2009). The reduced height of Locator attachment is the main advantageous in particular in cases with limited inter-occlusal space or when retrofitting an existing old denture (Pasciuta et al., 2005).

2.4 Stress distribution according to attachment types

The way stress is applied to implants following osseointegration is one of the features which should be investigated (Trakas et al., 2006). Telescopic IOD has been shown to improve chewing efficiency compared to bar attachments (Elsyad & Khairallah, 2017). However, with higher bite force, a higher stress could lead to greater risk of implant fatigue and even fracture (Heckmann et al., 2001). Correspondingly, Elsyad et al. (2013) in a 4 years retrospective study, observed an increased resorption and flabbiness of maxillary anterior residual ridge when telescopic attachments used in mandibular two-IOD.

Using an experimental resin model, Ichikawa et al. (1996) investigated the occlusal stress distribution on the implants supports IOD, and the authors concluded that even with the higher occlusal stress concentrated on implants especially in the distal areas, the modified magnetic attachment with silicone provided optimal stress distribution. Similarly, *in vitro* study by Gonda et al. (2004) observed that lateral stresses were reduced on the abutment tooth under tooth-supported overdentures which were not rigidly connected.

2.5 Occlusal registration methods

Any occlusal interference might not only affect implants and IOD prostheses. In fact, reduced chewing stability, pain, gum disease, headaches, and temporomandibular joint (TMJ) problems were possibly associated with occlusal force disturbances (Bicaj et al., 2015). Therefore, occlusal recording devices and methods are important factors in determining occlusal force distribution (Koc et al., 2010).

Various methods are employed to determine patients′ occlusal contact pattern after restoration to allow harmonious contact with the opposing teeth. These methods also provide information about the location, timing, direction, and magnitude of occlusal contacts (Baba et al., 2000). Universally used techniques for occlusal registrations are classified into qualitative and quantitative methods (Sharma et al., 2013).

2.5.1 Qualitative method

The qualitative method such as articulating paper requires an examiner to make his/her choice to determine the occlusal contact points, however, the sequence or density of the contacts could not be evaluated (Panigrahi et al., 2015). This method is concerned with the usage of the following materials; articulating paper/ribbon, silk strips, foils, impression, and occlusal indicator wax.

2.5.1.1 Articulating paper/ribbon

An articulating paper/ribbon can be a carbon paper, inked paper/ribbon or a paper/ribbon coated with glossy-colored dye. These materials are commonly used in clinical and laboratory settings to spot premature contacts in the occlusion. They are manufactured in different thicknesses, shapes, and colors to facilitate clinical usage (Oshida et al., 1994; Zuccari et al., 1996).

Excessive force or premature contact can be determined based on the marks on the tooth. Large and dark marks signify heavy occlusal load, while smaller and lighter marks are associated with reduced occlusal loads. Nevertheless, there is no scientific evidence to indicate that articulating papers is an ideal choice of material for occlusal correction. Clinical conclusions based on the heaviness of marks were reported to be an inexact approach for assessment of the contact density (Kerstein, 2008). Moreover, the articulating papers are demolished by saliva, resulting in a high percentage of pseudo contact markings (Maness, 1987a; Saraçoğlu & Özpinar, 2002). Therefore, application of articulating paper is considered in determining the location of tooth contacts. However, their low price and ease of use have made them the most widely used qualitative occlusal registration materials (Afrashtehfar et al., 2013).

2.5.1.2 Silk strips

Silk strips are the soft flexible indicator materials with various range of thickness (26-98 µm), which provide a higher reliability due to their texture. Furthermore, when perfectly adjusted to cusps and fossae they do not create pseudo contact markings (Schelb et al., 1985). One disadvantage with silk strip, however, the material could be altered and distorted by the presence of saliva (Reiber et al., 1989).

2.5.1.3 Foils

Foils are the thinnest occlusal registration materials which provide extra precise readings than paper and silk. However, their marking potential is diminished under lowered pressure and on glossy surfaces. As a consequence, for their best usage, a larger strip has to be used for occlusal detection (Reiber et al., 1989; Panigrahi et al., 2015).

2.5.1.4 Impression materials

Impression materials were used to record occlusal force by allowing biting without resistance (Molligoda et al., 1986). Due to its elastic characteristics, the occlusal impression material is used to mark the occlusal contacts and may be identified when the material was removed after setting (Millstein & Maya, 2001).

Silicone putty impression materials maybe used as an inter-occlusal recording material to evaluate occlusal contacts. The position of tooth contacts is displayed as perforations in the silicone impression material (Ziebert & Donegan, 1979; Sharma et al., 2013).

2.5.1.5 Occlusal indicator wax

Occlusal indicator wax originates from a concept similar to impression materials (Ehrlich & Taicher, 1981; Millstein, 1985; Kong et al., 1991). However, resistance exists when biting into the wax, then the occlusal wax indicator is inspected ahead on a light source. Each recording is situated on a diagnostic cast to visualize and confirm the accurate site of each contact. Nevertheless, inaccuracy and difficult handling were some drawbacks when wax was used as an occlusal material for clinical records (Ehrlich & Taicher, 1981; Murray et al., 1999).

2.5.2 Quantitative method

In the qualitative method, an estimation can be derived from the density of the contacts, for example, the degree of darkness of a tooth contact mark. This is however not considered as a precise measure for evaluation of tooth contact due to its association with human error (Sharma et al., 2013).

Photo-occlusion (Fitzig et al., 1985) and T-scan system (Maness, 1987b) are quantitative techniques used for detecting occlusal relationships through which the sequence and density of the contacts can be differentiated (Panigrahi et al., 2015).

2.5.2.1 Photo-occlusion system

Dental prescale system comprises a horseshoe-shaped bite foil of a pressure-sensitive film and a computerized scanning system for the examination of the load. A thin photo plastic film layer is positioned on the occlusal surface of the teeth where the patient bites for 10–20 sec. The force is then spread over to the occlusal contact and an ordered color is produced by a chemical reaction. The film layer is reviewed under a polariscope light to find the relative tooth contact intensity measurement. The area and color intensity of the red points are used to evaluate the occlusal contact area and pressure with automatic estimation of the occlusal loads (Hidaka et al., 1999; Shinogaya et al., 2000; Miura et al., 2001; Okiyama et al., 2003; Koc et al., 2010).

The dental prescale system, with a thin pressure sensitive foil of a 100 µm thickness (Sadamori et al., 2007), was found to be excellent in measuring biting force as compared to the ordinary measuring systems using a strain gauge transducer (Shinogaya & Matsumoto, 1998; Shinogaya et al., 2000). The foil width allows the bite force measurement close to the intercuspation position and instantaneous evaluation of load distribution over dentition can be made (Shinogaya et al., 2000; Shinogaya et al., 2001). However, this system has the disadvantage of its inability to record the occlusal contact time orders and difficulty to analyze premature and laterotrusive or mediotrusive contacts (Koos et al., 2010).

2.5.2.2 T-scan system

This type of computerized occlusal analysis system is a device that can reproduce the actual occlusal contacts and it also has an advantage over silk marking ribbon in terms of recording the time and force of each contact (Moini & Neff, 1991). Besides accuracy, Cerna et al. (2015) examined the reliability of the T-scan III system under laboratory conditions. The results showed a high degree of reliability when the T-scan III sensors of two different production series were used to perform repeated measurements.

T-scan occlusal analysis technique was introduced as an uncomplicated, easy-to-use method with high accuracy in determining the quantity of tooth contacts in maximum intercuspation position. It allows the occlusal contact data to be quantitatively analyzed, in contrast to other techniques which necessitate qualitative occlusal determination by the operator (Gonzalez Sequeros et al., 1997).

2.6 T-scan system development

The T-scan electrical structure was developed from experimental touch sensors, which were fabricated for robotic uses. Touch sensors were further developed by Purbrick (1981) and Hillis (1982), where conductive rubber elements were used to detect pressure at individual contact points. The material was constructed in such a manner that an increase in pressure will lead to a diminution in its electrical resistance. A similar concept is used with the T-scan, however, the conductive rubber base is replaced with an ultra-thin layer of a pressure-sensitive ink.

Maness (1987a) developed a T-scan system to allow interpretation of the teeth contact data and recording of stress magnitude at each contact by making use of time as the fundamental diagnostic variable. With the T-scan system, it was possible to report various occlusal parameters such as the timing of teeth contacts and their relative force. Maness (1987b) also advocated its use in diagnosis and treatment of occlusion due to its accuracy in detailing the tooth contact. This system is thus utilized to analyze the occlusal contact information collected via directing the subject to occlude on intraoral recording sensor. The system allows recognition of premature contacts or interferences in the dynamic occlusion (Koos et al., 2010), making it applicable in occlusal diagnosis and treatment (Reza & Neff, 1991; Kerstein, 2008; Throckmorton et al., 2009; Kerstein et al., 2013).

In 1995, the T-scan was further improved to T-scan II occlusal analysis system for Windows. The modifications comprised a hardware, software, and additional sensor developments that led to a third generation sensor (G3) with other sensor enhancements (Kerstein, 2004). The G3 sensor scheme was again modified to enlarge the active sensel size and reduce the inactive sensel area by 33% and 50%, respectively, in order to form the fourth generation sensor advancement (G4) with a higher definition scheme (Kerstein, 2011). According to the T-scan III manufacturer, the sensor is 100 µm thick and comprises around 2,500 sensing cells (sensels). The T-scan III G4 sensor contains two layers of Mylar polyester resin sheets with the net of resistive ink rows and columns printed between them. A row and a column are individually connected and signify one sensel, which is the force and time recording portion of the computerized occlusal analysis system. Both bigger sensels and lesser space between the sensels help to raise the total volume of recording surface area and simultaneously reduce the amount of inactive non-recording area between the sensels (Kerstein, 2011).

In 2008, T-scan III with Turbo recording was released. Turbo recording captured three times more occlusal data for analysis than was possible with the previous versions. This faster-scanning speed provides the clinician with greater ability to locate non-simultaneous tooth contact sequences and any abnormal occlusal force concentrations. T-scan III was further improved and in 2012 T-scan 8 was released, that was purposefully designed to minimize the T-scan III's user interface complexity by using fewer software toolbar buttons and icons for simpler data display (Kerstein, 2015).

2.6.1 T-scan system applications in Dentistry

2.6.1.1 Prosthodontics

To determine whether T-scan could be used to replace remounting procedures in CD reconstruction, a correlation between remounting and balance of occlusal load was determined in 10 patients who had new CDs. The results showed a very strong correlation in 9 out of 10 evaluated patients (Boening & Walter, 1992).

In another study, occlusion and force distribution characteristics of three CD patients, whose dentures were constructed in the postgraduate prosthodontic clinic, were analyzed in pre- and post-adjustment appointments using the T-scan II system. The computerized occlusal analysis was found to provide information on occlusal load distribution and adjustment, and it provides an efficient way for clinicians to improve denture stability (Olivieri et al., 1998).

2.6.1.2 Trauma from occlusion

Trauma from heavy occlusal contacts can lead to loss of periodontal attachment with increased tooth mobility (Harrel & Nunn, 2001). The T-scan III is a useful tool that can be used to identify premature occlusal contacts on a hypermobile tooth. Also, it is a valuable tool to identify contact intensity and to evaluate contact changes after occlusal adjustment with a diamond bur (Nguyen et al., 2007), and in the diagnosis and treatment follow-up until complete trauma resolution (Daing et al., 2012).

The T-scan III has also been used to determine centric and eccentric occlusion and occlusal time of patients with dysfunctional cranial-mandibular syndrome (Oprea et al., 2014).

2.6.1.3 Implant prostheses

Occlusal forces directed to implant prostheses with damaging component could reduce the durability of the restoration. Material failures together with implant loss of osseointegration could be linked to occlusal loading of dental implants (Kohavi, 1993; Isidor, 1997).

With the advance in the computerized T-scan occlusal analysis system, occlusal forces that are directed to implant prostheses can be quantitatively characterized for occlusal corrections. The occlusal force equilibration can lead to less damaging forces towards the prostheses and the underlying implant-bone interface (Cotruta et al., 2015).

Clinicians could obtain consistent and useful occlusal data for the placement, analysis, and repair of a dental implant prosthesis (Garg, 2007). As premature contacts in maximum intercuspation position must be eliminated when prosthesis is fixed to provide better force control both on the bone-implant interface and implant-prostheses assembly (Chapman, 1989).

A case of severe bruxism and masseteric hypertrophy, associated with repeated implant loss was reported by Sukegawa et al. (2016). A successful management of masseteric hypertrophy and subsequently avoidance of implant loss was achieved in this case where occlusal analysis was preferred using T-scan III prior to dental implant placement.

2.6.2 T-scan system limitations

It was revealed that thinner occlusal registration materials offer a more constant reading of the contact points (Reiber et al., 1989). To achieve the technological requirements, the T-scan sensors were prepared as thin as possible at 100 µm (Kerstein, 2007). However, these sensors are slightly thicker compared to other occlusal indicators such as articulating silk, which has the thickness within the range of 26-98 µm.

The sensitivity of the T-scan sensors also appears to reduce or fade when the sensors were used more than once. Previous studies have detected the absence of sensibility on some of its parts of the sensor, which resulted in incorrect recordings (Patyk et al., 1989; Yamamura et al. 1990; Harvey et al., 1991).

T-scan system measures force in percentages only instead of actual force in Newton. A vitro study, with a limited clinical trial on two individuals, was carried out to measure bite force by using the T-scan system by Lyons et al. (1991), concluded that the T-scan system does not precisely determine actual bite force.

2.7 Bone Resorption

Great individual variation in bone loss of the alveolar process occurs after tooth removal and it can be difficult to anticipate the extent of bone loss at the time of extraction. Alveolar bone loss can be minimized by preserving a few teeth in the arch or by implant placement to support the prostheses (Carlsson, 2014).

2.7.1 Residual ridge resorption

Bone remodeling that takes place after tooth removal occurs in two phases; an initial and fast phase that can be detected in the first three months and the succeeding second phase that is slow, and ongoing throughout life. During the early period of 6 and 12 months, there is new bone formation with the destruction of almost all of the alveolar crest height and reduction of nearly two-thirds of the ridge width (Schropp et al., 2003).

The rate of resorption then decelerates to minimal levels and significant reduction in bony dimensions could be seen particularly in patients become edentulous at younger age. The rate of residual ridge resorption (RRR) differs, between individuals, at different phases of life, and even at different sites in the same individual (D'Souza, 2012).

2.7.2 Consequences of residual ridge resorption

Residual ridge resorption is chronic and progressive, and in complete denture patients, it can result with denture wearing. As it is cumulative, patients with this disease can become dentally handicapped (Atwood, 1971).

An average rate of anterior vertical RRR of 0.5 mm per year could represent an average loss of 5 mm in anterior ridge height in 10 years with a different variation among some patients, resulting in a significant loss of vertical dimension, aesthetics, and comfort. Such remarkable changes in edentulous people represent a staggering need for prosthodontic care (Atwood & Coy, 1971).

2.7.3 Factors affecting residual ridge resorption

2.7.3.1 Anatomic factors

Anatomic factors include the amount and quality of bone. The amount of bone is not a dependable prognostic factor for the rate of RRR since it was viewed that some large ridges resorb quickly and certain knife-edge ridges could continue with slight variations for extended periods of time. Meanwhile, for the quality of bone, which is influenced by the bone density, the denser the bone, the slower the rate of resorption since there is more bone to be resorbed per unit of time (Winkler, 1988).

Regarding the difference in resorption rate in the maxilla and mandible, the anterior mandible resorbs four times faster than the anterior maxilla. This is possibly due to the variation within the surface square area of the maxilla and the mandible, the ‘shock absorber’ property of the mucoperiosteum, and the difference in the quality of bone of both jaws (D'Souza, 2012).

The maxillary denture surface square area is estimated to be 4.2 square inches and 2.3 square inches for the mandible (Ohashi et al., 1966), which is in the ratio of 1.8:1. Hence, if a patient bites with a force of 50 lbs, this is considered to be 12 lbs/square inches underneath the maxillary denture and 22 lbs/square inches underneath the mandibular denture. The difference in the two forces is thought to be a contributing factor to the difference in the rates of resorption between the arches (Woelfel et al., 1976).

On the other hand, the spongy nature of the mucoperiosteum has an inhibiting effect on the forces that are transferred to the alveolar ridge. As the overlying mucoperiosteum differs in its viscoelastic properties from one individual to other and from the mandible to the maxilla, its energy absorption abilities possibly will influence the rate of RRR. Cancellous bone has more favorable tendency to absorb and dissolve the occlusal forces. Maxillary bone is more cancellous in nature and its residual ridge is wider, flatter, and more cancellous than the mandibular ridge. Trabeculae in maxilla are positioned parallel to the direction of compression deformation, permitting for greatest resistance to distortion (D'Souza, 2012).

2.7.3.2 Prosthetic factors

Lack of retention and/or instability of removable prostheses has been implicated in higher rate of RRR (Atwood & Coy, 1971). Another study by Carlsson & Persson (1967) showed the increase in RRR rate of the edentulous ridge in denture wearers who had been using their denture for a long period.

Maxillary complete denture opposing mandibular natural teeth tended to have a greater bone resorption in the anterior segment of the maxillary residual ridge (Kelly, 1972).

2.7.3.3 Role of inflammatory mediators

Numerous inflammatory mediators, mostly prostaglandins, have been suggested to play a role in increasing the rate of RRR. When osteoblastic cells were exposed to cyclic mechanical stresses *in vitro*, there was a significant escalation in prostaglandin E2 synthesis (Yeh & Rodan, 1984).

Adrenomedullin hormone has been also reported to be able to stimulate the proliferation and migration of various cells including osteoblasts. The influence of local adrenomedullin in rats tooth extraction socket after 4, 8, 12 weeks, suggested that local application of adrenomedullin has the potential to preserve the residual alveolar ridge and accelerate the alveolar bone remodeling (Wang et al., 2013).

2.7.3.4 Post-menopausal osteoporotic changes

Kribbs (1990) compared mandibular bone mass, bone density, and cortex width, between 112 normal and osteoporotic women, and the results showed a decrease in bone mass and density and thinned cortex at the gonion area of osteoporotic women compared to women without osteoporosis.

Similarly, it was demonstrated in a longitudinal morphological study (Nishimura et al., 1992) that knife-edge mandibular residual ridge was positively correlated with osteopenic change at the center point of the body of the second vertebra. Additionally, postmenopausal women with lower densitometric bones showed a higher tendency to have a knife-edge mandibular residual ridge compared with men.

2.7.4 Methods to reduce residual ridge resorption after tooth loss

There are various methods that have been recommended for ridge preservation after extraction, with some of these methods effective in limiting the horizontal and vertical ridge changes. The prognosis for implant placement can be further improved with more bone available after tooth loss (Chladek et al., 2014).

2.7.4.1 Clinical and laboratory techniques

In CD the stress transmission to the underlining tissues beneath the prosthesis can be reduced by having broad coverage of the denture area (Chladek et al., 2014). An impression of a completely edentulous arch must accurately record the anatomic area of the residual ridge and surrounding tissues. McCord (2000) in his clinical review of the various modalities of impression making techniques, recommended the use of selective pressure impression techniques in the case of a flat mandibular ridge covered with atrophic mucosa. Also, Gandage Dhananjay et al. (2012) introduced a two-step impression for atrophic mandibular ridge by the use of monophase and light-bodied impression material, which was found to provide improved stability and retention of the denture base.

2.7.4.2 Surgical techniques for highly resorbed ridges

Several techniques have been recommended to enable bone formation in newly extracted sockets, thus, diminishing the loss of bone height and buccolingual width. Darby et al. (2009) reviewed the literature on post-extraction ridge preservation techniques, aim to determine the efficacy of these techniques in relation to successive implant placement. They found no evidence to support the superiority of one technique over another, however, ridge preservation techniques were found to be effective in limiting horizontal and vertical ridge alterations in post-extraction sites.

Aimetti et al. (2009) investigated the effect of the placement of calcium sulfate hemihydrate in fresh extraction sockets on the quality of newly formed bone. Their results showed that the effect of calcium sulfate hemihydrate was to reduce vertical resorption of the buccal socket walls and a reduction of the buccopalatal width at the applied sites. In the esthetic zone, augmentation of the proposed implant site makes it possible to achieve acceptable results (McCarthy et al., 2003).

A novel combination of recombinant human bone morphogenetic protein-2 and a bio-absorbable collagen sponge was investigated in a randomized controlled multicenter clinical study (Fiorellini et al., 2005), and the results showed a significantly greater bone regeneration associated with the use of this combination compared to without its use.

2.7.4.3 Implant-supported overdentures treatment

Mandibular overdenture retained by natural teeth exhibited a considerable decrease in the bone loss at 5 years study (Crum & Rooney, 1978). This study observed a 5.2 mm reduction in the anterior alveolar bone height in complete denture wearers, as compared to 0.6 mm bone height reduction in supported-overdenture patients. Kordatzis et al. (2003) found similar results after 5 years, in which the estimated average of reduction in height was 1.63 mm for conventional CD and 0.69 mm for IOD groups.

2.7.5 Methods of ridge resorption measurements

2.7.5.1 Dental cast measurement

Measurement of the dental cast was used to investigate variations in jaw bone contour of edentulous patients. Campbell (1960) investigated the differences in vertical and labiolingual dimensions of the ridges in denture wearers and non-denture wearers by using measurements on the dental stone cast.

Gypsum casts were used to measure bone resorption in a clinical case report of a 62-year-old woman, who used commercially home reliner to stabilize her lower CD for 8 years. The results showed higher bone resorption in her mandible compared to the upper maxillary ridges (Woelfel et al., 1962).

Närhi et al. (2000) investigated the possible changes in the width of the maxillary residual ridge on the diagnostic cast models after 6 years following mandibular IOD or conventional CD insertion. They found a reduction of the ridge width with time, regardless of the type of prostheses used. One concern with this method of measurement was the variability of the pressure applied during the impression making (McGivney et al., 1986), which could introduce some errors in the estimation.

2.7.5.2 Radiographical methods

Resorption of the alveolar ridge has been assessed with using radiographical images, such as lateral cephalometric (Atwood & Coy, 1971; Woelfel et al., 1976; Mercier & Lafontant, 1979; Tallgren et al., 1980; Jonkman et al., 1991) and panoramic radiographs (Wical & Swoope, 1974; Van Waas, 1983; Swart & Allard, 1985; Wilding et al., 1987; Humphries et al., 1989). The more recent imaging method using cone-beam computed tomography (CBCT) allows 3D view and compared to conventional cross-sectional imaging (CT), the CBCT reduced X-ray exposure (Angelopoulos et al., 2008).

*(a) **Cephalometric radiograph***

The advantages of the cephalometric technique are that the vertical and horizontal magnification factors are known, and both jawbones images can be clearly reproduced. Nevertheless, the superimposition of the alveolar ridges renders it impossible to differentiate the changes in resorption between the two sides (Xie et al., 1997b). An oblique cephalometric technique has resolved this problem (Freihofer & Hoppenreys, 1986; Jonkman et al., 1991); however, multiple radiographs are required for the area of investigation involves both the anterior and posterior regions on both sides of the arch.

(b) ***Panoramic radiograph***

A panoramic radiograph is a curved plane tomographic radiography permits visualization of the maxilla, mandible, TMJ joints and the lower one-half of the maxillary sinuses on a single image. This radiographic procedure is possibly one of the most operated diagnostic modality in implant dentistry (Dove & McDavid, 1993).

Panoramic radiography also provides valuable information about anatomic structures such as the inferior alveolar nerves, and mental foramen (Lee et al., 2012). Additionally, the examination of RRR in large numbers of patients with panoramic radiography is achievable as it is usually used in large institutional practices as a method of screening edentulous patients during routine treatment (Scandrett et al., 1973; Xie et al., 1997b).

Yet, there are some problems that limit the use of the panoramic radiography, for instance; 2D distortion, variation in magnification, the difficulties in standardizing the position of the head (Jacobs et al., 1993; Xie et al., 1997b).

(c) ***Cross-sectional imaging and cone-beam computed tomography scan radiographs***

Owing to the fact that cone-beam computed tomography (CBCT) images were reformatted in slices of the maxilla and mandible, they were free of magnification, superimposition of neighboring structures, and other problems characteristic to panoramic and cephalometric radiography. The recently introduced CBCT creates 3D image data by a single scan around the imaging volume of interest and this may result in very clear images representing the mandibular canal (Angelopoulos et al., 2008).

It was revealed that cross-sectional imaging (CT) images (Serhal et al., 2002; Jacobs et al., 2004; Angelopoulos et al., 2008) is an alternative for the exact visualization of the anatomical structures. However, panoramic radiographs were used due to its lower cost (Dharmar, 1997), and most of its use in implant surgery planning is extensively documented (Xie et al., 1997b).

2.7.6 Determination of alveolar bone resorption using panoramic radiographs

Panoramic radiography is considered a standard diagnostic procedure to evaluate residual ridge changes (Jacobs et al., 1992), and compared to cephalometric radiographs, it has no issues with overlapping of the left and right side images (Xie et al., 1997b). Current studies for measuring residual ridge bone height loss used two methods; the linear method and the area index method. However, panoramic radiographs still have some magnification and head position drawbacks (Wilding et al., 1987; Kreisler et al., 2000).

2.7.6.1 Linear method

This method has been used by many researchers in evaluating the bone loss in the mandible and maxilla. It is an easy method for recording the oral and related structures (Wical & Swoope, 1974; Xie et al., 1997b; Güler et al., 2005; Panchbhai, 2013).

Sağlam (2002) determined the variation in maxillary and mandibular vertical measurements based on the panoramic radiographic views for dentate and edentulous jaws. Ninety-six dentate and edentulous patients were enrolled and the measurements were made from reference lines drawn from anatomic landmarks on standardized panoramic radiographs. It was found that the reductions in the height of the edentulous mandible and maxilla were significantly more pronounced in women than in men.

2.7.6.2 Area index method

Area index method was developed by Wilding et al. (1987), to determine the accuracy of mandibular bone loss measurements made by panoramic radiographs. A comparison was made between measurements obtained directly from dry mandibles and those from panoramic radiographs of the same mandible using either area index or linear vertical methods. The area index method showed significant difference in the index between the left and right sides of the mandible, while the liner method showed no significant difference.

Kreisler et al. (2000) developed an *in vitro* method to enable the radiological investigation of RRR in the maxilla. Determined experimental and reference areas in the maxilla were drawn on transparent film laid over a panoramic radiograph and they were digitized. All areas were measured with an integrated planimetry program and expressed as a ratio. The effect of positioning errors on the reliability of the method was investigated on dry skulls. The correlation between the change in ratio and actual bone loss was examined by progressively reducing the height of an artificial residual ridge on one skull. Comparison of the experimental area with the reference area on serial panoramic radiographs appears suitable for the assessment of RRR in the maxilla.

Wright et al. (2002) investigated the change over time in the area of the posterior mandibular residual ridge in patients wearing either i) mandibular overdentures stabilized by two implants connected with a bar, or ii) mandibular fixed cantilever prostheses stabilized on 5 or 6 implants. Proportional measurements were made to compare the area of the residual ridge with an area of bone uninfluenced by resorption. Measurements were made by digital tracings of panoramic radiographs that were taken shortly after implant insertion and after follow-up of up to 7 years later. The results revealed that patients rehabilitated with mandibular implant overdentures demonstrated low rates of posterior mandibular RRR, while patients rehabilitated with implant-stabilized mandibular fixed cantilever prostheses demonstrated bone apposition in the same area.

In a 5 years observational study, Kordatzis et al. (2003), found the average reduction in the posterior mandibular residual ridge height was higher in conventional denture patients than in the implant overdenture patients. Moreover, female was found to have a higher risk factor for greater bone resorption.

Tymstra et al. (2011), utilized the proportional area measurements to determine RRR in the maxillary anterior and mandibular posterior areas over a period of 10 years in mandibular IOD, retained by two or four implants. Their results indicated that patients rehabilitated with IOD were not subjected to more RRR in the anterior maxilla as compared to patients wearing a conventional CD. While with respect to the mandibular posterior residual ridge, resorption was independent of wearing an IOD or a conventional CD.

Another study investigated the clinical and radiographic changes in the edentulous maxilla in patients with either ball or telescopic attachments of mandibular IODs (Elsyad et al., 2013). The proportional value between bone areas and of reference areas was expressed as a ratio. Change in ratio immediately before baseline and 4 years after overdenture insertion was calculated for the maxillary anterior and posterior regions. Telescopic attachments for mandibular IODs were associated with increased maxillary ridge resorption and flabbiness and decreased maxillary denture retention as compared to IOD retained by ball attachments.

2.8 Patient-reported outcomes

2.8.1 Health-Related Quality of Life

World Health Organization (WHO) has defined health as “a complete state of physical, mental, and social well-being and not just the absence of disease” (WHO, 1995). In the last 30 years, there was an increase in the use of the terms ‘health-related quality of life’ (HRQoL) and ‘quality of life’ (QoL) in medicine, relative to the outcomes of health conditions and therapy (Gill & Feinstein, 1994). QoL is defined as “an individual’s perception of his or her position in life in the context of culture and value systems in which they live, and in relation to their goals, expectations, standards, and concerns” (Group, 1995). This emerged out of a growing recognition that traditional clinical measures of health need to be supplemented by data obtained from patients and/or persons that capture their experiences and concerns (Fitzpatric et al., 1998).

2.8.2 Oral Health-Related Quality of Life

Oral health-related quality of life (OHRQoL) is defined as “a multi-dimensional construct that reflects people’s comfort when eating, sleeping, and engaging in social interaction; their self-esteem; and their satisfaction with respect to their oral health" (Health., 2006). It is a complex and multidimensional concept that focuses on the extent to which the well-being of individuals and society as a whole is affected by oral problems. Many variables influence the OHRQoL, including the association of patient's age and ethnicity (Atchison & Gift, 1997), gender, financial factors, current dentures, and psychosocial factors (Locker, 2009).

2.8.3 Oral Health Impact Profile (OHIP-49)

The Oral Health Impact Profile (OHIP) was established with the purpose of providing a full measure of self-reported dysfunction, discomfort, and disability attributed to oral conditions. It provides information about the 'burden of illness' within populations and the effectiveness of health services in reducing that burden of illness (Tugwell et al., 1984).

This instrument was first introduced by Slade and Spencer (1994) in Australia as the Oral Health Impact Profile (OHIP-49), following Locker's model of oral health (Locker, 1988). There are seven conceptual dimensions of impact; functional limitation, physical pain, psychological discomfort, physical disability, psychological disability, social disability, and handicap.

2.8.4 Oral Health Impact Profile (OHIP-14)

A shortened (14-item) version of the OHIP was developed by Slade (1997b). The shortened version was considered for the reason that the original questionnaires take a long time to complete, which place a burden on the patient and/or clinician. The respondent burden may be an issue when the participants in a study are weak, ill, or severely compromised and unable to cooperate for any length of time. Long scales are also more likely to be subject to item nonresponse, giving rise to problems of how to manage missing data (Locker & Allen, 2002).

Stewart et al. (1988) have described conceptual statistical and realistic requirements for health status questionnaires': 1. they should represent multiple health concepts and a range of health states pertaining to general functioning and well-being; 2. they should have good psychometric properties (reliability, validity, and precision); and 3. for clinic settings, they should be simple and easy to use.

2.8.5 Oral Health Impact Profile [S-OHIP(M)] Malaysia

Oral health-related quality of life measure for the Malaysian adult population aged 18 and above was developed by a cross-cultural adoption of the OHIP-45 (Saub et al., 2007). The OHIP was translated into the Malay language by using a forward-backward translation technique. Based on the translation process and interview results, a Malaysian version of the OHIP questionnaire that contained 45 items was produced. It was designated as the long OHIP Malaysian version, L-OHIP(M). Subsequently, a short version was developed, which contained 14 items by selecting the two most frequently reported items from each domain, and it was designated as the short OHIP Malaysian version S-OHIP(M). It has been shown to be valid, reliable, and appropriate for use in the cross-sectional studies on Malaysian adult populations (Saub et al., 2005).

2.8.6 The effect prosthesis types on the Oral Health-Related Quality of Life

A relatively high number of patients wearing mucosa-supported dentures were likely to be dissatisfied mostly with their mandibular dentures, due to stability and retention problems (Lechner & Roessler, 2001).

Dental implant therapy has become a satisfactory form of treatment to replace missing teeth and their associated infra-oral structures (Cooper, 2009). Once patients were rehabilitated with the dental implant, it was easier for them to accept it as natural and as a real part of their bodies (De Grandmont et al., 1994).

Higher levels of satisfaction have been reported for individuals rehabilitated through IOD prostheses in terms of comfort, stability, and aesthetics as compared to those treated with conventional CDs (De Grandmont et al., 1994; Awad & Feine, 1998; Vermylen et al., 2003).

2.8.6.1 Quality of life for patients using conventional complete dentures

Completely edentulous patients meet WHO criteria for being: (1) physically impaired, (2) disabled, and (3) handicapped (Felton, 2015). The OHIP and general HRQoL 36-item (SF-36) questionnaires had been used to measure the quality of life of patients new CDs (Kuoppala et al., 2013). Most participants reported medium satisfaction with their new CDs. Meanwhile, in another retrospective study, OHRQoL was compared between patients wearing both maxillary and mandibular CDs, and those with either the maxillary or the mandibular CDs. Patients wearing CDs in both jaws were less satisfied than patients who used a single CD (AlBaker, 2013).

2.8.6.2 Quality of life for patients using implant-supported overdentures

The inadequacy of conventional CD treatment in a certain group of edentulous patients and with the introduction of implants in dentistry, mandibular two-IOD has now become an alternative option in improving denture stability and retention (Boerrigter et al., 1995a; Meijer et al., 1999). Short and long-term improvement with IOD in terms of patients′ OHRQoL had been demonstrated (Awad et al., 2000a).

Several studies had investigated the impact on QoL of individuals treated with either conventional mandibular CDs or IODs. The results showed lower OHRQoL impacts in patients treated with IODs than CDs (Allen et al., 2001; Awad et al., 2003; Heydecke et al., 2003; Borges et al., 2010; Torres et al., 2011; Jabbour et al., 2012; Semyari et al., 2013).

In a recent prospective study, the OHRQoL of a group of patients provided with mandibular implant fixed partial prostheses and mandibular IOD prostheses. Improvement in the QoL was observed following both types of prostheses, with both groups demonstrated improved OHRQoL after implant rehabilitation. However, the partially dentate group showed greater improvement compared to totally edentulous group (Yunus et al., 2015).

2.8.7 Denture satisfaction

Significant improvement in stability, retention, bite force, chewing efficiency, in patients with severe problems adapting to conventional dentures (Fontijn-Tekampl et al., 1998; Pera et al., 1998; Awad et al., 2000a; Awad et al., 2003; Thomason et al., 2003) had been shown when implant prostheses were provided. In several clinical trials, implant therapy was compared to treatment with conventional dentures using patient-based outcomes (Wismeijer et al., 1992; Boerrigter et al., 1995a; Burns et al., 1995). Results from these studies suggested that implant treatment provided patients with more satisfactory prostheses compared to conventional dentures. It could because of better stability and retention of the mandibular denture, and hence better chewing experienced by patients, and greater satisfaction with aesthetics could be explained by the denture not visibly moving during function (Doundoulakis et al., 2003).

2.9 Masticatory performance

Simple and reliable methods for measuring masticatory performance would be useful aids in evaluating the success of dental restorative procedures. One goal of dental restoration is to improve the masticatory performance of patients who have lost their teeth (Manly & Braley, 1950).

2.10 Masticatory performance measurement methods

Agerberg & Carlsson (1981) evaluated the chewing ability of 1106 individuals by using questionnaires, and although the questionnaires were subjective, they found that masticatory performance was closely related to the number of residual teeth.

The subjective method of measuring the masticatory performance can be evaluated by questionnaires or personal interviews to assess an individual's chewing ability, while objective method can provide more information about the efficiency and performance in the mastication (Boretti et al., 1995).

Various methods had been developed and used for objective evaluation of masticatory performance. There are however only a few methods which had both the validity and reliability. Manly & Braley (1950) developed the sieving method for evaluation of masticatory performance by using peanuts, shredded coconut, carrots, and raisins. Theses test foods are natural food and some had used artificial food as they are easier to prepare and suitable for analysis using sieving method. Edlund & Lamm (1980) used a silicone compound (Optosil) as a test material for the sieving method because the variation of test-retest consistency was smaller than that used with natural test food (Olthoff et al., 1984).

Several studies have developed a method to measure masticatory performance by using two-colored chewing gum (Liedberg & Öwall, 1995; Matsui et al., 1996; Hayakawa et al., 1998). Further development was achieved by Hayakawa et al. (1998), where they used a spectrophotometer for analyzing the two-colored chewing gum. Reliability among examiners was found, however, the validity of this method was not known.

Another method was developed by Sato et al. (2003) to measure masticatory performance using the mixing ability index (MAI). This method used paraffin wax as a test material, in which small cuboids having identical dimensions were made from molten paraffin wax with either red or green dye. The chewed wax was digitally analyzed using image analyzer which provided a simple masticatory evaluation (Sato et al., 2003).

2.11 Acrylic denture risk of fracture

Acrylic dentures fracture and repairs continue to present a challenge to clinicians as it involved increased expenses to patients and health care (Darbar et al., 1994). Various materials had been used as denture base, however, acrylic resins are extensively used due to the aesthetic properties and ease of manufacture and repair. One of the drawbacks of the acrylic resin is its low resistance to fracture (Uzun & Hersek, 2002).

Due to acrylic denture fractures several studies had been conducted to investigate the stress and strain distributions in CD prostheses, they are listed as below:

1- Brittle lacquer coating (Wain, 1957).
2- Electrical strain gauges (Regli & Kydd, 1953; Regli & Gaskill, 1954; Wain, 1957; Lambrecht & Kydd, 1962; Johnson, 1965; Obeid et al., 1982; Stafford & Glantz, 1991; Prombonas & Vlissidis, 2006; Cilingir et al., 2013).
3- Scanning electron microscope (Lamb et al., 1985; Vallittu, 1996).
4- Photoelastic method (Kubota, 1959; Craig et al., 1974; Koran & Craig, 1974).
5- Finite element analysis method (Farah et al., 1973; Maeda et al., 1986; Maeda & Wood, 1989; Rees et al., 1990; Zhang, 1992; Kawano et al., 1993; Cheng et al., 2010).

The finite element method, which is a numerical method, seems to overcome a large portion of the problems related to different techniques and offers a wide potential for stress analysis in dentistry (Darbar et al., 1994).

2.11.1 Finite element analysis method

The use of finite element analysis (FEA) method was adopted in solving sophisticated geometric problems, for which it is extremely complicated to obtain an analytic answer. FEA is a procedure for acquiring data on complicated mechanical problems by means of dividing the problem domain (element) into a set of much smaller and less complicated domains. FEA technique, rather than looking for an explanation of the entire domain, construct an answer for each finite element and merges them to gain an answer to the total physique. A mesh is required in FEA to divide the entire domain into small elements. The procedure of creating the mesh, elements, their respective nodes, and defining boundary conditions is termed 'discretization' (Geng et al., 2008).

Even though the FEA method was generally used earlier within the sector of structural mechanics, it was efficaciously applied to answer several other forms of engineering issues in civil engineering, mechanical engineering, nuclear engineering, biomedical engineering, hydrodynamics, heat conduction, geomechanics, and others (Barkanov, 2001).

FEA has been used in medicine for the study of the biomechanical behavior of orthopedic instruments including hip, knee, and spinal implants, under various loading conditions (Crowninshield et al., 1983; Keyak & Falkinstein, 2003; Majumder et al., 2005; Morra & Greenwald, 2005; Goel et al., 2006; Poggie et al., 2007).

In the past two decades, FEA has become a valuable method in dentistry for the prediction of stress outcome on the implant and its surrounding bone. Vertical and transverse loads occurred during mastication result in axial forces and bending moments and their stress effects in the implant and surrounding bone (Geng et al., 2001).

2.11.2 Application of finite element analysis in dentistry

2.11.2.1 Implant stress analysis

The stress patterns in different implant structures and also in the peri-implant bone were determined by quality and quantity of bone and also by the implant number, diameter, length, thread profile, and material properties of implant components (Baggi et al., 2008; Vairo & Sannino, 2013).

2.11.2.2 Maxillary obturator

Biomechanics of implant-supported maxillary obturator prostheses had been investigated through FEA simulation, which was vital for predicting the endurance of implant-supported prosthetic rehabilitation of patients next to the maxillectomy defect (de Sousa & Mattos, 2014). The highest dislodgment of the implant-supported maxillary obturator was shown to increase with the reduction in the area of bone support, implants number and types of attachments.

2.11.2.3 Post and core restorations

FEA simulations could also be used to enhance the mechanical stability and durability of post-and-core restorations. Liu et al. (2014) analyzed the occlusal forces on limited coronal dentin areas with massive tissue loss. Preserving the remaining dentin had been accomplished by lowering the lateral occlusal contact area.

2.11.2.4 Trauma and fracture

FEA of simulated traumatic loads can be utilized to understand the biomechanics of fracture. Previously, cadaveric studies were used, but for ethical considerations, such studies are now no more permitted. Moreover, as most studies speculated that the ordinary age of patients with maxillofacial trauma is between 20–30 years, the age of death of a cadaver frequently do not fit with that of an ordinary facial trauma patient (Roccia et al., 2008; Elhammali et al., 2010).

2.11.2.5 Analysis of the biomechanical effects of occlusal loads on implant prostheses

Strain gauge measurements limited where the gauge can be attached, whereas the FEA can be used to calculate stress and strain in any region of the simulated model (Baiamonte et al., 1996; Cheng et al., 2010).

Implant-supported fixed prostheses with cantilevers aggregate additional causes that can affect stress distribution. With a 3D FEA model of a bilateral distal cantilever fixed prostheses supported with the aid of six implants in the mandible, Sertgöz & Güvener (1996) proposed that maximum stresses would occur at the most distal bone-implant interface on the loaded part and these stresses would increase drastically with the cantilever size.

Liu et al. (2013) conducted a 3D FEA to assess stress distribution in peri-implant bone and within the abutments of mandibular IOD anchored by limited numbers of implants under various loading conditions. They concluded that the single-implant-retained mandibular overdentures did not show harmful pressure within the bone around it.

2.11.3 Finite element analysis method assumptions

The fundamental problem in simulating the mechanical mode of dental implants is the modeling of human bone tissue and its reaction to the mechanical load. Some assumptions influence the accuracy of the FEA results. These include; detailed geometry of the bone and implant to be modeled, material properties, boundary and load conditions (Korioth & Versluis, 1997; Geng et al., 2001).

2.11.3.1 Detailed geometry

The first step in FEA modeling is to symbolize the geometry of concern within the computer software. In some 2D FEA reports, the bone used to be modeled as a simplified rectangular configuration with the implant (Rieger et al., 1990; Van Oosterwyck et al., 1998; Maeda et al., 2005).

Recently, effective digital imaging methods were available for the development of anatomically precise models. These include the application of special software for the direct transformation of 2D or 3D information in image data from computed tomography or magnetic resonance imaging into FEA meshes. Consequently, a 3D model was developed using CT images with a geometry for a specific region of interest (Eskitascioglu et al., 2004; Li et al., 2011; Shafi et al., 2013), or to acquire a geometry for the complete anatomical jaw (Liu et al., 2013; Shahmiri et al., 2013).

2.11.3.2 Material properties

The stress and strain distribution in a structure are commonly affected by material properties. These properties will also be modeled in FEA as isotropic, transversely isotropic, orthotropic, and anisotropic. In an isotropic material, the properties are identical in all directions. In most FEA studies, the assumption was made that the substances were homogeneous, linear and that they have elastic material manner characterized using material properties of Young's modulus and Poisson’s ratio (Geng et al., 2008).

2.11.3.3 Boundary conditions

In modeling the mandible and maxilla in most FEA studies, the boundary conditions were fixed. For more design simplification, Zhou et al. (1999) used a full constraint boundary conditions for an FEA mandibular model constructed from a 3D scanned CT image. Meanwhile, for a maxillary model, Cheng et al. (2010) used a W-shaped constraint boundary condition between the maxilla and the base of the skull.

2.11.3.4 Loading conditions

Boundary conditions varied markedly among the models, depending on the loading involved. Applied loads in several FEA models involved forces placed on selected teeth (Korioth & Versluis, 1997).

Load values used in FEA are in accordance with the clinically measured bite force. The bite force measurement using a strain gauge by patients wearing CD was found to be 120 N and 160 N for others wearing IODs (Fontijn-Tekamp et al., 2000). In another study, the bite force was found to be 138N and 77N for IODs and CDs, respectively, by using pressure load cells (Ahmad et al., 2015).

2.11.4 Limitations of finite element analysis method

FEA modeling of the geometry, material properties, boundary conditions, and loading conditions could be subjectively determined. Additionally, FEA needs broad experience within the problem modeling and in results interpretation (Geng et al., 2008).

The actual force distribution across the dental arch in clinical situations could differ from one patient to another. Consequently, the load values used in the FEA analysis may not represent actually how the occlusal forces normally occur. It is necessary to investigate multiple loading instead of applying unilateral or bilateral loads on a selected area (Ahmad et al., 2015).

Most of computerized *in vitro* FEA studies analyzed stress under static loading, and the mechanical properties of materials were set as isotropic and linearly elastic. However, in reality, different mechanical properties could occur which may not be completely simulated (Merdji et al., 2010; Trivedi, 2014).

CHAPTER 3: METHODOLOGY

3.1 Patient selection

In this study, 32 patients who had received two mandibular implant-supported overdentures (IOD) and maxillary conventional complete dentures (CD) were enrolled. Patients were provided with two implants of various implant diameters and varying heights. Twenty patients had Ankylos implants (Ankylos C/X, Dentsply Friadent, Mannheim, Germany), while 12 patients had Straumann implants (Straumann, Basel, Switzerland). Implants were inserted in the parasymphyseal region of the edentulous mandibular arch. The IOD prostheses were retained by either telescopic attachments (Ankylos Syncone C/ 5° Abutment, Dentsply Friadent, Mannheim, Germany) or Locator attachments (Zest Anchors, Escondido, CA, USA) (Figure 3.1).

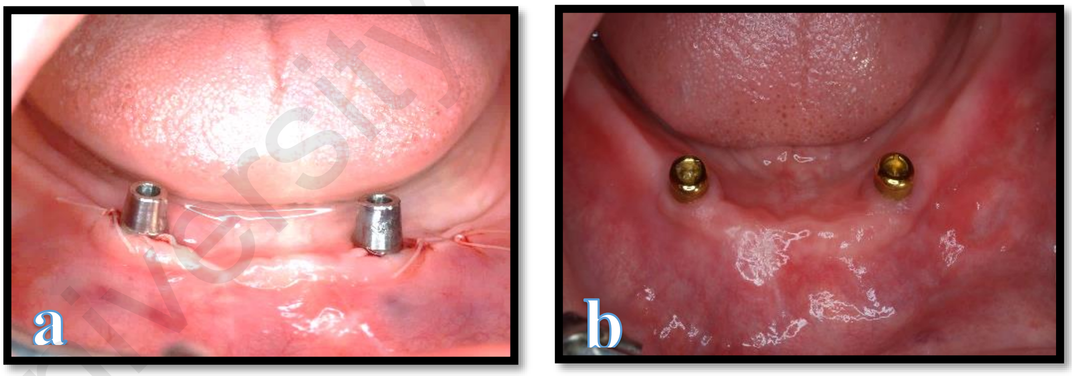

Figure 3.1: Intraoral view of the (a) telescopic and (b) Locator abutments in IOD patients.
(Courtesy: Dr. Norsiah Yunus)

Diagnostic dental panoramic radiographs (DPR s) for 4 years follow-up were available from the patients' records at the Department of Restorative Dentistry, Faculty of Dentistry, University of Malaya. Among those patients, there was one deceased patient and three patients who were not able to participate because they had changed their living address to another city, and one patient had a speech impairment, and movement disability. Additionally, four patients were excluded from the study due to missing or unclearly visible DPRs in their records. For the conventional CD group 32 patients, were identified from the list of patients who had previously received conventional CD prostheses. They were recalled and among those, two patients declined to participate due to engagement of full-time jobs, while seven were excluded due to missing or unclearly visible DPRs.

All the patients were notified by telephone and informed about this study; once agreed, an appointment was set. They were provided with oral and written information (Appendix A), regarding the aims and procedures of the study. A consent form (Appendix B) was signed by the patients once they agreed to participate. The protocol of the study was approved by the Medical Ethics Committee, Faculty of Dentistry, University of Malaya [DF CO1513/0074(P)], (Appendix C). The study was supported by grant/PPP–Research/PG197-2015A, from the University of Malaya Post, Graduated Dental Research and was clinically registered in ClinicalTrials.gov with the ID number NCT03026894.

3.2 Masticatory performance

Masticatory performance for CD and IOD groups was measured using mixing ability index (MAI) following the previous method described by Sato et al. (2003). In this method, two-colored paraffin wax cubes having dimensions of 12 x 12 x 12 mm were used as a test material (Figure 3.2).

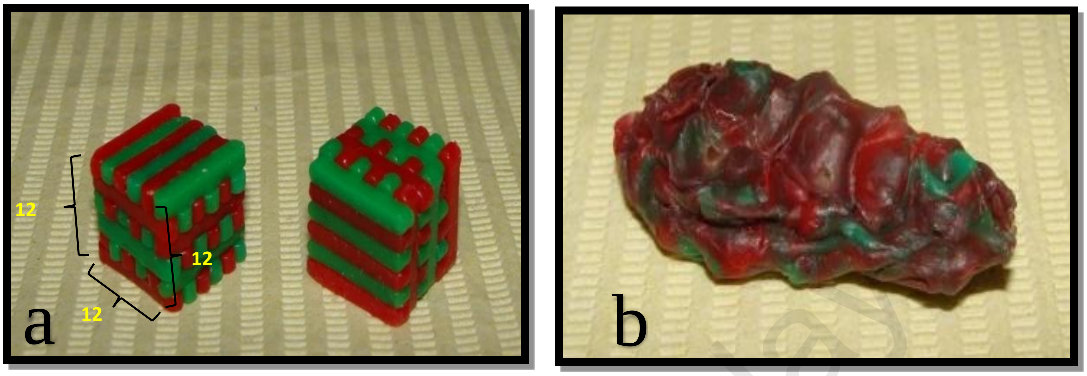

Figure 3.2: Paraffin wax cube; (a) before, (b) after the masticatory test.

The wax was kept in an incubator at 37 °C for 24 hours before each test. Ahead of starting the test, patients were given instructions on how to chew the wax cubes. Then each patient was asked to chew a piece of wax on their preferred chewing site for 10 strokes.

The samples of the chewed wax cubes were removed and then washed with water and disinfectant in Perform® 2% solution for 10 minutes submersion time. Three chewed wax samples were collected for each patient and were labeled by patients' name and study registration number. The color and shape of the chewed wax were digitally analyzed using image analyzer (Luzex-FS, Nireco Co., Tokyo, Japan) after being photographed with a colored camera (XC-003, Sony Co., Tokyo, Japan). The mean value of MAI for each patient was obtained from three chewed wax samples.

3.3 Occlusal force distribution measurement using T-scan III

The use of T-scan III device (Tekscan Inc., South Boston, MA, USA) for occlusal analysis and occlusal balance adjustment has been described by various authors (García et al., 1997; Kerstein & Radke, 2006; Koos et al., 2010; da Silva Martins et al., 2014). T-scan III System is a computerized device that consists of a handle, a computer software, and a U-shaped pressure measuring sensor with a supporting tray (Figure 3.3), which are matched into the patient’s mouth in the middle of the upper and lower teeth. Measurements are produced at a consistent rate of 100 Hz in a frame-by-frame (equal to 0.01 sec) of T-scan movie (Garg, 2007).

Figure 3.3: T-Scan III system, (a) handle, (b) supporting tray and (c) sensor.

In this study, the participants were similarly requested to close firmly on the recording sensor (100 µm thickness) in maximum intercuspation position for 1-3 secs. This procedure was repeated three times and a movie recording was saved on a computer for analysis. The participant was seated in an upright position, and the sensor was positioned parallel to the upper denture occlusal plane at the midline between the central incisor denture teeth. The sensor size, either small or large, was decided according to each denture arch shape. The sensitivity range of the system was adjusted before recording. One examiner (author) performed this measurement procedure.

Occlusal parameters were displayed on a computer screen, which included the force distribution in percentages (OF%) and subdivided into quadrants (left side, right side, anterior, and posterior) (Figure 3.4). Additionally, the relative maximum occlusal force and occlusal time in seconds from the initial contact to the maximal force were provided by default in the software and recorded. Data were summed up on the left and right sides.

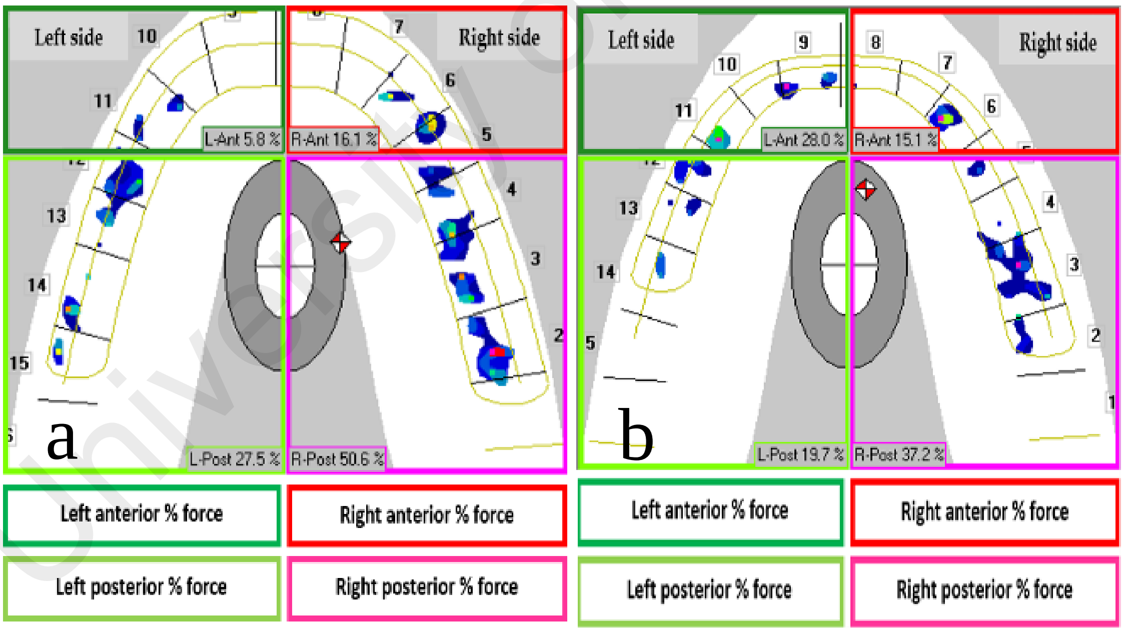

Figure 3.4: An example of 2-Dimensional representation of the occlusal contact and occlusal force distribution at the maximal intercuspation position retrieved from force/view pane of T-Scan III system at various quadrants [L-Ant (Left anterior), R-Ant (Right anterior), L-Post (Left posterior), R-Post (Right posterior) on (a) IOD (b) CD].

3.4 Residual ridge resorption measurements

Maxillary and mandibular residual ridge resorption (RRR) were determined using the proportional area index method, which was described previously by Kreisler et al. (2000) for the maxillary arch and by Wilding et al. (1987) for the mandibular arch. DPRs were taken at the baseline and in 4 years mean follow-up observation period in both groups. All the DPRs were made in a standard manner with a panoramic unit (Veraviewepocs 2D/J; Morita, Kyoto, Japan) which was operated at 62/7.5: kV/mA and an exposure time of 14.9 seconds while using an amplification ratio of 1.3000.

Any missing, overlap and unclearly visible DPRs of the anatomic landmarks between the maxillary and mandibular jaw bones were excluded from the study. The locations of the anatomic landmarks for the maxillary and mandibular jaw bones are listed as in Table 3.1 and illustrated in Figure 3.5.

Table 3.1: Radiographical landmarks according to the maxillary and mandibular jaws.

Locations	Anatomic landmarks
Maxilla	The lowermost margin of the orbit.
	The anterior nasal spine.
	The most inferior point of the articular tubercle.
Mandible	The most inferior point of the mental canal.
	Sigmoid notch.
	Gonion.

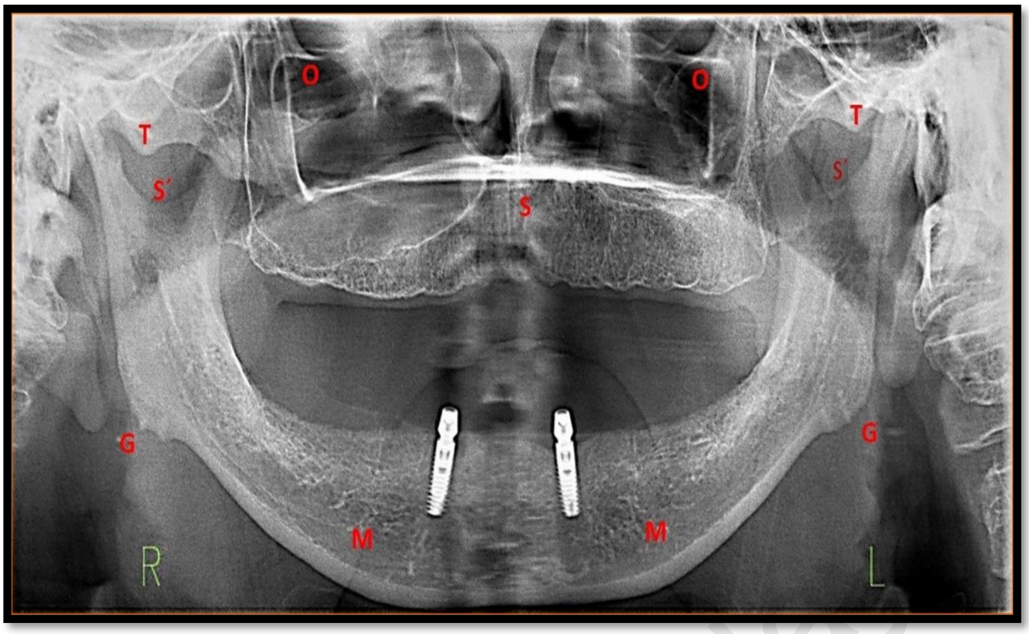

Figure 3.5: Radiographical landmarks as determined on DPR image of 2 implants mandibular overdenture patient showing reference points;

- **i. O (lowermost margin of the orbit).**
- **ii. S (anterior nasal spine).**
- **iii. T (most inferior point of the articular tubercle).**
- **iv. M (most inferior point of the mental canal).**
- **v. S′ (Sigmoid notch).**
- **vi. G (Gonion).**

Reference points and landmarks were digitally traced using Corel Draw X4 software version (14.0.0.701; 2008 Corel Corporation, Ottawa, Ontario, Canada), as follows:

1- In the maxillary arch; the anterior nasal spine S, the most inferior points of orbit O and articular tubercle T (on the left and right sides). A triangle formed by joining O-S-O points and P-S line was drawn perpendicular to the middle of O-O line. Then, S-P` line was drawn equal in length to P-S line. R-R` line was drawn perpendicular to P-O line at one-third of its length near O point. Next, U-U line through S and R`-R` through P` line were drawn perpendicular to R-R` line. T-S and T-R` lines were drawn and T-S line met R-R` line at point V. In the middle of T-V line, X-Y line was drawn perpendicular to the T-V line at X and met T-R` line at Y point. Points 1, 2 and 3 represented the alveolar crest intersections at the following lines respectively; P`-P, R`-R and X-Y.

2- In the mandibular arch; the most inferior point of mental canal M, sigmoid notch S´ and gonion G (on the left and right sides) were used to construct the triangle M- S´-G with point N center. A-M line was drawn perpendicular to G-M line, then G-F line was drawn through N. A and F represented the intersection points with the alveolar crest. G-F line extended to meet S´-M line at Q and L-M line was drawn to be equal in length to N-F line.

These geometric designs divided the maxilla into anterior and posterior areas and the mandible into posterior areas (on the left and right sides). A quadrilateral shape for each area was determined by representing the anatomical area following the alveolar crest intersections (X) and a reference area (Y). Anterior X and Y maxillary areas were outlined by S12U and by SP´R´U respectively, and posterior maxillary X and Y areas were outlined by V23X and VR´YX respectively. Meanwhile, posterior mandibular X and Y areas were outlined by AFNM and LQNM respectively (Figure 3.6).

The surface area measurements were determined for each X and Y areas using the Image J software version 1.49 (Wayne Rasband, National Institutes of Health, Bethesda, MD, USA). The width of each DPR image was used as a known distance to set the Image J software scale in (mm) before surface area measurements (Figure 3.7).

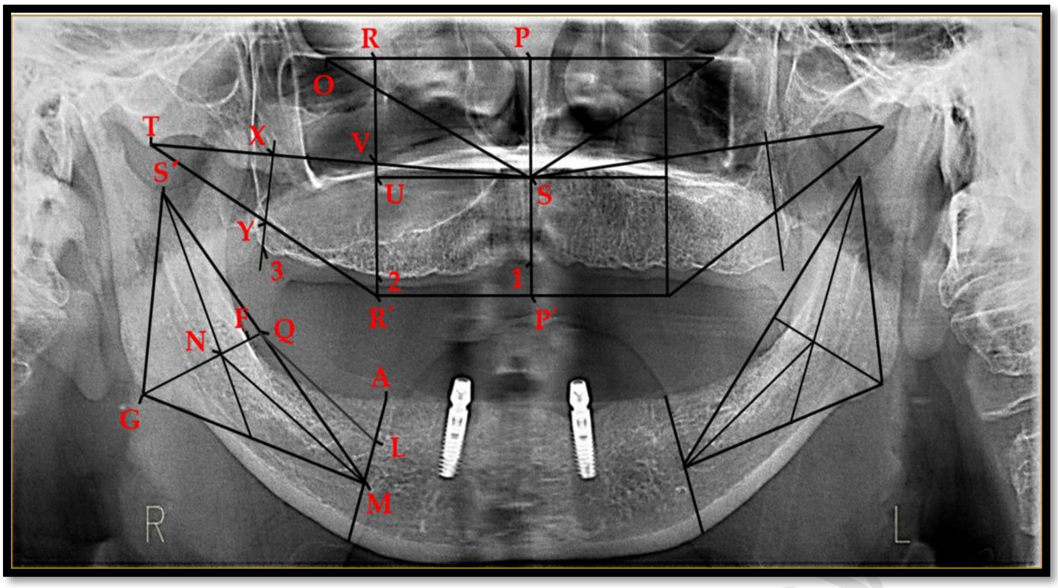

Figure 3.6: Traced geometry on DPR image of IOD patient showing outlines of anatomical and reference areas on the right side only;

i. Anterior maxilla (anatomical area S12U and reference area SP´R´U).
ii. Posterior maxilla (anatomical area V23X and reference area VR´YX).
iii. Posterior mandible (anatomical area AFNM and reference area LQNM).

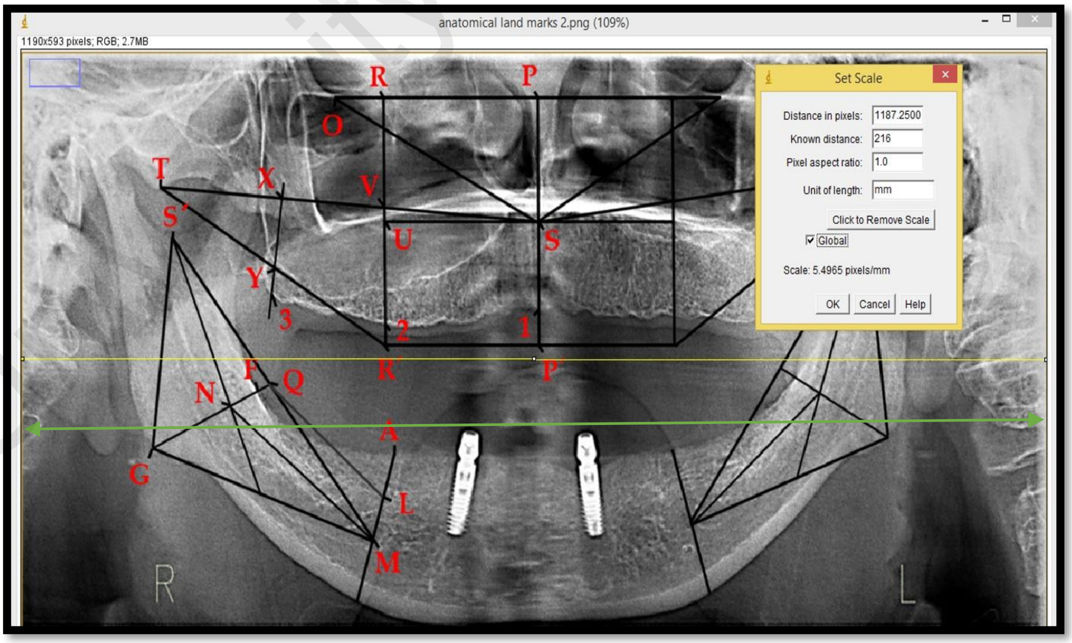

Figure 3.7: Image J software scale setting on DPR image of IOD patient.

The ratio for each of these segments was calculated by dividing X/Y at each side while the RRR was measured by subtracting the ratio at the baseline from the ratio at the follow-up (Negative value indicates bone resorption). Data were averaged on the left and right sides.

The area index was determined by one examiner (author) and calibrated with an experienced oral radiologist. The same measurements procedures for five patients from each group were done to confirm the inter-examiner reliability.

3.5 Patient-reported outcomes

In this part of the study, patients from both groups were requested to complete OHRQoL and denture satisfaction questionnaires at the recall appointment. Questionnaires were provided and collected by another examiner and not by the original investigator.

3.5.1 Patients OHRQoL evaluation

Oral health-related quality of life was measured using the shortened Oral Health Impact Profile Malaysian version [S-OHIP-14 (M)] (Saub et al., 2005). This version contained 14 items investigating seven domains; functional limitation, physical pain, psychological discomfort, physical disability, psychological disability, social disability, and handicap. Answers for each item were on a level of 5 points Likert scale; 0 = Never, 1 = Seldom, 2 = Sometimes, 3 = Quite Often, and 4 = Very Often.

The range of total OHIP-14 scores was between 0-56 and lower scores indicated improved QoL. Patients answered the questionnaire, which was available in English and Malay language and patients were given the choice to choose either version (Appendix D).

3.5.2 Denture satisfaction evaluation

Denture satisfaction (DS) was assessed using the questionnaire items exploring stability, comfort, and chewing ability for maxillary and mandibular dentures separately and two items focused on general satisfaction and aesthetics of the dentures (Fenlon & Sherriff, 2004). Answers for each item were on a level of 4 points Likert scale; 0 = Very satisfied, 1 = Satisfied, 2 = Dissatisfied, and 3 = Very dissatisfied.

The range of total DS scores was between 0-24 and lower scores indicated improved DS. For appearance and general satisfaction items score, the DS ranged between 0-9 (Appendix E).

3.6 Implant overdenture prostheses complications

Denture complications were recorded form the patients in the IOD group, based on the clinical records for these patients during their follow-up visits. The frequency of mechanical complications related to fracture of the acrylic mandibular prostheses and abutment/attachment loosening or dislodgement were retrieved from the 4 years records. An example of IOD complication in the telescopic attachment impression surface is illustrated in Figure 3.8.

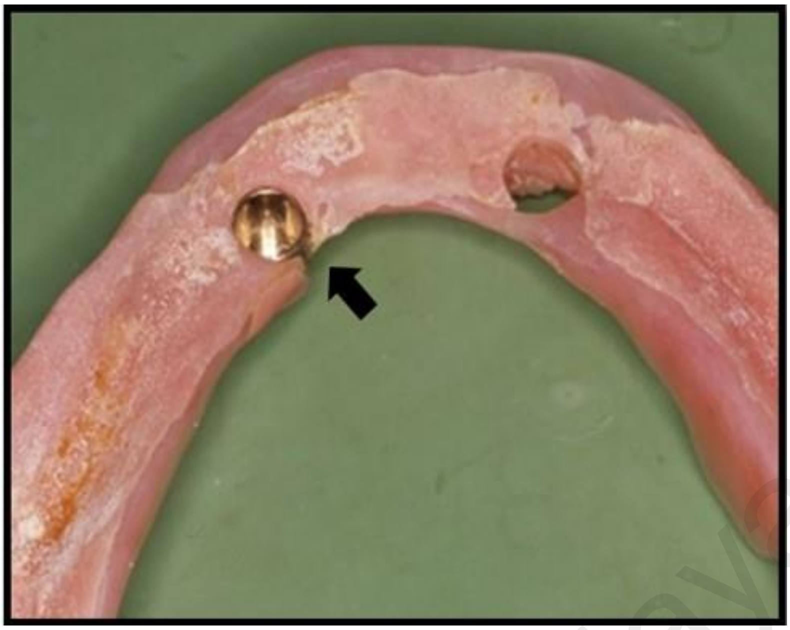

Figure 3.8: Impression surface of mandibular IOD denture showing fracture incidence around telescopic attachment. (Courtesy: Dr. Norsiah Yunus)

3.7 *In-vitro* strain investigation using finite element analysis

In this part of the study, finite element analysis (FEA) was used to predict strain at different locations of the CD and IOD prostheses. A 3D modeling comprised of maxillary and mandibular jaw bone tissues, implants, and acrylic prostheses were constructed using different software. Additionally, the FEA assumptions were followed for the models construction which included; detailed geometry, material properties, constraints, and load conditions.

3.7.1 Hard and soft tissue simulations of edentulous maxilla and mandible

A diagnostic cone beam computed tomography (CBCT) image of an edentulous patient taken for diagnostic purpose prior to implant placement was selected to develop the 3D model of maxillary and mandibular jaw bones (Figure 3.9). The CBCT image was transferred into a DICOM file using i-CAT Vision software (version 1.7.1.10, Imaging Sciences International Inc., Hatfield, PA, USA) and which was then imported into the InVesalius software (Version 3.0-Beta 5, 2007-2013 Renato Archer Information Technology Center-CTI, Brazil) where was used for review the data in the 3D Standard Triangle Language (STL) format.

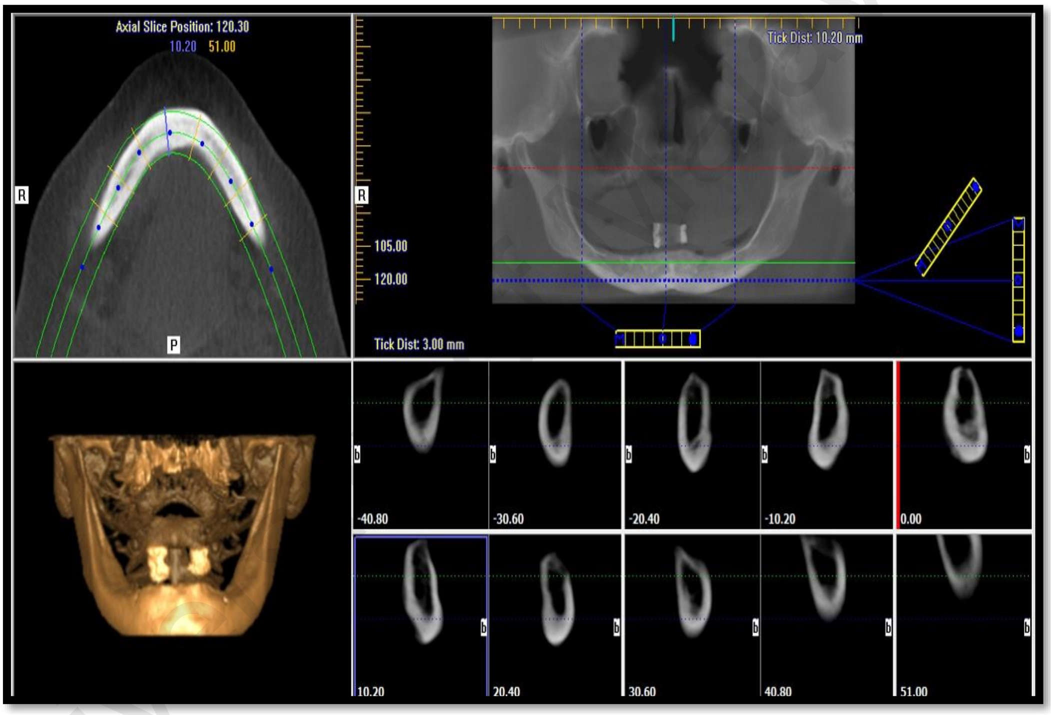

Figure 3.9: CBCT image data of a patient taken with surgical stent prior to implant surgery.

The mucosal tissue thickness of 2 mm in the maxilla and 1.5 mm in the mandible (Uchida et al., 1989) was developed in the STL file (Figure 3.10) using Geomagic Design X software (version 2016.1.0, 3D Systems Inc. Rock Hill, SC, USA).

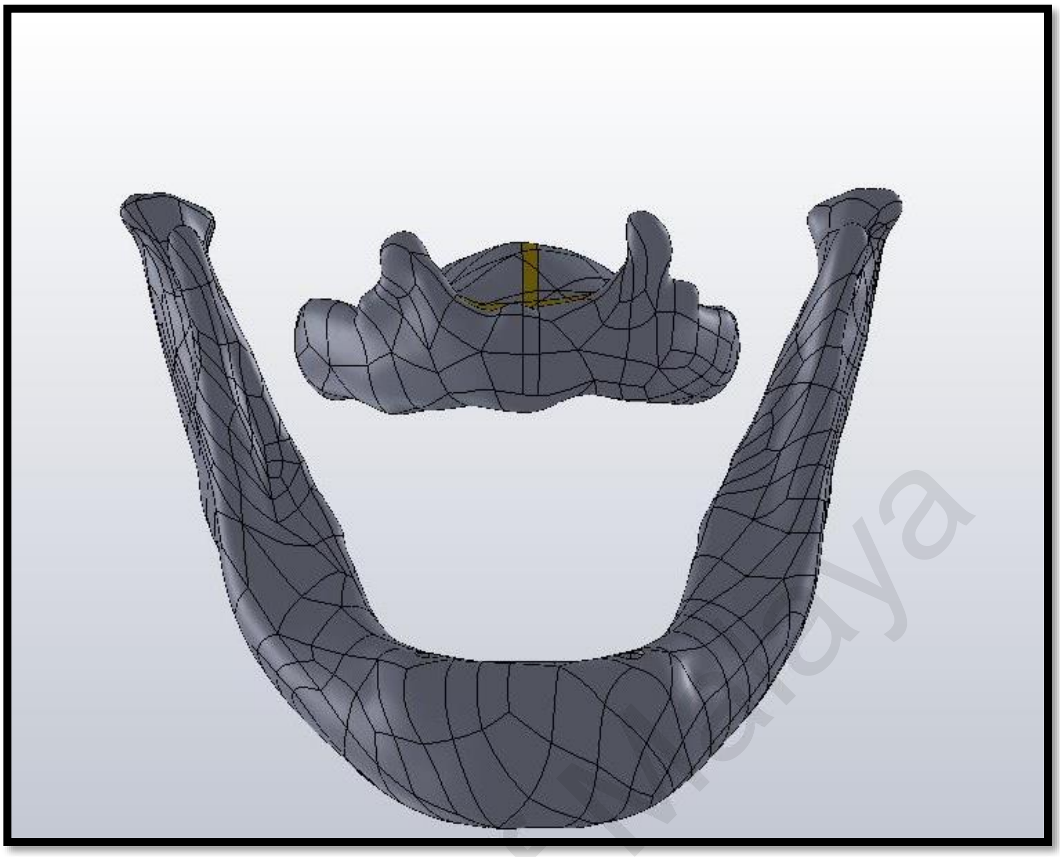

Figure 3.10: Maxillary and mandibular models with mucosa.

3.7.2 Acrylic denture prostheses, implants and attachments simulation

A 3D laser scanner (3D Capture 2014, 3D System Inc., Rock Hill, SC, USA) was used to obtain images of maxillary and mandibular dentures of the same patient, dental implants (Ankylos) and the two different abutments with their corresponding attachments (telescopic and Locator). The images were converted into STL files (Figure 3.11).

Figure 3.11: Maxillary and mandibular dentures (a) original model, (b) simulation model, attachments assembly; (c) telescopic and (d) Locator.

The implant body was simulated with no threads in order to reduce the model complexity and thus the analysis time. It was not the intention of this study to investigate strain around the implants and surrounding bone. The dental implants, abutments, and their attachments dimensions are illustrated in Table 3.2.

Table 3.2: Characteristics of the Ankylos dental implants, abutments, and attachments used in the FEA study.

Manufacturer					
Product Name	**Product Details**	**Order Number**	**Diameter (mm)**	**Height (mm)**	
Implant	Ankylos C/X, Dentsply[a]	31010408	3.5	9.5	
Implant abutments	Ankylos Locator C/ Abutment, Dentsply[a]	31022612	3.8	4.5	
	Ankylos Syncone C/ 5° Abutment, Dentsply[a]	31022130	4.0	4.5	
Telescopic attachment	Ankylos Taper Cap Degulor for Syncone C/, Dentsply[a]	31022199	4.7	5.0	
Locator attachment	Ankylos Locator Cap	Dentsply[a]	32453347	5.5	2.3
	Ankylos Locator Nylon Male				

[a]Dentsply Friadent, Mannheim, Germany.

The STL files for bone, mucosal tissue, acrylic dentures, abutments, and implants with their attachments were exported into the Geomagic Design X software for triangular mesh construction in 3D point nodes, gaps filling, and noise removal. A subsequent cloud point was then transferred into solid bodies using the auto surface option of Geomagic design X software, followed by importing into SolidWorks software (Version Premium 2016 ×64 Edition, SolidWorks®, Waltham, MA, USA) for analysis.

For implant fixture simulation, two implants were positioned; one of each side of the arch, at the canine area. The top of the implants was placed 1 mm submerged below the cortical bone level as recommended by the implant manufacturer (Ankylos C/X, Dentsply Friadent, Mannheim, Germany). A hole in the denture base was prepared to accommodate the abutment and attachment cap according to the dimensions of each attachment type, which was prepared directly above the implant head, using the Geomagic design X software (Figure 3.12).

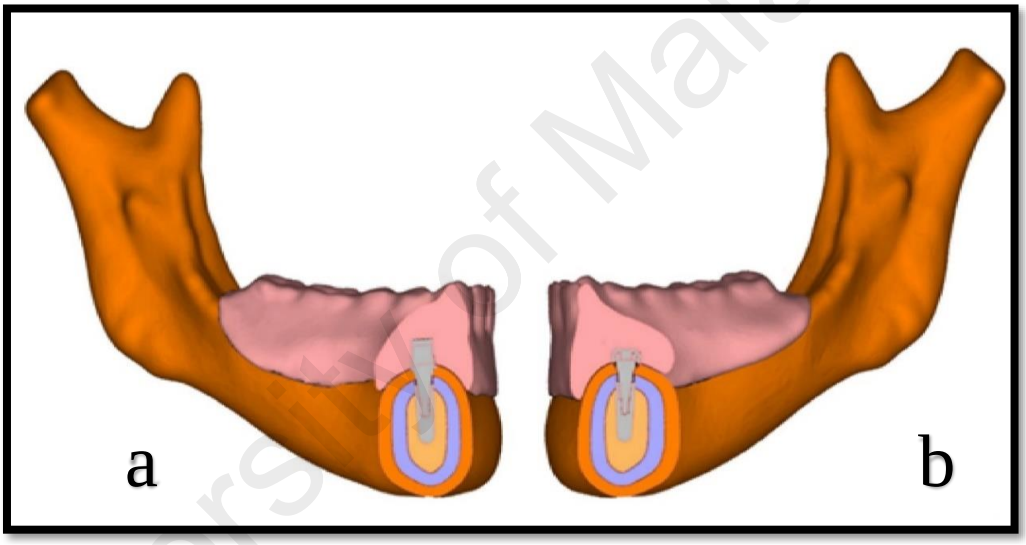

Figure 3.12: Schematics of the (a) telescopic, and (b) Locator attachments and their positioning in the developed 3D model.

3.7.3 Assembly simulation

The CD models were assembled in the following sequence; maxillary and mandibular acrylic dentures, mucosal tissue, and cortical and cancellous bones. Meanwhile, the mandibular IOD with Locator or telescopic attachments models were also assembled in the following sequence; acrylic dentures, implant attachments, abutments, implants, mucosal tissue, and cortical and cancellous bones. The implant metal cap models for both attachments were assembled following their structures according to the manufactures instructions; a cylindrical cap for the telescopic and a cap with nylon male positioned inside for the Locator attachments (Table 3.2).

The superimposed acrylic dentures for all models with the tissues, implants, and implant attachments were sectioned for both maxillary and mandibular models. Each section was corrected whenever necessary using the Cubify Sculpt Software (Version: V2014. 64-Bit, Copyright 1993-2015 3D Systems, Inc. Rock Hill, SC, USA) to achieve the optimal fit between the impression surface of the prostheses and underlying parts of the attachment assembly.

3.7.4 Boundary conditions determination

Constraints for the maxillary denture were determined bilaterally following the union between the maxilla with the base of the skull in a W shape (Cheng et al., 2010). Meanwhile, the mandible was constrained bilaterally at its lower border (Uchida et al., 1989), condyle, and angle areas (Marinescu et al., 2005) (Figure 3.13).

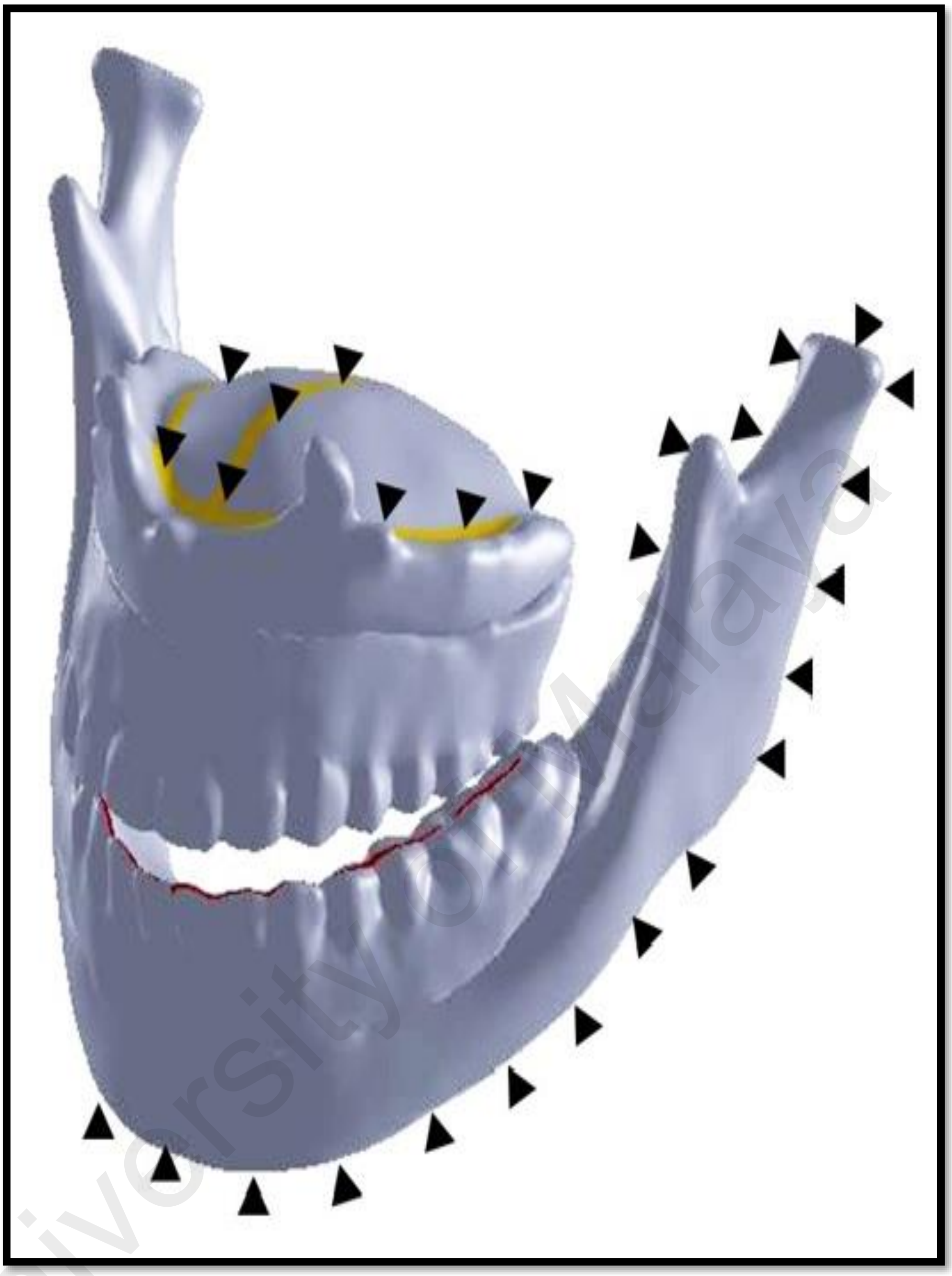

Figure 3.13: Schematics illustration of the model constraints.

3.7.5 Load application

3.7.5.1 Relative load determination

For the vertical occlusal load simulation, the mean percentage of occlusal force distribution in 23 patients with conventional CD and 23 with mandibular IOD were analyzed. This was achieved using the computerized occlusal analyzer T-scan III, where patients were instructed to clench with their prostheses on a horseshoe-shaped metallic sensor and the system analyzed the relative occlusal forces distribution at left and right, anterior, and posterior quadrants. The data obtained from these two groups of patients are as follows; anterior right and left from central incisor to canine, while posterior right and left from the 1st premolar to 2nd molar teeth (Figure 3.14 a and b).

3.7.5.2 Actual load distribution and direction

A pilot study was conducted to measure the actual bite force for each group at two locations and these values were used in the load simulation. Five patients from each group were invited, seated in an upright position, instructed to bite bilaterally on the molar area (left and right sides) using a digital dynamometer device (model IDDK 200, Kratos–Equipamentos Industriais Ltd, Cotia, Sa˜o Paulo, Brazil). Three readings were measured for each patient; then, data on the left and right sides were averaged. One examiner (author) performed this measurement procedure for both groups. Non-significant differences in the mean force value were observed. Therefore, a 150 N was considered as an actual real load for the analysis (Table 3.3).

Table 3.3: Bite force average of five patients on the right and left sides for total and according to CD and IOD groups.

	Mean (SD)				
	Total (n=10)		**CD (n=5)**	**IOD (n=5)**	**P-value**
Bite force (N)	141(39.7)		132(56.3)	150(13.4)	0.508

Independent t-test used at a significant level of P<0.05. CD= Complete denture; IOD= Implant overdenture.

The actual occlusal loads were applied simultaneously in the vertical direction to mimic maximal intercuspation position upon biting and according to the predetermined relative occlusal forces for patient groups, as shown in Figures 3.14 and 3.15. The obtained occlusal forces at different quadrants were further employed in the FEA analyses to determine the areas with high tensile or compressive strain concentrations.

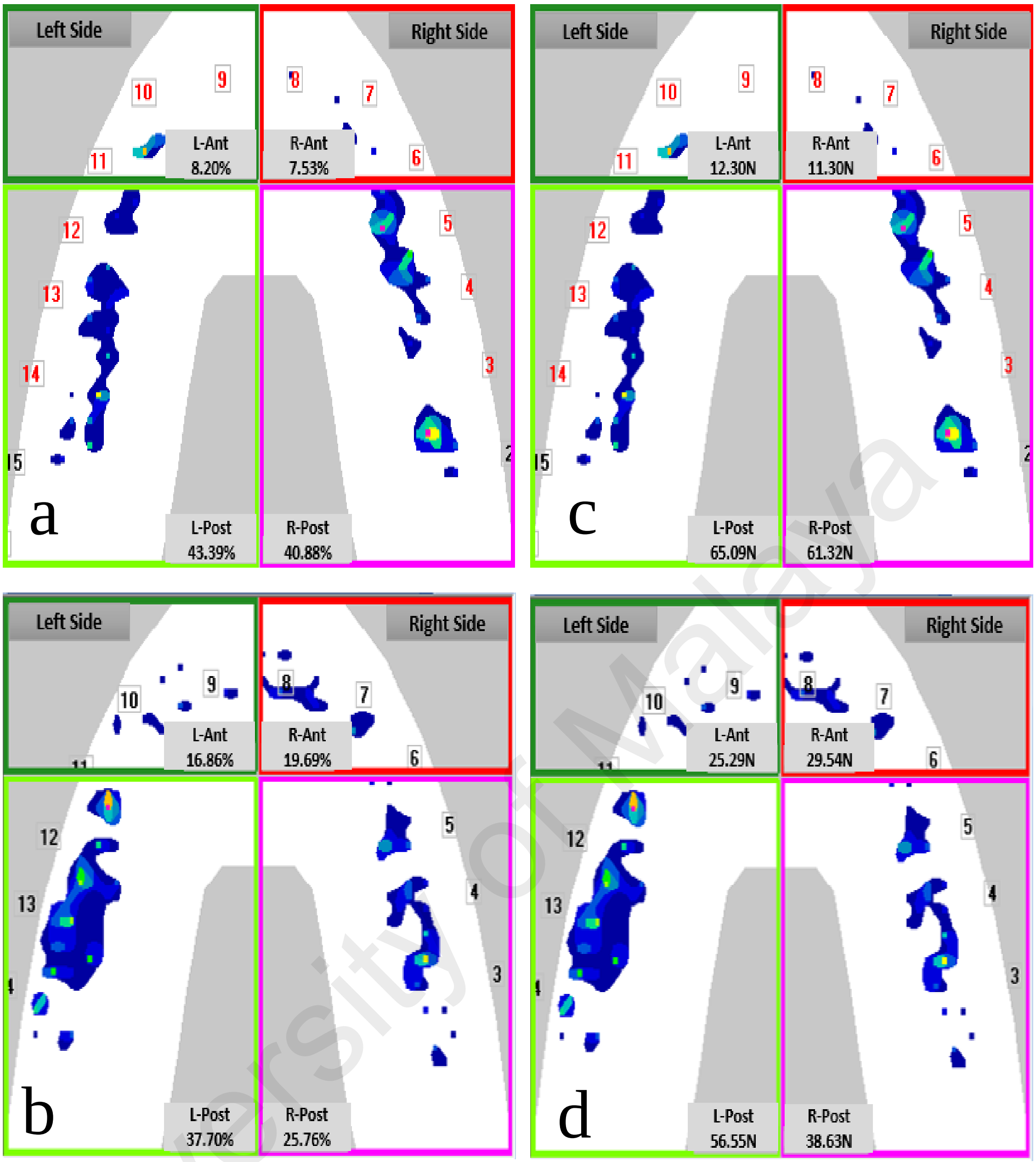

Figure 3.14: An example of T-scan III screen showing the (a, b) percentages of force distribution, and (c, d) mean values of occlusal force at various quadrants of (a, c) IOD, and (b, d) CD prostheses [L-Ant (Left anterior), R-Ant (Right anterior), L-Post (Left posterior), R-Post (Right posterior)].

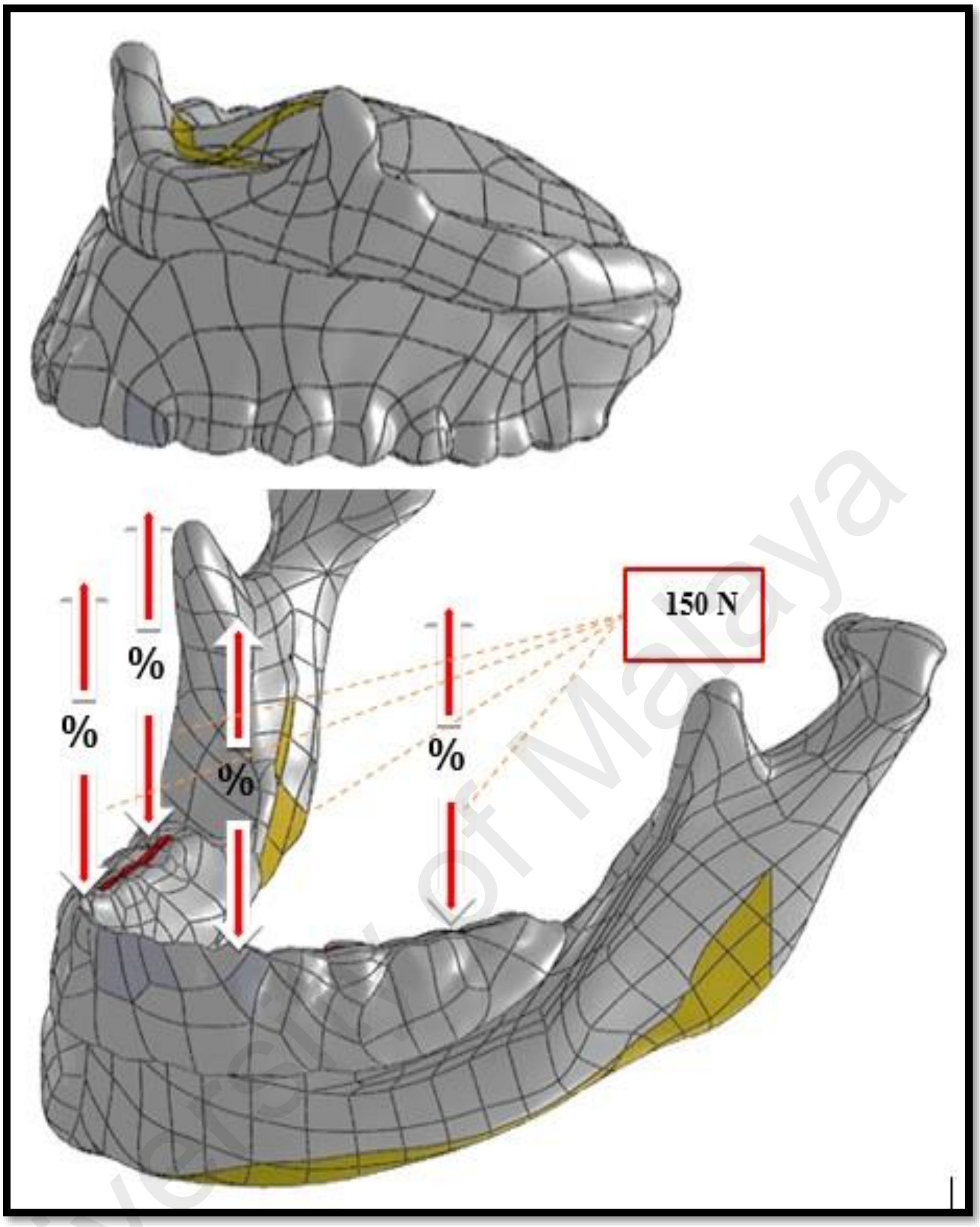

Figure 3.15: Schematic illustration of the occlusal load distribution across the dental arch following T-scan III percentage of occlusal forces at four quadrants in each model.

3.7.6 Finite element analysis output

Analysis type was static with solid mesh simulation and the model type was linear, elastic, and isotropic. The number of nodes and elements of the models are illustrated in Table 3.4, while other materials properties are shown in Table 3.5.

FEA output data was analyzed by strain values in με, in which the (+ve) value indicated tensile strain while (–ve) for the compressive strain. The strain was determined by propping the highest strain concentration areas (Solidworks ® Premium 2015 ×64 Edition).

Table 3.4: Characteristics of the nodes and elements in the developed finite element model.

		Number of nodes	**Number of elements**
Complete denture	**Maxillary**	193566	115607
	Mandibular	137430	76160
Mandibular IOD	**Locator attachment**	87795	47302
	Telescopic attachment	84226	45245

Table 3.5: Material properties applied in the FEA.

	Elastic modulus ($N.mm^{-2}$)	Poisson's ratio	Reference
Cortical jaw bone	13700	0.30	(Menicucci et al., 2002)
Cancellous jaw bone	1370	0.30	(Menicucci et al., 2002)
Acrylic resin	3200	0.36	(Cheng et al., 2010)
Titanium	110000	0.35	(Sevimay et al., 2005)
Nylon in Locator Cap	2400	0.39	(Pellizzer et al., 2010)
Mucosa soft tissue	2.80	0.40	(Cheng et al., 2010)

3.8 Statistical analyses

3.8.1 Sample size calculation

There were in total 64 participants, with 32 subjects in the IOD and 32 subjects in the CD groups. For sample size calculation a computer program (G*Power Version 3.0.10, 2008) was used with a given power of 80% (alpha, set at 0.05). This was based on the data of bone resorption (bone area index) at the anterior maxillary area of patients rehabilitated with conventional CD or IOD (Tymstra et al., 2011), (Appendix F). However, following the exclusion criteria and due to some subjects who were unable to participate in this study, another sample size calculation of 46 participants with 23 subjects for each group was performed using the data of bone area index. Comparison of data between groups at the anterior maxillary area was done and the estimated power was 95% (alpha, set at 0.05) (Appendix G).

3.8.2 Data analysis

The normality of the distribution of MAI, T-scan III, radiographic bone resorption, OHIP-14, and DS data was determined using Shapiro-Wilk tests. Normally distributed variables were reported as means and standard deviations, while for medians, 25% and 75% quartiles were reported for the variables that violated the normality assumption. Data were analyzed by using SPSS (Version 20; IBM Corp., Armonk, NY, USA) with significance set at $p<0.05$.

3.8.2.1 Socio-demographic data

Chi-square test was used to evaluate the gender difference between the groups. An independent t-test was used for age evaluation and Mann-Whitney test for years of edentulousness, between groups.

3.8.2.2 Masticatory performance data

Data for mixing ability index was analyzed using the independent t-test.

3.8.2.3 Occlusal parameters data

Mann-Whitney test was used to investigate occlusal parameters between the study groups, while Wilcoxon Signed-test was used to investigate occlusal parameters between anterior and posterior areas within the groups.

3.8.2.4 Residual ridge resorption data

Interclass correlation using Cronbach's alpha was used to detect the correlation between two examiners with regards to the RRR bone area indices, at various arch locations in the two groups. Two-way factorial ANOVA was used to detect an interaction between bone resorption locations and patient groups. Independent t-test was used to investigate RRR between groups at the anterior and posterior maxillary areas. Mann-Whitney test was used to investigate RRR at the posterior mandibular area. One-way ANOVA and Tukey's posthoc test was used to determine within groups the differences at various locations in the maxilla and mandible. The association between residual ridge resorption with other variables was determined using multivariate regression analysis.

3.8.2.5 Patient-reported outcomes data

Total OHIP-14 and their individual domain scores between groups were evaluated using the Mann-Whitney test. Total DS score was evaluated using independent t-test while the Mann-Whitney test was used to evaluate their subscale scores. The OHIP-14 and the DS total scores association with other variables were determined using multivariate regression analysis.

3.8.2.6 Clinical attachments complication data

Chi-square test was used to analyze the frequency of clinical complication between telescopic and Locator attachments in IOD group.

CHAPTER 4: RESULTS

4.1 Patient socio-demographic data

A total of 64 patients were initially identified from the list of patients treated at the faculty, with 32 patients wearing implant overdenture (IOD) and 32 with conventional complete denture (CD). However, 18 patients were excluded due to death, illness, change of living address and missing or unclearly visible dental panoramic radiographs (DPRs). Socio-demographic data of 46 edentulous patients enrolled in this study are presented in Table 4.1. There were 23 patients, in each group and the results showed no significant difference in patients' demographic variables between IOD and CD groups in terms of gender, age, and years of edentulousness.

Table 4.1: Socio-demographic data of patients enrolled in the study for total and according to CD and IOD groups.

Variables		Groups				
		Total (n=46)		**CD (n=23)**	**IOD (n=23)**	**P-value**
				n (%)		
Gender	**Male**	18(39%)		12(52%)	6(26%)	0.070[a]
	Female	28(61%)		11(48%)	17(74%)	
				Mean years (SD) **Median years (25, 75% IQR)**		
Age		66(9) 64(59,71)		65(10) 63(58,72)	66(8) 65(59,70)	0.641[b]
Years of edentulousness		6(6) 3(1,10)		6(6) 3(1,10)	5(5) 2(1,10)	0.467[c]

[a]Chi-square test, [b]Independent t-test and [c]Mann-Whitney test.

4.2 Masticatory performance

Masticatory performance was evaluated by the mixing ability index (MAI) using 2-colored wax cubes as a testing material. The results for the MAI showed no significant difference between CD and IOD groups (Table 4.2).

Table 4.2: Mean MAI for total and according to CD and IOD groups.

	Mean (SD)				
	Total (n=46)		**CD (n=23)**	**IOD (n=23)**	**P-value**
MAI	0.2(0.7)		0.0(0.7)	0.3(0.8)	0.134[a]

[a] Independent t-test.

Figure 4.1 showed a plot graph of MAI mean values for CD and IOD individual patients. Positive values indicated good masticatory performance while negative values referred to poor performance. Generally, patients of the IOD group showed a trend of better MAI than the CD group.

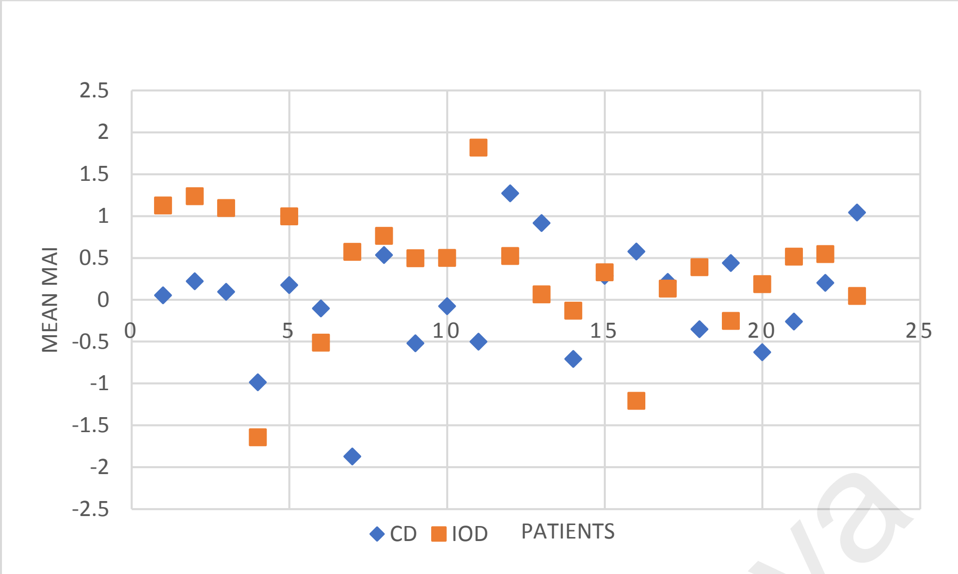

Figure 4.1: A plot graph of mean MAI for patients in CD and IOD.

4.3 Occlusal parameters recorded using digital occlusal analyzer system T-scan III

The occlusal parameters included occlusal force (OF%) at different ridge locations, maximum occlusal force (%), and occlusal time (sec). The occlusal parameters for each patient were recorded in a single movie using computerized T-scan III system. The occlusal parameter values and comparison between CD and IOD groups are shown in Table 4.3.

Table 4.3: Distribution of mean % occlusal force (OF%) at anterior and posterior arches, maximum occlusal force (%) and occlusal time (sec) for total and according to CD and IOD groups.

Occlusal parameters			Mean (SD) Median (IQR)				
			Total (n=46)		**CD (n=23)**	**IOD (n=23)**	**P-value**
OF(%)	**Anterior ridge**	**Left**	13(11) 10(3,19)		17(13) 15(7,21)	8(7) 5(2,12)	0.009[a]
		Right	14(15) 8(2,18)		20(17) 16(5,29)	8(9) 4(1,10)	0.007[a]
	Posterior ridge	**Left**	41(18) 44(28,54)		38(20) 38(16,53)	43(15) 44(36,57)	0.423
		Right	33(19) 30(22,48)		26(16) 25(15,34)	41(19) 43(28,52)	0.007[a]
Maximum OF (%)			89(11) 93(80,98)		88(11) 90(78,98)	90(12) 96(85,98)	0.496
Occlusal time (sec)			2(2) 2(1,2)		3(2) 2(1,3)	2(1) 2(1,2)	0.272

Significant difference between groups (P<0.05) using [a]Mann-Whitney test.

Significant difference in the OF% was observed between groups at anterior left (P=0.009) and anterior and posterior right (P=0.007). However, no significant difference in the posterior left region was observed (P=0.423). Significantly higher force distribution was observed on the posterior ridge in IOD than in CD groups. However, a significantly higher force distribution was observed anteriorly in the CD group. The maximum OF% and occlusal time showed no significant differences between groups.

The OF% distribution data showed similar results on the left and right sides after being summed up for both groups (Table 4.4). The IOD group recorded significantly higher posterior OF% distribution compared to the CD group, while significantly higher anterior OF% was observed in the CD group (P=0.002). Besides, the posterior OF% was significantly higher than the anterior OF% in both groups (P=0.021 and P=0.000) for CD and IOD groups, respectively.

Table 4.4: Distribution of mean % occlusal force (OF%) at anterior and posterior arches after pooling the right and left sides for total and according to CD and IOD groups.

	Occlusal force (%) Mean (SD) Median (IQR)			
	Total (n=46)	**CD (n=23)**	**IOD (n=23)**	**P-value**
Anterior arch	26(23) 22(6,39)	37(24) 34(14,57)	16(16) 11(4,29)	0.002[a]
Posterior arch	74(23) 78(61,95)	63(24) 67(43,86)	84(16) 89(71,96)	0.002[a]
P-value		0.021[b]	0.000[b]	

Horizontally superscript [a] indicates significant difference (P<0.05) between groups using Mann-Whitney test and vertically superscript [b] indicates significant difference (P<0.05) between groups using Wilcoxon Signed test.

4.4 Residual ridge resorption

4.4.1 Reproducibility

The mean bone area indices measured by two examiners at various arch locations in IOD and CD groups was analyzed for reproducibility using interclass correlation coefficient (ICC). An agreement between both examiners at various locations range from 0.70 (anterior maxilla of IOD) to 0.929 (posterior mandible of CD group) (Table 4.5).

Table 4.5: Reproducibility of bone resorption at various locations according to patient groups (CD and IOD).

Locations		Maxillary anterior	Maxillary posterior	Mandibular posterior
ICC	CD	0.703	0.851	0.929
	IOD	0.70	0.714	0.728

ICC= inter-class correlation coefficient.

4.4.2 The effect of arch locations and treatment groups on residual ridge resorption

A two-way factorial ANOVA showed significant difference in the mean bone resorption for the treatment group (P=0.001) and between arch locations (P=0.005); however, no interaction (P=0.799) was observed (Table 4.6) and (Appendix H). This indicated that the greatest bone loss was found in the maxillary anterior region while the least in maxillary posterior.

Table 4.6: Interaction between bone resorption locations and patient groups (CD and IOD).

	df	Mean Square	F	P-value	Partial Eta Squared
Patient treatment groups	1	0.100	10.56	0.001[a]	0.074
Bone resorptions locations	2	0.053	5.57	0.005[a]	0.078
Patient groups and bone resorptions locations	2	0.002	0.23	0.799	0.003

Significant difference between variables (P<0.05) using [a]2- way ANOVA test.

4.4.3 Residual ridge resorption at different locations

Bone resorption in the maxillary anterior area was significantly higher in CD than IOD groups (P=0.013). While no significant differences between the groups were observed in the maxillary (P=0.101) and mandibular (P=0.116) posterior areas. There were no significant differences in bone resorption at various location in CD group (P=0.086); however significant differences were observed in IOD group (P=0.038), at maxillary and mandibular posterior (P=0.049) areas. In the IOD group, the mandibular posterior area showed significantly greater resorption (Table 4.7).

Table 4.7: Bone resorption at various locations for total and according to CD and IOD groups.

Locations		Mean (SD) Median (IQR)			
		Total (n=46)	CD (n=23)	IOD (n=23)	P-value
Maxilla	Anterior	-0.108(0.09) -0.094(-0.164,-0.033)	-0.142(0.10) -0.139(-0.206,-0.072)	-0.074(0.07) -0.0670(-0.108,-0.026)	0.013 [a]
	Posterior	-0.046(0.10) -0.042(-0.129,0.011)	-0.073(0.10) -0.086(-.162,-0.024)	-0.020(0.11)[c] -0.0185(-0.076,0.023)	0.101
Mandible	Posterior	-0.102(0.09) -0.093(-0.165,-0.039)	-0.123 (0.11) -0.132(-0.205,-0.057)	-0.082(0.07)[c] -0.072(-0.131,-0.037)	0.116
P-value			0.086	0.038 [b]	

Significant difference between variables ($P<0.05$) using [a]Independent t-test and [b]One way ANOVA. Vertically, superscript [c] indicates significant difference ($P<0.05$) between groups using Tukey's post hoc test.

4.4.4 Association of bone resorption with the OF%, treatment groups, and socio-demographics

Multivariate linear regression analysis model was used to detect the association between bone resorption as the dependent variable with OF%, treatment group, gender, age, and years of edentulousness as predicted variables (Table 4.8).

Table 4.8: Multivariate regression analysis of the association between bone resorption at various locations with OF%, treatment group, gender, age and years of edentulousness.

Variables	Bone resorption locations					
	Maxilla				Mandible	
	Anterior		Posterior		Posterior	
	Coefficient (SE)[d]	P-value	Coefficient (SE)[d]	P-value	Coefficient (SE)[d]	P-value
Intercept	0.048(0.080)	0. 552	-0.005(0.152)	0.972	-0.008(0.128)	0.949
OF%	-0.003(0.001)	0.000 [a]	-0.002(0.001)	0.094	-0.002(0.001)	0.023 [a]
Treatment group[b]	0.006(0.023)	0.785	0.085(0.038)	0.033 [a]	0.078(0.032)	0.021 [a]
Gender[c]	-0.010(0.021)	0.646	-0.004(0.035)	0.906	0.008(0.029)	0.784
Age (Years)	-0.001(0.001)	0.365	0.001(0.002)	0.725	0.000(0.002)	0.831
Years of edentulousness	0.001(0.002)	0.738	-0.001(0.003)	0.808	0.001(0.003)	0.567
R2	0.584		0.135		0.230	

[a] Indicates significant difference between variables (P<0.05).
[b] 0 = CD; 1 = IOD, [c] 0 = Female; 1 = Male and [d] SE = Standard error.

The results revealed that the increase in the anterior and the posterior OF% significantly showed increased bone resorption (negative value indicating bone resorption) for the maxillary anterior area (P=0.000) and the mandibular posterior area (P=0.023). However, the IOD group demonstrated less bone resorption compared to CD in maxillary posterior (P=0.033) and mandibular posterior (P=0.021) areas. No significant association was observed; however, between the two groups with respect to the bone resorption in the anterior maxillary ridge, indicating that in this region, the bone resorption was significantly associated only with the OF% exerted in the anterior maxilla. Other patients' predicted variables showed no significant associations with bone resorption at any of the arch location areas.

4.5 Patient-reported outcomes

For this part of the study, shortened Oral Health Impact Profile Malaysian version [S-OHIP-14 (M)] and denture satisfaction (DS) questionnaires were used to evaluate patient-reported outcomes. Lower scores of OHIP-14 and DS represented better patient-reported outcomes.

4.5.1 OHIP-14

The study groups were compared in relation to the OHIP-14 total scores and individual domains which included functional limitation, physical pain, psychologic discomfort, physical disability, psychologic disability, social disability and handicap (Table 4.9).

Table 4.9: Median OHIP-14 scores for total and according to CD and IOD treatment groups.

Variables	Median (IQR)				
	Total (n=46)		CD (n=23)	IOD (n=23)	P-value
Total OHIP-14 score[b]	8(5,16)		13(6,19)	7(3,11)	0.027 [a]
Individual domains[c]					
Functional limitation	2(0,3)		2(0,4)	2(0,3)	0.312
Physical pain	2(1,4)		4(2,5)	2(1,3)	0.024 [a]
Psychologic discomfort	2(1,4)		2(0,4)	2(1,3)	0.309
Physical disability	2(0,2)		2(0,3)	1(0,2)	0.173
Psychologic disability	0(0,1)		0(0,3)	0(0,0)	0.051
Social disability	0(0,1)		0(0,1)	0(0,0)	0.156
Handicap	0(0,0)		0(0,1)	0(0,0)	0.078

Significant difference between variables ($P<0.05$) using [a]Mann-Whitney test.
[b] score = 0-56; [c] score = 0-5. Lower score indicates better OHRQoL.

The total OHIP-14 score for the IOD group was significantly lower compared to the CD group (P=0.027). The seven individual domains showed no significant difference between groups, except for the physical pain domain (P=0.024), where the IOD showed lower score.

4.5.2 Denture satisfaction

The study groups were compared in relation to the DS total score and subscale scores which included maxillary DS, mandibular DS, appearance, and general satisfaction (Table 4.10).

Table 4.10: Median denture satisfaction scores for total and according to CD and IOD treatment groups.

Variables	Mean (SD) Median (IQR)				
	Total (n=46)		**CD (n=23)**	**IOD (n=23)**	**P-value**
Total denture satisfaction score[c]	9(5) 9(8,12)		11(4) 10(8,13)	8(4) 8(6,9)	0.030 [a]
Subscale scores					
Maxillary denture satisfaction[d]	3(2) 3(2,4)		3(2) 3(3,4)	3(2) 3(2,5)	0.964
Mandibular denture satisfaction[d]	4(2) 3(3,6)		5(2) 5(3,6)	3(2) 3(2,3)	0.001 [b]
Appearance[e]	1(1) 1(1,1)		1(1) 1(1,2)	1(1) 1(1,1)	0.091
General satisfaction[e]	1(1) 1(1,2)		1(1) 1(1,2)	1(1) 1(1,1)	0.135

Significant difference between groups (P<0.05) using [a]Independent samples t-test and [b]Mann-Whitney test.
[c]score = 0-24; [d] score = 0-9; [e] score = 0-3. Lower score indicates greater satisfaction.

The total DS score for the IOD group showed significantly lower value than the CD group (P=0.030). For DS subscale scores, there was a significantly lower score in relation to satisfaction with mandibular prostheses in IOD than CD groups (P=0.001). No difference was observed between the groups regarding maxillary DS, appearance, and general satisfaction (Table 4.10).

4.5.3 Association of the patient-reported outcomes total score with OF%, MAI, treatment groups and socio-demographics

Multivariate linear regression analysis model was used to detect the association of the OHIP-14 and DS total scores as dependent variables with OF%, treatment group, gender, age, years of edentulousness and MAI as predicted variables (Table 4.11).

Table 4.11: Multivariate regression analysis to detect the association of the OHIP-14 and DS scores with OF%, treatment group, gender, age, years of edentulousness and MAI.

Variables		Total OHIP-14		Total DS	
		Coefficient (SE)[d]	P-value	Coefficient (SE)[d]	P-value
Anterior	Intercept	21.062 (9.990)	0.041	2.501 (5.469)	0.650
	OF%	-0.105 (0.068)	0.128	-0.031 (0.037)	0.412
Posterior	Intercept	10.537 (11.191)	0.352	-0.569 (6.126)	0.926
	OF%	0.105 (0.068)	0.128	0.031 (0.037)	0.412
Treatment group [b]		-8.098 (2.838)	0.007 [a]	-3.946 (1.554)	0.015 [a]
Gender [c]		-0.577 (2.583)	0.824	1.820 (1.414)	0.206
Age		0.010 (0.132)	0.941	0.109 (0.072)	0.139
Years of Edentulousness		-0.411 (0.219)	0.069	-0.027 (0.120)	0.823
MAI		-2.606 (1.675)	0.128	-0.758 (0.917)	0.413
R2		0.345		0.216	

[a] Indicates significant difference between variables (P<0.05).
[b] 0 = CD; 1 = IOD, [c]0 = Female; 1 = Male and [d]SE = Standard error.

Both the OHIP-14 and DS scores showed significant association with treatment group. Other patients' variables revealed no significant associations with OHIP-14 or with DS scores.

4.6 Clinical complications with implant overdenture prostheses

The frequencies of mechanical complications in patients wearing IOD which were retained by telescopic or Locator attachments are given in Table 4.12. For telescopic retained group, 100% of patients showed complications which were mostly related to dislodgement of the attachment cap from the acrylic denture base. Lower percentage of complications were observed in Locator attachment group.

Table 4.12: Frequency of complications in telescopic and Locator implant attachments.

Attachments	N	With Complication (%)	Without Complication (%)	P-value
Telescopic	8	100	0	0.005 [a]
Locator	15	40	60	
Total	23	61	39	

Significant difference between variables (P<0.05) using [a] Chi-square test.

4.7 Finite element strain investigation

Finite element analysis method (FEA) was used to predict the strain concentration areas at polished and impression surfaces of both CD and IOD prostheses. The strain generated at various locations of the simulated models was presented by tensile (+ve) and compressive (-ve) strain.

4.7.1 Strain analysis in maxillary complete denture prostheses

The tensile strain on the polished surface of the maxillary CDs model opposing mandibular CD was mainly concentrated around the central incisor teeth at the incisal notch (Figure 4.2)

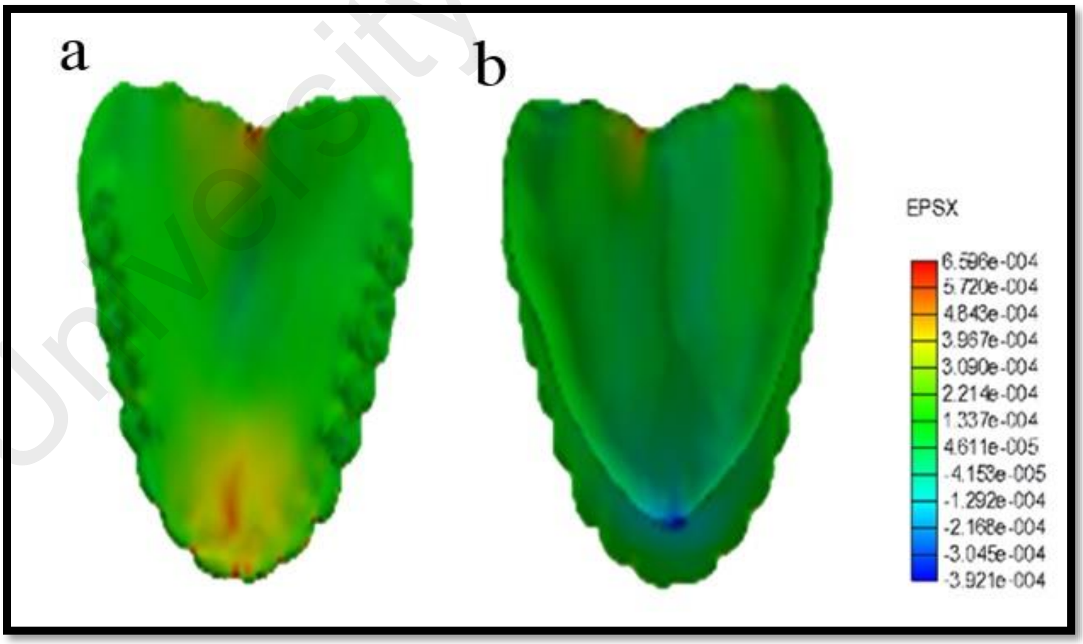

Figure 4.2: Strain distribution on the polished (a), and impression (b) surfaces of the maxillary CD opposing mandibular CD.

In contrast, the strain concentration was observed palatal to the central incisor of maxillary CD when opposed to mandibular IOD models (Figure 4.3).

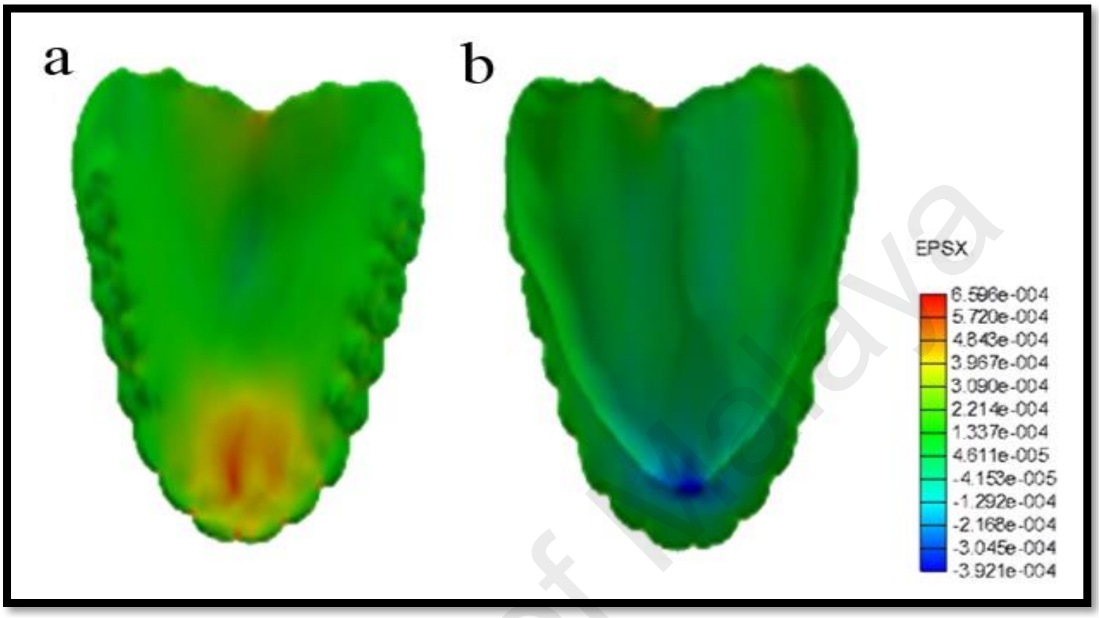

Figure 4.3: Strain distribution on the polished (a), and impression (b) surfaces of the maxillary CD opposing mandibular IOD.

A higher maximum tensile strain value (1254 με) in the maxillary CDs model opposing mandibular CD was observed compared to maxillary CD opposing mandibular IOD models (1055 με) (Table 4.13).

Table 4.13: Strain values (με) distribution around midline area on polished and impression surfaces of maxillary CDs opposing mandibular CD and IOD.

Locations	CD/CD		CD/IOD	
	Polish surface	Impression surface	Polish surface	Impression surface
Incisal notch	+1254	NA	+847	NA
Labial Frenal notch	NA	-1250	NA	-1642
Anterior palatal area	+988	-559	+1055	-613
Posterior palatal area	+883	-186	+723	-175

+ values indicate tensile strain.
- values indicate compressive strain.
NA= Not applicable.

4.7.2 Strain analysis in the mandibular prostheses

In the mandibular CD model, the tensile strain was mostly concentrated at the incisal notch between the lateral incisor and canine, with less concentration at lingual flange area, followed by the lower sulcus border of the lingual flange area. The strains at the labial flange, labial frenal area polished surfaces, and denture impression surface were compressive (Figure 4.4).

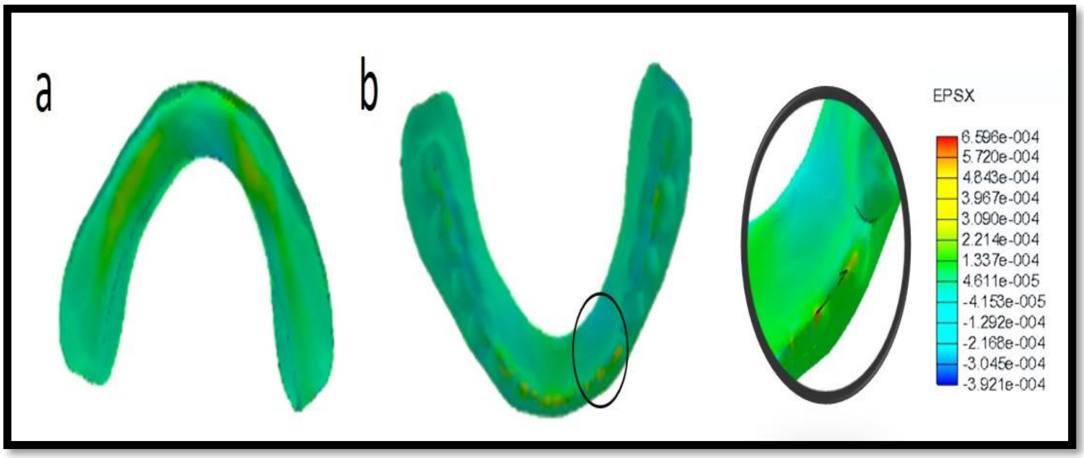

Figure 4.4: Strain distribution on the impression (a), and polished (b) surfaces of the mandibular CD. Circle showed enlarged view of the section.

The strain distribution in the IOD model with either Locator or telescopic attachments showed a similar pattern, where the strain was distributed anteriorly in the midline and mesially to the attachment locations (Figure 4.5). The highest tensile strains were located at the incisal notch, followed by lingual and labial flanges of the polished surfaces. The strains on the labial frenum, lower sulcus border of lingual flange of the polished surfaces, and denture impression surface were compressive.

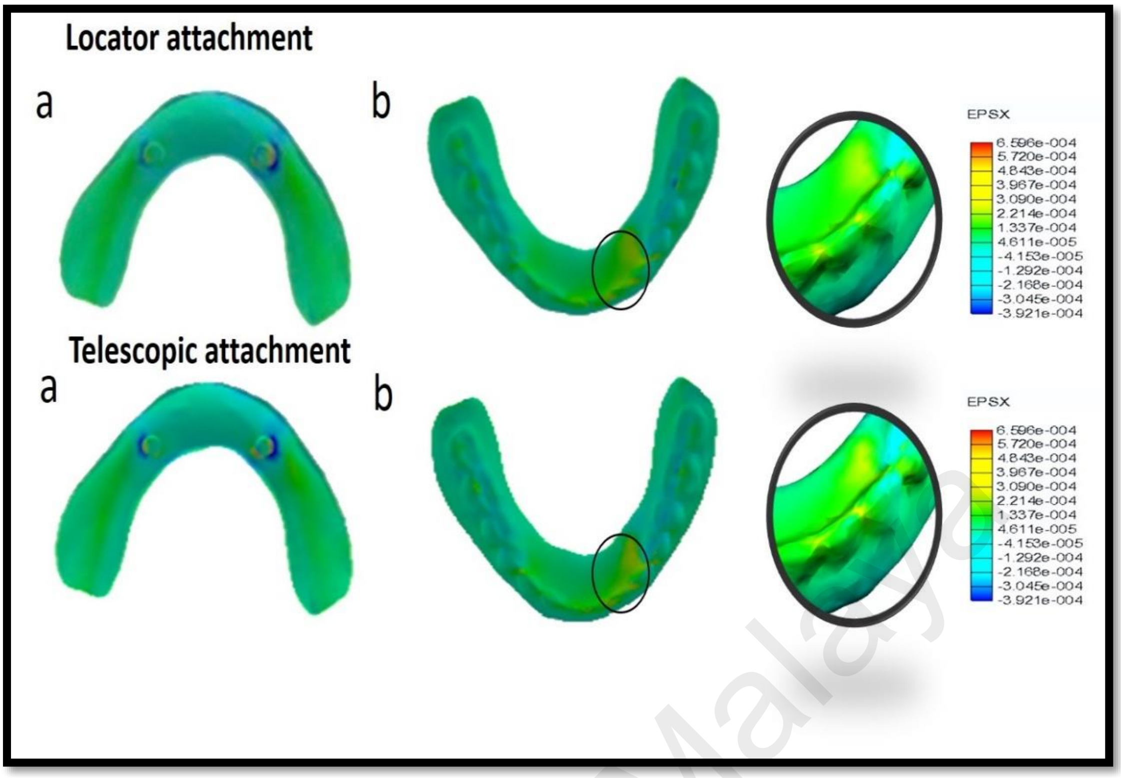

Figure 4.5: Strain distribution on the impression (a) and polished (b) surfaces of mandibular IOD with two attachment types. Circles showed enlarged views of the sections.

The highest tensile strain was observed at the incisal notch of the mandibular CD (135 με), with lower strain in IOD with telescopic attachment (116 με) and followed by Locator attachment (91 με). The values of strain at different denture locations in the mandibular prostheses are illustrated in Table 4.14.

Table 4.14: Strain values (με) distribution on polished and impression surfaces of mandibular CD and IODs with Locator and telescopic attachments.

Locations	CD[a]		IOD[b]			
			Locator		Telescopic	
	Polish surface	Impression surface	Polish surface	Impression surface	Polish surface	Impression surface
Incisal notch	+135	NA	+91	NA	+116	NA
Lingual flange	+68	NA	+87	NA	+68	NA
Labial flange	-28	NA	+3	NA	+0.07	NA
Labial frenum	-17	NA	-116	NA	-102	NA
Lower border of lingual flange	+32	NA	-77	NA	-76	NA
Denture base	NA	-309	NA	-36	NA	-33

+ values indicate tensile strain.
- values indicate compressive strain.
NA= Not applicable.

4.7.3 Strain analysis at the acrylic/attachments interface area

For strain distributions in mandibular IOD prostheses with telescopic and Locator attachments, the maximum tensile strain values in both attachments were found in the acrylic denture-attachment interfaces on the impression surfaces (Figure 4.6).

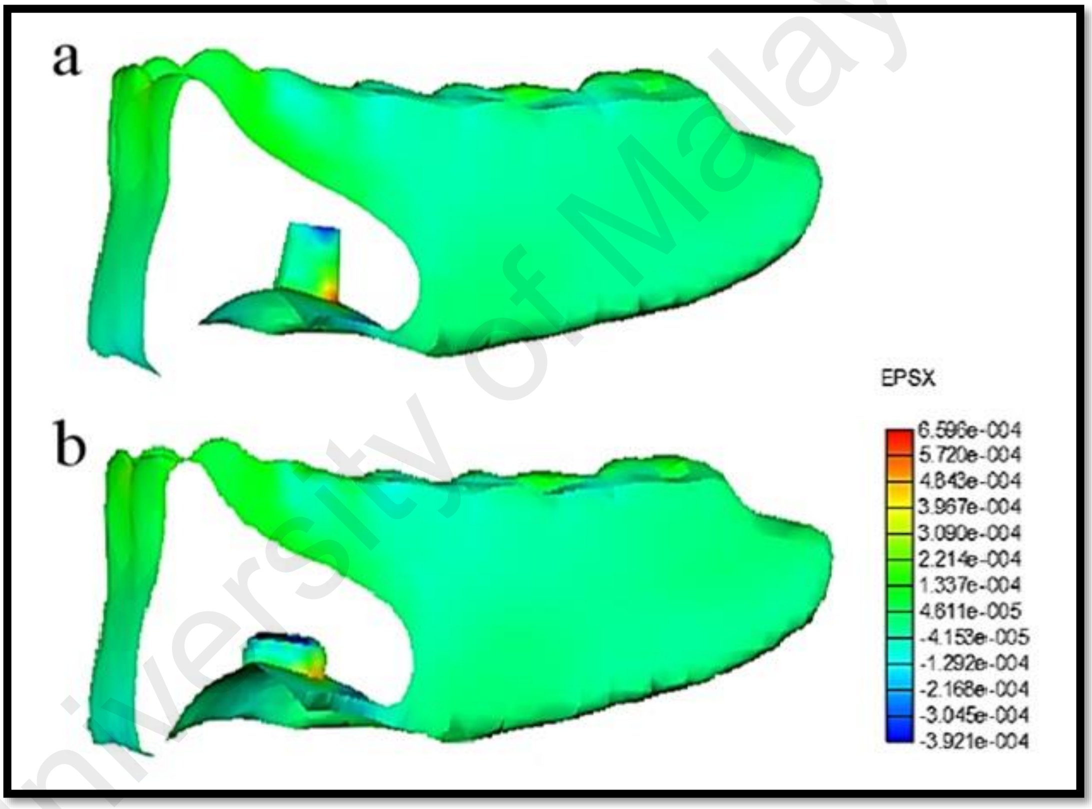

Figure 4.6: Strain distribution at acrylic/attachment interfaces of mandibular IOD with (a) telescopic, and (b) Locator attachments.

In the telescopic attachment model, lower strain value was observed at the lower border of the lingual flange, compared to the lower borders of both lingual and labial flanges of the Locator attachment in IOD models (Table 4.15). The maximum tensile strain in the acrylic denture/telescopic attachment interface (561 $\mu\varepsilon$) was higher than that of Locator (323 $\mu\varepsilon$) model. Hence fracture risk is higher with telescopic attachment was IOD prostheses.

Table 4.15: Strain values (με) distribution on polished and impression surfaces of telescopic and Locator attachments of mandibular IOD prostheses.

	IOD attachments			
Locations	**Locator**		**Telescopic**	
	Polish surface	**Impression surface**	**Polish surface**	**Impression surface**
Acrylic/attachments interface	NA	+323	NA	+561
Incisal tip	-61	NA	+24	NA
Lower border of lingual flange	+225	NA	-259	NA
Lingual flange	-188	NA	+268	NA
Lower border of labial flange	+191	NA	-16	NA

+ values indicate tensile strain.
- values indicate compressive strain.
NA= Not applicable.

CHAPTER 5: DISCUSSION

5.1 Introduction

As per the survey for Malaysian National Oral Health Plan conducted in 2011, 32% of the estimated adult population above 65 years was edentulous (Oral Health Division, 2011). Hence, the concern for oral health in edentulous patients is considerable as well as the concern of the rehabilitation of patients with conventional or implant prostheses still remains. In some edentulous patients, providing mucosa-borne conventional complete dentures (CD) is not considered as satisfactory treatment modality due to its lack of retention and stability. Moreover, patients using conventional CD may be susceptible to malnutrition due to their reduced capability of chewing (Awad et al., 2003).

The removable mandibular implant overdenture (IOD) is supported by both implant and mucosa, where fewer implants are required as compared to fixed full-arch implant prostheses. Additionally, removable mandibular IODs serves as a less complex and less expensive option for edentulous patients (Johns et al., 1992). It has been shown that the use of IOD may inhibit bone loss and may lead to bone apposition in the severely resorbed mandible (Sennerby et al., 1988; Davis et al., 1999). However, the individual masticatory occlusal muscle force may create pressure against the alveolar ridges leading to residual ridge resorption (RRR). Therefore, occlusal force must be considered as a determining factor for RRR. On the other hand, the chewing and biting functions in IOD patients are similar to those in people with natural teeth (Mericske-Stern et al., 1993); however, are better than patients using CD (Fontijn-Tekampl et al., 1998). This may be due to the smaller cross-sectional area of masticatory muscles in edentulous patients, as compared to dentate patients, which may affect their masticatory performance (Newton et al., 1993). Therefore, a greater bite force and higher satisfaction scores were observed in IOD than

CD wearers (Geckili et al., 2012a). However, most studies focused on stress distribution around the implants, and the way in which the presence of implants affects loading patterns of the edentulous ridge is still not known (Kordatzis et al., 2003).

With many clinical complications related to denture fractures, the strain distribution in acrylic dentures has been previously evaluated in different studies *in vivo* or *in vitro* using strain gauges or finite element method for analysis (FEA) (Prombonas & Vlissidis, 2006; Cheng et al., 2010; Cilingir et al., 2013). However, the force that is clinically distributed on the dentures and its relation with the clinical complications is still not determined.

5.2 Study design and sample population

This study was a cross-sectional study to determine the occlusal force distribution in edentulous patients wearing mandibular IOD and conventional maxillary CD and comparison made with patients with conventional maxillary and mandibular CDs. The findings of this study also provide an insight into the patient's masticatory performances, bone resorption patterns across maxillary and mandibular ridges, and clinical complications in mandibular IOD prostheses. While the subjective assessment included the oral health-related quality of life (OHRQoL) and denture satisfaction, the acrylic denture strain distribution was investigated using FEA.

The sample of this study comprised of 64 participants, gave a power of 80% (α was set at 0.05) and was estimated based on the results comparing the bone resorption between patients rehabilitated with conventional CD and IOD using area index method as described by a previous study (Tymstra et al., 2011). Many studies have measured area index in the mandibular (Wilding et al., 1987; Jacobs et al., 1992; Wright et al., 2002; Kordatzis et al., 2003) or maxillary ridges (Jacobs et al., 1993; Kreisler et al., 2003), whereas Tymstra et al. (2011) conducted a study that measured area index at both ridges.

Subsequently, owing to the exclusion criteria and some participants' unwillingness to participate, the sample size estimation was based on the preliminary results comparing RRR for 10 patients wearing CD and IOD prostheses. The required number of 46 patients participated in the study, thereby giving a power of 95% (α was set at 0.05).

5.3 Masticatory performance

Several different methods have been used to evaluate masticatory performances. A subjective questionnaire method was employed to evaluate the masticatory performance in CD and/or IOD wearers (Agerberg & Carlsson, 1981; Feine & Lund, 2006). Chewing ability in the previous studies was determined based on the individual's own assessment of his/her masticatory performance. However, many individuals evaluated the masticatory performance of their dentures as good compared to dentate while a comminution test resulted in much lower values than dentate subjects (Carlsson, 1984). Hence, this subjective nature of the observation from the evaluation of patients' satisfaction necessitated the use of an objective method. The objective methods employed to measure masticatory performance include sieving with natural foods (Manly & Braley, 1950), sieving with artificial foods (Edlund & Lamm, 1980), two-colored chewing gums (Liedberg & Öwall, 1995; Matsui et al., 1996; Hayakawa et al., 1998) or mixing ability index (MAI) with two-colored paraffin wax cubes (Sato et al., 2003).

Ishikawa et al. (2007) investigated the correlations between two different objective methods with the subjective outcome measures. They used the color change of the chewing gum as the objective method and found a greater association with the subjective evaluation outcomes, compared to the masticatory performance using sieving with natural food objective method (Ishikawa et al., 2007). However, the chewing gum method requires a special device (colorimeter CR-13) (Kamiyama et al., 2010), and the limitation of this method was observed in its reliability and validity (Hama et al., 2014).

Masticatory performance, using MAI with two-colored paraffin wax cubes, integrated the degree of color mixing and the shape of a chewed-food test into one-dimensional value. Moreover, previously MAI was validated by Sato et al. (2003) for objective measurement of masticatory performance in denture wearers for clinical use. Hence, it was employed in the present study as an objective method to evaluate the masticatory performance.

The MAI results in the present study showed no significant differences between CD and IOD groups after four years of denture use, despite the better masticatory performance trend observed in the IOD mean readings as compared to CD readings. The greater retention and stability of an IOD could improve the masticatory performance (Van Kampen et al., 2004). Similarly, in this study, we found better masticatory performance in the IOD group as compared to the CD group.

However, our results contradict the previous studies that found a significant improvement in the MAI for IOD prostheses, using the similar MAI method, for analyses of the patients' masticatory performance (Yunus et al., 2014; Bae et al., 2015). Two to three months after patients had their CD dentures converted to IOD prostheses, the mean MAI values of 0.66 (Yunus et al., 2014) and -0.03 (Bae et al., 2015) were reported. In the present study, slightly different MAI mean values 0.0 and 0.3 were observed for CD and IOD groups, respectively, after four years of wearing dentures, even though the same MAI method was used for evaluation of masticatory performance. Our results probably contradict the findings of the previous studies because the previous studies examined the same group of patients using conventional CD dentures after conversion into IOD ones, whereas we examined different groups of patients and the conventional CD patients did not participate in any previous clinical study for implant rehabilitation. Moreover, different attachment systems and sample sizes were used in the previous studies. Seventeen patients wearing IOD, with telescopic attachments, participated in the study by Yunus et al. (2014) while only eight patients wearing IOD, with Locator attachments, participated in the study by Bae et al. (2015).

In the study conducted by Yunus et al. (2014), the mean MAI (0.86) for IOD, after the patients wore their dentures for one year, did not show considerable improvement as compared to the three months observation. This finding was in agreement with the results of our study, following four years of wearing dentures. This finding could be explained as most of the denture wearers are probably used to their dentures, thereby feeling comfortable with chewing as with their mandibular and maxillary prostheses (Feine & Lund, 2006; Yunus et al., 2014).

5.4 Occlusal parameters recorded using T-scan III

Many previous studies used strain-gauge transducers with a bite fork to clinically measure the bite force of patients (Lassila et al., 1985; Fontijn-Tekampl et al., 1998; Rismanchian et al., 2009). However, strain-gauge transducers measured the bite force unilaterally and they had different thickness that ranged between 3–6 mm. Additionally, strain-gauges are covered by certain materials, such as polyvinyl chloride, to protect the teeth and appliances, and a plastic bag is also used to reduce moisture. These protection requisites were found to reduce the bite force by 15% (Bakke et al., 1990). The T-scan III occlusal analysis system, with its 100 µm thickness compared to strain gauges higher thickness could be a more appropriate clinical method to detect patients' occlusal force distribution. Moreover, the U-shaped design of T-scan III enables it to measure the occlusal force bilaterally.

In clinical conditions, there is a different force distribution across the arch in dentate subjects, which could be manifested by the asymmetry in the left and right sides with shifted the higher occlusal forces from anterior to posterior teeth (Koos et al., 2012). Similarly, Kerstein et al. (2013) determined the occlusal force distribution in CD wearers with maximum intercuspation. There was a higher force distribution in the posterior (premolar and molar) areas than the anterior (incisor and canine) areas. Similarly, in this study occlusal forces demonstrated different distributions, higher in the posterior areas of the arch than anterior areas, in completely edentulous patients wearing mandibular IOD more than patients wearing conventional CD prostheses. Patients wearing IOD might exhibit a higher masseter muscles' electromyographic activity than patients with mucosa-supported CD during maximum intercuspation (Shah et al., 2012). On the other hand, the IOD showed lower force distribution anteriorly compared to the CD prostheses, which may be because the patients with IOD had an open occlusal relationship in centric occlusion to reduce stress on the implants, preserve premaxillary bone area and direct occlusal forces towards the center of mandibular teeth (Becker et al., 1977; Denissen et al., 1993).

Other occlusal parameters measured in this study include occlusal time—the time that passes between the first and last occlusal contacts. The results of occlusal time in this study showed an average of 2 secs which is longer than the occlusal time in dentate subjects (<0.2 secs) (Kerstein & Grundset, 2001). Edentulous patients might need longer occlusal time compared to dentate patients, probably due to prostheses instability in completely edentulous patients, especially for the mandibular prostheses (Van Waas, 1990). However, occlusion time was also found to be shorter (0.4 secs) in another study with patients wearing conventional CD (Abdelnabi et al., 2016). These contradictory values could be due to the improved stability of CD observed in the study by Abdelnabi et al. (2016) after the application of denture adhesive, while in the present study no adhesive was applied before occlusal parameters' analyses.

Besides occlusal force distribution and occlusion time measurements, maximum occlusal force percentage in maximum intercuspation was also determined. There were similar maximum occlusal force results recorded for CD and IOD groups. These findings are in accordance with the results obtained in our pilot study, which determined the bite force using a strain gauge device. There was no significant difference between the CD and IOD groups, in spite of the higher mean bite force (150 N) observed in the IOD than the CD group (132 N). Similarly, in the study by Fontijn-Tekampl et al. (1998) the mean maximum bite force values observed were 154 N and 123 N for IOD and CD, respectively; however, the maximum bite force in patients with mandibular IOD was significantly higher than in patients with conventional CD. These results could be due to the limited number of patients (ten patients) enrolled in our pilot study. Also, Fontijn-Tekampl et al. (1998) used trans-mandibular and mucosa-borne implant types to retain their IOD patients.

5.5 Maxillary and mandibular residual ridge resorption at different locations and their association with the occlusal force distribution

The present study employed an established method to determine RRR at mandibular posterior ridge and opposing maxillary edentulous anterior and posterior ridges, in patients wearing mandibular IOD and conventional CD prostheses. Using this method, the bone resorption ratio (bone area/reference area) from dental panoramic radiographs (DPRs) taken at intervals could be compared with minimal errors related to radiographic magnification and positional variation between radiographs (Wilding et al., 1987; Kreisler et al., 2000). As opposed to linear measurements, the proportional ratio of bone area to reference area remained relatively constant with changes in the exposure angle of X-ray beam (Kreisler et al., 2000).

The use of DPRs is well established; however, cone beam computed tomography (CBCT) has been suggested as an alternative method with greater accuracy to measure and determine the shape and size of alveolar ridges in edentulous patients (Varón de Gaitán et al., 2014). On the other hand, repeated exposures to high doses of radiation and extra costs might not justify the routine use of CBCT for follow-up evaluation. Moreover, DPR was more routinely used for edentulous patients seeking CD treatment in this establishment.

Higher levels of occlusal force increase the RRR rate as shown by many previous studies (Jaul et al., 1980; Maruo et al., 2010; Fujiki et al., 2013; Ahmad et al., 2015). However, with even force distribution and the concentration of occlusal forces over maximal denture bearing area, this could reduce the unnecessary concentration of stress, and hence slow the RRR (Maeda & Wood, 1989). Therefore, the effect of force distribution on bone resorption at different areas across the dental arch was investigated using the T-scan system which has been shown to measure the occlusal force distribution in an effective and dynamic way (Maness, 1987b; Cartagena et al., 1997).

It has been shown that different patterns of ridge resorption occurred at different locations within edentulous mandibular (Klemetti & Vainio, 1993) and maxillary (Klemetti et al., 1996) arches. The present study did not aim to determine and compare absolute values but rather to compare RRR depending on the arch locations in both the maxilla and mandible. Another study on IOD by Tymstra et al. (2011) found no correlation between the posterior mandibular and the anterior maxillary RRR; however, they did not include posterior maxillary ridge in their comparisons. Therefore, this study included the latter in the investigation and further analyzed the potential confounding factors affecting ridge resorption based on the arch locations.

It has also been previously reported that patients using maxillary CDs and mandibular IODs have an increased anterior maxillary ridge resorption (Salvador et al., 2007). This situation is similar to a common clinical condition described as the Combination Syndrome (Kelly, 1972), in which the edentulous maxilla opposes a partially dentate mandible in presence of anterior teeth. One of the features of this syndrome is a flabby maxillary anterior ridge associated with advanced bone resorption. However, when Närhi et al. (2000) adopted an occlusal concept with an anterior open bite occlusion in an attempt to avoid overloading of the anterior maxillary ridge, it was found that the reduction in the anterior ridge was not associated with implant-supported or conventional removable prostheses. Similarly, in this study, it was observed that the type of prostheses has no influence on the bone reduction in the anterior maxilla but it is related to the distribution of occlusal force. A systematic review by Rutkunas et al. (2008) did not show evidence for the maxillary ridge resorption acceleration with the two-implant supported mandibular overdenture prostheses of various degrees of resilient attachments. The finding of the present study was also in agreement with another study (Tymstra et al., 2011) that employed proportional area measurement and reported that patients rehabilitated with an implant retained mandibular overdenture did not exhibit more RRR as compared to patients wearing a conventional CD.

On the other hand, a different observation was found in the posterior arches, where maxillary and mandibular ridge reduction was affected by the type of prostheses. There was lesser posterior ridge resorption with implant prostheses compared to conventional CDs, even though higher chewing forces and improved masticatory performances were reported with implant therapy (Yunus et al., 2014; Bae et al., 2015). This observation concurred with the results of Kordatzis et al. (2003), where they employed similar proportional area measurements using panoramic radiographs to determine ridge reduction within five years. The authors attributed this, lesser posterior ridge resorption, to the more favorable loading and protection of the residual posterior ridge from an excessive load of the mandibular anterior implants. Similarly, a recent systematic review concluded alveolar ridge preservation with implant-assisted restorations (Khalifa et al., 2016).

Regarding the within-group comparisons at various locations of the mandibular and maxillary edentulous arches, the conventional CD group showed similar residual ridge reduction at all locations, whereas the IOD group showed significantly greater posterior ridge resorption in the mandible than in the maxilla. A greater percentage of occlusal force was shifted to the posterior areas in IOD patients, and the posterior mandible appeared to respond less favorably, hence, had a greater RRR as compared to the antagonistic residual ridge. The maxillary denture base coverage provided more tissue support for maxillary prostheses (Tallgren, 1972), compared to the smaller denture bearing area available for mandibular dentures (Jivraj et al., 2006), thereby reducing the occlusal load per unit area on the tissue. The occlusal factor showed no significant role in the bone reduction in the maxillary posterior ridge, and this was confirmed by the regression analyses.

5.6 Patient-reported outcomes and their association with the occlusal force distribution

Oral Health Impact Profile (OHIP) is considered as one of the most common instruments to assess the OHRQoL (Slade, 1997a). The shortened Oral Health Impact Profile Malaysian version [S-OHIP-14 (M)] was used in this study to compare the quality of life between CD and IOD groups. The S-OHIP-14 (M) was shown to be valid, reliable and appropriate for use in the cross-sectional studies in Malaysian adult populations (Saub et al., 2005).

The OHIP-14 questionnaires measured seven conceptual dimensions of impact: functional limitation, physical pain, psychological discomfort, physical disability, psychological disability, social disability, and handicap. However, during its function, the prostheses can be uncomfortable or unstable, especially due to a poor fitting surface (Veyrune et al., 2005). Therefore, a denture satisfaction questionnaire (DS) developed by Fenlon & Sherriff (2004) was used in this study as well to evaluate DS outcomes. This subjective instrument has been previously tested for its reliability (Fenlon et al., 2000). The association of patient-reported outcomes with objective clinical tests, such us occlusal force distribution and masticatory performances, were also investigated in this study.

Patients were assessed for their perception with regards to the experience using their current prostheses. An overall lower scores were observed in OHIP-14 and DS total scores for the IOD type more than CD type of prostheses, which could be due to better stability and retention achieved with the IOD (Boerrigter et al., 1995a; Boerrigter et al., 1995b; Meijer et al., 1999). This finding was in agreement with results of previous clinical studies (Awad et al., 2000a; Awad et al., 2003; Heydecke et al., 2003; Torres et al., 2011; Jabbour et al., 2012; Yunus et al., 2014).

Regarding the OHIP-14 individual domains, the patients in the IOD group reported significantly lower score for physical pain than those in CD group, while there were no differences in the other domains. This finding was in congruence with another similar study conducted by Geckili et al. (2012a). The greater score in physical pain in CD group may be attributed to the undesirable denture movements associated with the reduced stability of CD, thereby resulting in increased pain sensation compared to the IOD group (Cakir et al., 2014). Previous investigators have also shown a higher association between complaint of pain and denture mucosal bearing areas in CD patients (Brunello & Mandikos, 1998). The remaining OHIP-14 domains, however, showed no difference between CD and IOD groups, which contradicts the findings of a study by Yunus et al. (2014). This could be due to the different observation time because patients in the previous study (Yunus et al., 2014) were evaluated one year after their dentures were converted to IOD, while in the present study the patients were evaluated after four years. Patients rehabilitated with CD need additional time to adapt to the new dentures than patients with fixed or removable partial dentures, and the OHRQoL improvement was observed following two years of prosthodontic treatment (Aarabi et al., 2015).

Regarding the denture satisfaction in IOD patients, there was greater satisfaction in relation to stability, comfort, and chewing ability compared to those in CD patients.

Completely edentulous patients are frequently dissatisfied with their dentures (Lechner & Roessler, 2001), especially with the mandibular dentures, due to compromised retention, stability and masticatory performance (Van Waas, 1990). Patients' habituation to their mandibular dentures may explain greater satisfaction with mandibular compared to maxillary prostheses (Fenlon & Sherriff, 2004).

In this study, no association was observed between the occlusal force distribution and OHRQoL and denture satisfaction. This finding contradicted with other studies (Lassila et al., 1985; Rismanchian et al., 2009) where they found the bite force was positively correlated with patient satisfaction. However, our results were in line with other studies (Cune et al., 2005; Geckili et al., 2012b) where increased bite force was not found to enhance patient life expectation or satisfaction. These contradictory findings of bite force association to patients satisfaction of the previous studies (Lassila et al., 1985; Rismanchian et al., 2009), could be due to the variations in bite force measurement devices used in these studies. These studies employed pezioelectronic strain gauges with 3-6 mm thickness; while in this study the thickness of sensor was 100 µm. The U-shaped sensor used in the present study allowed bilateral balanced force measurements.

The objective method to determine masticatory performance was made using the measurement of MAI. The association between masticatory performance and the patient-reported outcomes was also determined. However, we found that MAI was neither associated with the total OHIP-14 nor with total DS scores. This finding contradicts the results of a study conducted by Bae et al. (2015), that investigated masticatory performance, using MAI, and reported its correlation to the findings of a satisfaction questionnaire in CD and IOD patients. Bae et al. (2015) found a positive correlation between overall patients' satisfaction and MAI values. These contradicting findings could be due to the different sample sizes used in both studies because 46 patients were enrolled with Locator and telescopic attachments in the present study while only 8 IOD patients with Locator attachments participated in their study (Bae et al., 2015).

5.7 Demographics data

5.7.1 Age

Decreased bone mineral density, lowered secretion of estrogen as well as physical activity, diet, race, and heredity may all contribute to age-related bone loss (Kumar et al., 2016). However, previous studies found no association of age, as a risk factor, with bone resorption in patients rehabilitated with CD, fixed dentures, and IOD (Wright et al., 2002; Kordatzis et al., 2003). The results of our study were in agreement with previous studies showing that age was not associated with RRR. Additionally, in the present study, age was not associated with patient satisfaction, which is consistent with the findings of Khalid et al. (2016) that showed no association between age and IOD patients' OHRQoL and satisfaction. The mean age of patients enrolled in the present study was 66 years, and no difference was observed between the CD and IOD groups. According to Kuoppala et al. (2013), older patients (above 65 years) were more satisfied in the aspects of psychological discomfort and disability when compared with younger patients. The people in the youngest age group were usually involved in working life and had to deal with different social conditions, and their demands of oral status might have been higher than those in the older age groups.

5.7.2 Gender

One of the advantages of using relative occlusal force, rather than absolute bite force, in determining ridge resorption was that it is non-gender-specific (Koos et al., 2012). Hence, the use of computerized T-scan occlusal analysis system in this study seemed appropriate, considering the evidence that shows females are at higher risk of severe resorption in the mandible (Kordatzis et al., 2003) or in the maxilla (Jacobs et al., 1993). Also, previous studies had found that females were less satisfied than males with new CD (Pan et al., 2008), and masticatory performance was higher in males than females (Pan et al., 2010). However, the results of the present study found no association between gender or masticatory performance with denture satisfaction.

5.7.3 Years of edentulousness

The absence of natural teeth results in several complications, including functional, aesthetic, phonetic complications, and also affects the physical, biological, social and psychological state of individuals (Özdemir et al., 2006; Scott et al., 2006). Moreover, long edentulous periods (20 years on average) could affect the RRR in edentulous patients (Tymstra et al., 2011). In contrast, the present study found no association between length of time that the patients were edentulous and their RRR at different locations. This may be due to the reduced number of years of patients having been totally edentulousness in our study (6 years) as compared to the previous study. This result was also in accordance with the findings of other studies, which showed that the time for which the patient had been edentulous was not associated with the extend of ridge resorption (Wright et al., 2002; Kordatzis et al., 2003). Following tooth extraction, a slow resorption rate of the ridge was observed for some years; hence, the effect of time was not considered as a significant factor (Kordatzis et al., 2003). In the present study, years of edentulousness was not associated with OHRQoL and denture satisfaction. This lack of association was similar to a study by Khalid et al. (2016), where they also observed that the years of edentulousness had no association with the patient-reported outcomes. The groups of patients in this study and their study (Khalid et al., 2016) were similar in this respect.

5.8 Strain investigation within denture prostheses and attachment clinical complications

Fatigue of denture base polymer could be one of the main factors leading to acrylic denture fractures—which is still one of the clinical problems faced in prosthetic dentistry (Smith, 1961). Fatigue failure does not necessitate higher biting forces, and small forces caused by the masticatory system, over a period of time, can ultimately lead to the formation of small cracks which propagate in the dentures causing fractures (Farmer, 1983).

FEA is considered as a more suitable method for strain analysis as compared to the strain gauges because FEA does not have special measure requirements such as a dry field, which is required for the latter method (Darbar et al., 1994). Furthermore, FEA can measure strain on two surfaces, unlike strain gauges which measure strain only on one surface (Cheng et al., 2010). However, for vertical occlusal load simulations in FEA, previous studies had applied 40% maximum bite force bilaterally on the first molars of the prostheses, assuming a nearly symmetric loading condition at the left and right sides of the arch (Gibbs et al., 1981; Ahmad et al., 2015). However, in this study, the application of simulated load, at the anterior and posterior quadrants varied since the occlusal force distribution was found to be different. A smaller proportion of the vertical occlusal force was applied in anterior quadrants than posterior quadrants and this could be clinically more relevant when the maxillary and mandibular teeth simultaneously come into contact.

The T-scan occlusal force distribution can differentiate occlusal force area and helps in the force analyses at different zones across the dental arch (Cartagena et al., 1997; Kumagai et al., 1999). The occlusal force distribution between CD and IOD groups, in this study, showed different strain concentrations and fracture initiation sites. Moreover, different strain concentrations were observed between the maxillary and mandibular prostheses.

The strains generated on polished and impression surfaces of the maxillary CD models were tensile and compressive, respectively, regardless of the opposing mandibular denture type. A previous study which used brittle lacquer coating materials (Matthews & Wain, 1956), showed that a higher tensile stress was distributed at the mid-palatal polished surface of the maxillary CD. Similarly, the FEA results of the present study indicated that the maxillary CD was more susceptible to fractures in the mid-palatal area of the polished surface when opposing the mandibular CD model. During mastication, the maxillary CD is bent at the mid-palatal line as the fulcrum axis, thus making the denture fractures more likely to initiate from this area (Anusavice et al., 2013). Improper fitting of the dentures another factor that might increase the deflection of the removable dentures during mastication; subsequently, predisposing the dentures to fatigue fractures (Vallittu et al., 1994; Vallittu et al., 1996). A recent FEA study (Cheng et al., 2010) also reported a similar area as the fracture initiation zone and the maximum tensile strain measured at the tip of the incisal notch was 1917 με which was higher than that observed in our study 1254 με. This difference could be due to the application of a bilateral 230 N load on the posterior region in their study, while our study used a load of 150 N which was heterogeneously distributed in the anterior and posterior areas.

When the maxillary CD model opposed the mandibular IOD models, a different strain distribution scenario was observed where the fracture initiation areas were found to be more palatal to the anterior teeth position, incisal notch, and the mid-posterior palatal area. The strain distribution patterns in the maxillary CD models, when opposing mandibular CD was different from the IOD models. This could be due to the different occlusal force distributions between conventional and implant mandibular prostheses. The occlusal force was relatively more homogeneous in the mandibular CD model. For mandibular IOD models, higher occlusal forces were applied in the posterior quadrants as compared to the anterior quadrants.

Investigations of the strain distribution in the mandibular CD model indicated a higher tensile strain at the incisal notch of the lower incisors and canines. This finding was in agreement with the results of previous studies, which investigated the fracture phenomena using scanning electron microscope (Lamb et al., 1985; Vallittu, 1996). The initiation of crack growth in the anterior zone is probably attributed to continuous flexing of dentures from the lateral extension of their posterior part during the application of force (Vallittu, 1996).

The FEA results indicated that different tensile and compressive strain distributions were generated in the mandibular IOD and the mandibular CD prostheses, due to their different rotation axes around the intercepted areas between the attachments and the acrylic denture bases (Solomons, 2000).

The strain concentration around the acrylic denture/attachment interface may consequently lead to fractures, especially when self-cure resin materials are used in the attachment pick-up procedures that results in a weak mechanical bond. This was in agreement with some previous studies that used cast metal frameworks to minimize denture base fractures in the root-retained overdentures and IOD prostheses (Langer & Langer, 1991; Walton & MacEntee, 1994).

Regarding the attachment design, it was found that the Locator and telescopic attachments possess their own unique mechanisms to retain the prostheses. With Locator attachment, the maximum tensile strain was observed at the acrylic denture/attachment interface with lesser strain at the lower sulcus border of the lingual and labial flange areas. Telescopic attachment similarly demonstrated tensile strain around the interface, with lesser strain at the top of the telescopic attachment. This indicated the likelihood of fracture initiation from the acrylic denture/attachment area regardless of the attachment type used.

From the clinical perspective of this study, it was observed that IOD retained by telescopic attachments showed 100% complications, whereas only 40% complications were observed in Locator attachments. As the tensile strain distribution around the telescopic attachment was higher and significantly greater frequency of mechanical complications was observed, seems to be there is a higher risk of clinical complications with telescopic attachment compared to Locator attachment in IOD prostheses. Telescopic attachment occupied greater space (5 mm) within the prosthesis compared to Locator attachment (2.3 mm). The rigidity of the telescopic attachment is high as compared to Locator attachment where the latter allows some degree of resilience in both vertical and horizontal directions when in function (Evtimovska et al., 2009).

These findings contradict the previous results shown by Dong et al. (2006), who undertook an FEA study in which the highest tensile strain was on top of the overdenture copings regardless of their height. This could be due to the different load applications seen in the previous study and their distributions across the arch. For instance, Dong et al. (2006) applied a vertical force of 49 N individually on the first premolar, first molar, and second molar areas; whereas in this study the force was vertically applied following the relative occlusal force distribution obtained from digital occlusal analysis system T-scan sensor.

Comparison of the maximum tensile strain values in all the studied models indicated that maxillary CD had higher tensile strains than the opposing mandibular CD either with Locator and telescopic attachment. Hence, fracture was more likely to occur in maxillary denture. This was in agreement with a previous survey on the clinical denture repair, which found two-fold higher incidences of fractures in maxillary to mandibular dentures (Beyli & Von Fraunhofer, 1981).

5.9 Summary

Patients using maxillary CDs and mandibular IODs have an increased anterior maxillary ridge resorption (Salvador et al., 2007) which was thought to be related to the type of the prostheses used rather than the effect of occlusal force distribution. Hence, this cross-sectional study determined the RRR in edentulous patients wearing mandibular IOD or conventional CD, opposing conventional maxillary CDs. This study also investigated the association of RRR with occlusal force distribution in different areas in the maxillary and the mandibular arches as well as with other confounding factors, such as age, gender, and years of edentulism. It was observed that the type of mandibular prostheses has no influence on the bone resorption at the anterior maxilla. However, the bone resorption was associated with the occlusal force distribution, and with the type of mandibular prostheses at the posterior arches of the maxilla and mandible. Higher chewing forces and improved masticatory performances were reported with IOD prostheses, however, no association was observed between patient perceptions and the occlusal force distribution in both IOD and conventional CD patients.

The risk of acrylic denture prostheses fracture has been previously investigated by FEA simulation using specific occlusal load which was applied on molar teeth, however, the occlusal load did not represent the actual clinical force distribution. Therefore, this study retrieved the T-scan III occlusal force distribution at different locations across the dental arch in the FEA load simulation. The results showed that there were different strain concentrations and fracture initiation sites observed between CD and IOD models.

CHAPTER 6: CONCLUSIONS

6.1 Conclusions

Mandibular overdenture supported by two implants is more retentive and it has been shown to improve patients OHRQoL and satisfaction over conventional complete denture treatment. However, there is still a lack of information available about the occlusal force distribution and its association to residual ridge resorption, patient-reported outcomes, as well as the other mechanical and clinical factors. T-scan III occlusal analysis system was used in this study to determine the percentage of occlusal force distribution. The findings observed from this study could be useful for better prostheses design avoiding residual ridge resorption, and minimizing the denture risk of fracture.

Within the limitation of this study, we can conclude that:

6.1.1 Clinical Study

1 There was no significant difference in the masticatory performance of patients wearing conventional complete denture and mandibular implant-overdenture prostheses.

2 The anterior and posterior occlusal force distribution showed significant differences between conventional complete denture and mandibular implant-overdenture prostheses. Significant differences between anterior and posterior occlusal force distribution were also observed within each group.

3 Mandibular implant-overdenture patients showed better oral health-related quality of life and denture satisfaction than conventional complete denture patients.

4 Greater occlusal force percentage was associated with increased bone resorption in the anterior maxilla and posterior mandibular area.

5 Mandibular implant-overdenture prostheses showed less residual ridge bone resorption in the posterior maxilla and mandible areas.

6 Mandibular implant-overdenture with Locator attachment showed lower clinical complications compared to the telescopic attachment.

6.1.2 Finite element analysis study

1. The risk of fracture incidence in the maxillary conventional complete denture was higher than those of mandibular conventional complete denture and mandibular implant-overdenture prostheses, especially at the anterior palatal area of the polished surface of the acrylic denture base.
2. Mandibular conventional complete denture prostheses showed higher strain values at the midline area of the polished surface in contrast to the mandibular implant-overdenture prostheses with either Locator or telescopic attachments.
3. Mandibular implant-overdenture with Locator attachment showed lower fracture susceptibility compared to the telescopic attachment at the denture-attachment interface.

6.2 Limitations of the study

1- T-scan III system was only used to record the relative occlusal force distribution rather than the actual force distribution

2- Utilization of combined force distribution values for telescopic and Locator attachments is considered as one of the limitation observed in this study, due to an unequal number of attachments used in the implant-overdenture group (15 patients having Locator and eight having telescopic attachments).

3- The implant fixture was simulated without threads in order to reduce the analysis time and model complexity, as the major concern was to measure the strain distribution of the acrylic denture base and its interference with the attachments.

4- The load value of 150 N used in FEA simulation might not present the actual force applied for conventional complete denture and mandibular implant-overdenture models since it is higher in the latter group (Ahmad et al., 2015). However, a pilot study was conducted to measure this force and the results showed a non-significant difference between the groups and the higher mean of force (150 N) was applied for load simulation.

6.3 Study recommendations

1- Future studies could involve investigating residual ridge resorption in relation to the distribution of force at various time sequences extending from the point of initial tooth contact to maximal intercuspation position and to complete disocclusion.

2- Investigation of the effect of eccentric occlusal movements in relation to residual ridge resorption are suggested for future studies.

3- Future studies are necessary to investigate the stress distribution within the dental implants and their supporting tissues in mandibular implant-overdenture retained by telescopic or Locator attachments opposing conventional maxillary complete denture based on their occlusal force distribution.

REFERENCES

Aarabi, G., John, M. T., Schierz, O., Heydecke, G. & Reissmann, D. R. (2015). The course of prosthodontic patients' oral health-related quality of life over a period of 2 years. *Journal of Dentistry*. *43*(2):261-268.

Abdelnabi, M. H., Swelem, A. A. & Al-Dharrab, A. A. (2016). Influence of denture adhesives on occlusion and disocclusion times. *Journal of Prosthetic Dentistry*. *115*(3):306-312.

Afrashtehfar, K. I., Akanksha Srivastava, B. & Esfandiari, S. (2013). A health technology assessment report on the utility of digital occlusal analyzer system t-scan® in temporomandibular disorders. (report no: S2013.02). Montreal, Canada: Faculty of Dentistry, Mcgill university. Https://www.Mcgill.Ca/dentistryohs/courses-and-events/dent-655/hta-reports:1-54.

Agerberg, G. & Carlsson, G. E. (1981). Chewing ability in relation to dental and general health: Analyses of data obtained from a questionnaire. *Acta Odontologica Scandinavica*. *39*(3):147-153.

Ahmad, R., Chen, J., Abu-Hassan, M. I., Li, Q. & Swain, M. V. (2015). Investigation of mucosa-induced residual ridge resorption under implant-retained overdentures and complete dentures in the mandible. *International Journal of Oral and Maxillofacial Implants*. *30*(3):657-666.

Aimetti, M., Romano, F., Griga, F. & Godio, L. (2009). Clinical and histologic healing of human extraction sockets filled with calcium sulfate. *International Journal of Oral and Maxillofacial Implant*. *24*(5):901-909.

Al-Shammari, K. F., Al-Khabbaz, A. K., Al-Ansari, J. M., Neiva, R. & Wang, H.-L. (2005). Risk indicators for tooth loss due to periodontal disease. *Journal of Periodontology*. *76*(11):1910-1918.

AlBaker, A. M. (2013). The oral health-related quality of life in edentulous patients treated with conventional complete dentures. *Gerodontology*. *30*(1):61-66.

Allen, P. F. & McMillan, A. S. (2003). A review of the functional and psychosocial outcomes of edentulousness treated with complete replacement dentures. *Journal of the Canadian Dental Association 69*(10):662-662.

Allen, P. F., McMillan, A. S. & Locker, D. (2001). An assessment of sensitivity to change of the oral health impact profile in a clinical trial. *Community Dentistry and Oral Epidemiology*. *29*(3):175-182.

Alsabeeha, N. H., Payne, A. G. & Swain, M. V. (2009). Attachment systems for mandibular two-implant overdentures: A review of in vitro investigations on retention and wear features. *International Journal of Prosthodontics*. *22*(5):429-440.

Alsiyabi, A. S., Felton, D. A. & Cooper, L. F. (2005). The role of abutment-attachment selection in resolving inadequate interarch distance: A clinical report. *Journal of Prosthodontics*. *14*(3):184-190.

Andreiotelli, M., Att, W. & Strub, J.-R. (2010). Prosthodontic complications with implant overdentures: A systematic literature review. *International Journal of Prosthodontics*. *23*(3):195-203.

Andreyeva, T., Michaud, P.-C. & Van Soest, A. (2007). Obesity and health in Europeans aged 50 years and older. *Public Health*. *121*(7):497-509.

Angelopoulos, C., Thomas, S., Hechler, S., Parissis, N. & Hlavacek, M. (2008). Comparison between digital panoramic radiography and cone-beam computed tomography for the identification of the mandibular canal as part of presurgical dental implant assessment. *Journal of Oral and Maxillofacial Surgery*. *66*(10):2130-2135.

Anusavice, K. J., Shen, C. & Rawls, H. R. (2013). Phillips' science of dental materials. 12th ed., ST. Louis, MO: Elsevier Sanders Co.

Atchison, K. & Gift, H. (1997). Perceived oral health in a diverse sample. *Advances in Dental Research*. *11*(2):272-280.

Atwood, D. A. (1971). Reduction of residual ridges: A major oral disease entity. *Journal of Prosthetic Dentistry*. *26*(3):266-279.

Atwood, D. A. & Coy, W. A. (1971). Clinical, cephalometric, and densitometric study of reduction of residual ridges. *Journal of Prosthetic Dentistry*. *26*(3):280-295.

Awad, M., Locker, D., Korner-Bitensky, N. & Feine, J. (2000a). Measuring the effect of intra-oral implant rehabilitation on health-related quality of life in a randomized controlled clinical trial. *Journal of Dental Research*. *79*(9):1659-1663.

Awad, M. A. & Feine, J. S. (1998). Measuring patient satisfaction with mandibular prostheses. *Community Dentistry and Oral Epidemiology*. *26*(6):400-405.

Awad, M. A., Lund, J. P., Shapiro, S. H., Locker, D., Klemetti, E., Chehade, A., Savard, A. & Feine, J. S. (2003). Oral health status and treatment satisfaction with mandibular implant overdentures and conventional dentures: A randomized clinical trial in a senior population. *International Journal of Prosthodontics*. *16*(4):390-396.

Baba, K., Tsukiyama, Y. & Clark, G. T. (2000). Reliability, validity, and utility of various occlusal measurement methods and techniques. *Journal of Prosthetic Dentistry*. *83*(1):83-89.

Bae, J.-C., Jeong, S.-H., Jeong, C.-M. & Huh, J.-B. (2015). Comparison of the masticatory functions of complete dentures and implant-retained overdentures. *International Journal of Prosthodontics*. *28*(4):345-347.

Baggi, L., Cappelloni, I., Di Girolamo, M., Maceri, F. & Vairo, G. (2008). The influence of implant diameter and length on stress distribution of osseointegrated implants related to crestal bone geometry: A three-dimensional finite element analysis. *Journal of Prosthetic Dentistry*. *100*(6):422-431.

Baiamonte, T., Abbate, M., Pizzarello, F., Lozada, J. & James, R. (1996). The experimental verification of the efficacy of finite element modeling to dental implant systems. *Journal of Oral Implantology*. *22*(2):104-110.

Bakke, M., Holm, B., Jensen, B. L., Michler, L. & Møller, E. (1990). Unilateral, isometric bite force in 8-68-year-old women and men related to occlusal factors. *European Journal of Oral Sciences*. *98*(2):149-158.

Barkanov, E. (2001). Introduction to the finite element method. *Institute of Materials and Structures Faculty of Civil Engineering Riga Technical University*.1-70.

Batenburg, R. H., Raghoebar, G. M., Van Oort, R. P., Heijdenrijk, K. & Boering, G. (1998). Mandibular overdentures supported by two or four endosteal implants: A prospective, comparative study. *International Journal of Oral and Maxillofacial Surgery*. *27*(6):435-439.

Becker, C. M., Swoope, C. C. & Guckes, A. D. (1977). Lingualized occlusion for removable prosthodontics. *Journal of Prosthetic Dentistry*. *38*(6):601-608.

Beyli, M. & Von Fraunhofer, J. (1981). An analysis of causes of fracture of acrylic resin dentures. *Journal of Prosthetic Dentistry*. *46*(3):238-241.

Bicaj, T., Pustina, T., Ahmedi, E., Dula, L., Lila, Z., Tmava-Dragusha, A., Ademi-Abdyli, R. & Ajeti, N. (2015). The relation between the preferred chewing side and occlusal force measured by t-scan iii system. *Open Journal of Stomatology*. *5*(04):95-101.

Boening, K. W. & Walter, M. H. (1992). Computer-aided evaluation of occlusal load in complete dentures. *Journal of Prosthetic Dentistry*. *67*(3):339-344.

Boerrigter, E., Geertman, M., Van Oort, R., Bouma, J., Raghoebar, G., Van Waas, M., Van't Hof, M., Boering, G. & Kalk, W. (1995a). Patient satisfaction with implant-retained mandibular overdentures. A comparison with new complete dentures not retained by implants—a multicentre randomized clinical trial. *British Journal of Oral and Maxillofacial Surgery*. *33*(5):282-288.

Boerrigter, E., Stegenga, B., Raghoebar, G. & Boering, G. (1995b). Patient satisfaction and chewing ability with implant-retained mandibular overdentures: A comparison with new complete dentures with or without preprosthetic surgery. *Journal of Oral and Maxillofacial Surgery*. *53*(10):1167-1173.

Bolhofner, K. L. & Baker, B. J. (2012). Dental ablation in ancient nubia: Evulsion at the ginefab school site. *American Journal of Physical Anthropology*. *147*:102-102.

Boretti, G., Bickel, M. & Geering, A. H. (1995). A review of masticatory ability and efficiency. *Journal of Prosthetic Dentistry*. *74*(4):400-403.

Borges, T. F., Mendes, F. A., de Oliveira, T., Gomes, V. L., do Prado, C. J. & das Neves, F. D. (2010). Mandibular overdentures with immediate loading: Satisfaction and quality of life. *International journal of prosthodontics*. *24*(6):534-539.

Boskey, A. L. (2013). Bone composition: Relationship to bone fragility and antiosteoporotic drug effects. *Bone Key Reports*. *4*(710):1-11.

Brånemark, P.-I. (1959). Vital microscopy of bone marrow in rabbit. *Scandinavian Journal of Clinical and Laboratory Investigation*. *11*:1-82.

Brånemark, P.-I. (1977). Osseointegrated implants in the treatment of the edentulous jaw. Experience from a 10-year period. *Scandinavian Journal of Plastic and Reconstructive Surgery*. *16*:1-132.

Brånemark, P.-I. (1983). Osseointegration and its experimental background. *Journal of Prosthetic Dentistry*. *50*(3):399-410.

Brunello, D. L. & Mandikos, M. N. (1998). Construction faults, age, gender, and relative medical health: Factors associated with complaints in complete denture patients. *Journal of Prosthetic Dentistry*. *79*(5):545-554.

Burns, D. R., Unger, J. W., Elswick, R. K. & Giglio, J. A. (1995). Prospective clinical evaluation of mandibular implant overdentures: Part ii—patient satisfaction and preference. *Journal of Prosthetic Dentistry*. *73*(4):364-369.

Cakir, O., Kazancioglu, H. O., Celik, G., Deger, S. & Ak, G. (2014). Evaluation of the efficacy of mandibular conventional and implant prostheses in a group of Turkish patients: A quality of life study. *Journal of Prosthodontics*. *23*(5):390-396.

Campbell, R. L. (1960). A comparative study of the resorption of the alveolar ridges in denture-wearers and non-denture-wearers. *Journal of the American Dental Association*. *60*(2):143-153.

Carlsson, G. & Persson, G. (1967). Morphologic changes of the mandible after extraction and wearing of dentures. A longitudinal, clinical, and x-ray cephalometric study covering 5 years. *Odontologisk Revy*. *18*(1): 27-54.

Carlsson, G. E. (1984). Masticatory efficiency: The effect of age, the loss of teeth and prosthetic rehabilitation. *International Dental Journal*. *34*(2):93-97.

Carlsson, G. E. (2014). Implant and root supported overdentures-a literature review and some data on bone loss in edentulous jaws. *Journal of Advanced Prosthodontics*. *6*(4):245-252.

Carlsson, G. E., Kronström, M., De Baat, C., Cune, M., Davis, D., Garefis, P., Heo, S. J., Jokstad, A., Matsuura, M. & Närhi, T. (2004). A survey of the use of mandibular implant overdentures in 10 countries. *Journal of Prosthetic Dentistry*. *92*(2):211-217.

Carlsson, G. E. & Omar, R. (2010). The future of complete dentures in oral rehabilitation. A critical review. *Journal of Oral Rehabilitation*. *37*(2):143-156.

Cartagena, A. G., Sequeros, O. G. & Garcia, V. G. (1997). Analysis of two methods for occlusal contact registration with the t-scan system. *Journal of Oral Rehabilitation*. *24*(6):426-432.

Cerna, M., Ferreira, R., Zaror, C., Navarro, P. & Sandoval, P. (2015). Validity and reliability of the t-scan® iii for measuring force under laboratory conditions. *Journal of Oral Rehabilitation*. *42*(7):544-551.

Chapman, R. (1989). Principles of occlusion for implant prostheses: Guidelines for position, timing, and force of occlusal contacts. *Quintessence International*. *20*(7):473-480.

Cheng, Y. Y., Cheung, W. L. & Chow, T. W. (2010). Strain analysis of maxillary complete denture with three-dimensional finite element method. *Journal of Prosthetic Dentistry*. *103*(5):309-318.

Chladek, G., Żmudzki, J. & Kasperski, J. (2014). Long-term soft denture lining materials. *Materials*. *7*(8):5816-5842.

Chung, K. H., Chung, C. Y., Cagna, D. R. & Cronin, R. J. (2004). Retention characteristics of attachment systems for implant overdentures. *Journal of Prosthodontics*. *13*(4):221-226.

Cilingir, A., Bilhan, H., Baysal, G., Sunbuloglu, E. & Bozdag, E. (2013). The impact of frenulum height on strains in maxillary denture bases. *Journal of Advanced Prosthodontics*. *5*(4):409-415.

Cleary, T. J. & Hutton, J. E. (1995). An assessment of the association between functional edentulism, obesity, and NIDDM. *Diabetes Care*. *18*(7):1007-1009.

Cooney, P. (2010). Report on the findings of the oral health component of the Canadian health measures survey 2007–2009. *Ottawa: Health Canada*.1Á111.

Cooper, L. F. (2009). The current and future treatment of edentulism. *Journal of Prosthodontics*. *18*(2):116-122.

Cotruta, A. M., Mihaescu, C. S., Tănăsescu, L. A., Mărgărit, R. & Andrei, O. C. (2015). Analyzing the morphology and intensity of occlusal contacts in implant-prosthetic restorations using t-scan system. *Romanian Journal of Morphology and Embryology*. *56*(1):277-281.

Cox, J. & Zarb, G. (1987). The longitudinal clinical efficacy of osseointegrated dental implants: A 3-year report. *International Journal of Oral and Maxillofacial Implant*. *2*(2):91-100.

Craig, R. G., Farah, J. W. & El-Tahawi, H. M. (1974). Three-dimensional photoelastic stress analysis of maxillary complete dentures. *Journal of Prosthetic Dentistry*. *31*(2):122-129.

Crowninshield, R., Brand, R. & Pedersen, D. (1983). A stress analysis of acetabular reconstruction in protrusio acetabuli. *Journal of Bone and Joint Surgery*. *65*(4):495-499.

Crum, R. J. & Rooney, G. E. (1978). Alveolar bone loss in overdentures: A 5-year study. *Journal of Prosthetic Dentistry*. *40*(6):610-613.

Cune, M., Van Kampen, F., Van der Bilt, A. & Bosman, F. (2005). Patient satisfaction and preference with magnet, bar-clip, and ball-socket retained mandibular implant overdentures: A cross-over clinical trial. *International Journal of Prosthodontics*. *18*(2):99-105.

Cunha-Cruz, J., Hujoel, P. & Nadanovsky, P. (2007). Secular trends in socio-economic disparities in edentulism: USA, 1972–2001. *Journal of Dental Research*. *86*(2):131-136.

Curtis, D., Sharma, A., Finzen, F. & Kao, R. (2000). Occlusal considerations for implant restorations in the partially edentulous patient. *Journal of the California Dental Association*. *28*(10):771-779.

D'Souza, D. (2012). Residual ridge resorption-revisited. In oral health care-prosthodontics, periodontology, biology, research and systemic conditions. Intech. INTECH Open Access Publisher.

da Silva Martins, M. J., Caramelo, F. J., da Fonseca, J. A. R. & Nicolau, P. M. G. (2014). In vitro study on the sensibility and reproducibility of the new t-scan® iii hd system. *Revista Portuguesa de Estomatologia, Medicina Dentária e Cirurgia Maxillofacial*. *55*(1):14-22.

Daing, A., Singh, A., Dixit, J. & Anand, V. (2012). Management of periodontal lesion associated with traumatic deep bite: A case report. *International Journal of Dental Case Reports*. *2*(3):48-53.

Darbar, U., Huggett, R. & Harrison, A. (1994). Stress analysis techniques in complete dentures. *Journal of Dentistry*. *22*(5):259-264.

Darby, I., Chen, S. T. & Buser, D. (2009). Ridge preservation techniques for implant therapy. *International Journal of Oral and Maxillofacial Implant*. *24*(s):260-271.

Davis, W. H., Lam, P. S., Marshall, M. W., Dorchester, W., Hochwald, D. A. & Kaminishi, R. M. (1999). Using restorations borne totally by anterior implants to preserve the edentulous mandible. *Journal of the American Dental Association*. *130*(8):1183-1189.

De Grandmont, P., Feine, J., Tache, R., Boudrias, P., Donohue, W., Tanguay, R. & Lund, J. (1994). Within-subject comparisons of implant-supported mandibular prostheses: Psychometric evaluation. *Journal of Dental Research*. *73*(5):1096-1104.

de Pablo, P., Dietrich, T. & McAlindon, T. E. (2008). Association of periodontal disease and tooth loss with rheumatoid arthritis in the US population. *Journal of Rheumatology*. *35*(1):70-76.

de Sousa, A. A. & Mattos, B. S. C. (2014). Finite element analysis of stability and functional stress with implant-supported maxillary obturator prostheses. *Journal of Prosthetic Dentistry*. *112*(6):1578-1584.

Denissen, H., Kalk, W., Van Waas, M. & Van Os, J. (1993). Occlusion for maxillary dentures opposing osseointegrated mandibular prostheses. *International Journal of Prosthodontics*. *6*(5):446-450.

Dharmar, S. (1997). Locating the mandibular canal in panoramic radiographs. *International Journal of Oral and Maxillofacial Implant*. *12*(1):1-7.

Doğan, B. G. & Gökalp, S. (2012). Tooth loss and edentulism in the Turkish elderly. *Archives of Gerontology and Geriatrics*. *54*(2):e162-e166.

Dong, J., Ikebe, K., Gonda, T. & Nokubi, T. (2006). Influence of abutment height on strain in a mandibular overdenture. *Journal of Oral Rehabilitation*. *33*(8):594-599.

Doundoulakis, J. H., Eckert, S. E., Lindquist, C. C. & Jeffcoat, M. K. (2003). The implant-supported overdenture as an alternative to the complete mandibular denture. *Journal of the American Dental Association*. *134*(11):1455-1458.

Dove, S. & McDavid, W. (1993). Digital panoramic and extraoral imaging. *Dental Clinics of North America*. *37*(4):541-551.

Edlund, J. & Lamm, C. (1980). Masticatory efficiency. *Journal of Oral Rehabilitation*. *7*(2):123-130.

Ehrlich, J. & Taicher, S. (1981). Intercuspal contacts of the natural dentition in centric occlusion. *Journal of Prosthetic Dentistry*. *45*(4):419-421.

Elhammali, N., Bremerich, A. & Rustemeyer, J. (2010). Demographical and clinical aspects of sports-related maxillofacial and skull base fractures in hospitalized patients. *International Journal of Oral and Maxillofacial Surgery*. *39*(9):857-862.

Elsyad, M. A., Errabti, H. M. & Mustafa, A. Z. (2016). Mandibular denture base deformation with locator and ball attachments of implant-retained overdentures. *Journal of Prosthodontics*. *25*(8):656-664.

Elsyad, M. A. & Khairallah, A. S. (2017). Chewing efficiency and maximum bite force with different attachment systems of implant overdentures: A crossover study. *Clinical Oral Implants Research*. *28*(6):677-682.

Elsyad, M. A., Khairallah, A. S. & Shawky, A. F. (2013). Changes in the edentulous maxilla with ball and telescopic attachments of implant-retained mandibular overdentures: A 4-year retrospective study. *Quintessence International*. *44*(7):487-495.

Emami, E., de Souza, R. F., Kabawat, M. & Feine, J. S. (2013). The impact of edentulism on oral and general health. *International Journal of Dentistry*. *2013*(2012):1-7.

Eskitascioglu, G., Usumez, A., Sevimay, M., Soykan, E. & Unsal, E. (2004). The influence of occlusal loading location on stresses transferred to implant-supported prostheses and supporting bone: A three-dimensional finite element study. *Journal of Prosthetic Dentistry*. *91*(2):144-150.

Evtimovska, E., Masri, R., Driscoll, C. F. & Romberg, E. (2009). The change in retentive values of locator attachments and hader clips over time. *Journal of Prosthodontics*. *18*(6):479-483.

Farah, J., Craig, R. & Sikarskie, D. (1973). Photoelastic and finite element stress analysis of a restored axisymmetric first molar. *Journal of Biomechanics*. *6*(5):511-520.

Farmer, J. B. (1983). Preventive prosthodontics: Maxillary denture fracture. *Journal of Prosthetic Dentistry*. *50*(2):172-175.

Feine, J. & Carlsson, G. (2003). Implant overdentures. *The standard of care for edentulous patients. Chicago: Quintessence*. *2003*:145–154.

Feine, J., Carlsson, G., Awad, M., Chehade, A., Duncan, W., Gizani, S., Head, T., Lund, J., MacEntee, M. & Mericske-Stern, R. (2002). The McGill consensus statement on overdentures. Mandibular two-implant overdentures as first choice standard of care for edentulous patients. Montreal, Quebec, May 24-25, 2002. *International Journal of Oral and Maxillofacial Implant*. *17*(4):601-602.

Feine, J. & Lund, J. (2006). Measuring chewing ability in randomized controlled trials with edentulous populations wearing implant prostheses. *Journal of Oral Rehabilitation*. *33*(4):301-308.

Felton, D. A. (2009). Edentulism and comorbid factors. *Journal of Prosthodontics*. *18*(2):88-96.

Felton, D. A. (2015). Complete edentulism and comorbid diseases: An update. *Journal of Prosthodontics*. *25*(1):5-20.

Fenlon, M. R. & Sherriff, M. (2004). Investigation of new complete denture quality and patients' satisfaction with and use of dentures after two years. *Journal of Dentistry*. *32*(4):327-333.

Fenlon, M. R., Sherriff, M. & Douglas Walter, J. (2000). An investigation of factors influencing patients' use of new complete dentures using structural equation modeling techniques. *Community Dentistry and Oral Epidemiology*. *28*(2):133-140.

Fiorellini, J. P., Howell, T. H., Cochran, D., Malmquist, J., Lilly, L. C., Spagnoli, D., Toljanic, J., Jones, A. & Nevins, M. (2005). Randomized study evaluating recombinant human bone morphogenetic protein-2 for extraction socket augmentation. *Journal of Periodontology*. *76*(4):605-613.

Fitzig, S., Serfaty, V. & Gazit, E. (1985). Photocclusion technique for simultaneous qualitative and quantitative occlusal contact registration. *Journal of Prosthetic Dentistry*. *53*(3):413-414.

Fitzpatric, R., Davey, C., Buxton, M. & Jones, D. (1998). Evaluating patient based outcome measures for use in clinical trial. *Health Technology Assessment*. *2*(14):1-74.

Fontijn-Tekamp, F., Slagter, A., Van Der Bilt, A., Hof, M. V. T., Witter, D., Kalk, W. & Jansen, J. (2000). Biting and chewing in overdentures, full dentures, and natural dentitions. *Journal of Dental Research*. *79*(7):1519-1524.

Fontijn-Tekampl, E., Slagter, A., Van't Hof, M., Geertman, M. & Kalk, W. (1998). Bite forces with mandibular implant-retained overdentures. *Journal of Dental Research*. *77*(10):1832-1839.

Freihofer, H. P. M. & Hoppenreys, T. J. (1986). Mandibular ridge augmentation by visor osteotomy combined with a subperiosteal rib graft. *Journal of Maxillofacial Surgery*. *14*(6):301-307.

Friberg, B. & Jemt, T. (2015). Rehabilitation of edentulous mandibles by means of osseointegrated implants: A 5-year follow-up study on one or two-stage surgery, number of implants, implant surfaces, and age at surgery. *Clinical Implant Dentistry and Related Research*. *17*(3):413-424.

Fujiki, K., Aoki, K., Marcián, P., Borák, L., Hudieb, M., Ohya, K., Igarashi, Y. & Wakabayashi, N. (2013). The influence of mechanical stimulation on osteoclast localization in the mouse maxilla: Bone histomorphometry and finite element analysis. *Biomechanics and Modeling in Mechanobiology*. *12*(2):325-333.

Fukuda, Y., Nakamura, K. & Takano, T. (2005). Accumulation of health risk behaviours is associated with lower socioeconomic status and women's urban residence: A multilevel analysis in Japan. *BioMed Central Public Health*. *5*(1):53-53.

Gandage Dhananjay, S., Kini Ashwini, Y., Gangadhar, S., Lagdive, S. & Pai, U. Y. (2012). Two-step impression for atrophic mandibular ridge. *Gerodontology*. *29*(2):e1195-e1197.

García, V. G., Cartagena, A. G. & Sequeros, O. G. (1997). Evaluation of occlusal contacts in maximum intercuspation using the t-scan system. *Journal of Oral Rehabilitation*. *24*(12):899-903.

Garg, A. K. (2007). Analyzing dental occlusion for implants: Tekscan's tscan iii. *Dental Implantology Update*. *18*(9):65-70.

Geckili, O., Bilhan, H., Mumcu, E., Dayan, C., Yabul, A. & Tuncer, N. (2012a). Comparison of patient satisfaction, quality of life, and bite force between elderly edentulous patients wearing mandibular two implant-supported overdentures and conventional complete dentures after 4 years. *Special Care in Dentistry*. *32*(4):136-141.

Geckili, O., Bilhan, H., Mumcu, E. & Tuncer, N. (2012b). The influence of maximum bite force on patient satisfaction and quality of life of patients wearing mandibular implant overdentures. *Journal of Oral Implantology*. *38*(3):271-277.

Geng, J.-P., Tan, K. B. & Liu, G.-R. (2001). Application of finite element analysis in implant dentistry: A review of the literature. *Journal of Prosthetic Dentistry*. *85*(6):585-598.

Geng, J., Yan, W. & Xu, W. (2008). Application of the finite element method in implant dentistry. Springer Science & Business Media. Berlin. pp 3–6.

Gibbs, C. H., Mahan, P. E., Lundeen, H. C., Brehnan, K., Walsh, E. K. & Holbrook, W. B. (1981). Occlusal forces during chewing and swallowing as measured by sound transmission. *Journal of Prosthetic Dentistry*. *46*(4):443-449.

Gill, T. M. & Feinstein, A. R. (1994). A critical appraisal of the quality of quality-of-life measurements. *Journal of the American Medical Association*. *272*(8):619-626.

Goel, V. K., Panjabi, M. M., Patwardhan, A. G., Dooris, A. P. & Serhan, H. (2006). Test protocols for evaluation of spinal implants. *The Journal of Bone and Joint Surgery*. *88*(suppl 2):103-109.

Gonda, T., Ikebe, K., Dong, J. & Nokubi, T. (2007). Effect of reinforcement on overdenture strain. *Journal of Dental Research*. *86*(7):667-671.

Gonda, T., Ikebe, K., Ono, T. & Nokubi, T. (2004). Effect of magnetic attachment with stress breaker on lateral stress to abutment tooth under overdenture. *Journal of Oral Rehabilitation*. *31*(10):1001-1006.

Gonda, T., Maeda, Y., Walton, J. N. & MacEntee, M. I. (2010). Fracture incidence in mandibular overdentures retained by one or two implants. *Journal of Prosthetic Dentistry*. *103*(3):178-181.

Gonzalez Sequeros, O., García, V. G. & Cartagena, A. G. (1997). Study of occlusal contact variability within individuals in a position of maximum intercuspation using the t-scan system. *Journal of Oral Rehabilitation*. *24*(4):287-290.

Goodacre, C. J., Bernal, G., Rungcharassaeng, K. & Kan, J. Y. (2003). Clinical complications with implants and implant prostheses. *Journal of Prosthetic Dentistry*. *90*(2):121-132.

Gotfredsen, K. & Holm, B. (2000). Implant-supported mandibular overdentures retained with ball or bar attachments: A randomized prospective 5-year study. *International Journal of Prosthodontics*. *13*(2):125-130.

Gracht, I., Derks, A., Haselhuhn, K. & Wolfart, S. (2017). Emg correlations of edentulous patients with implant overdentures and fixed dental prostheses compared to conventional complete dentures and dentates: A systematic review and meta-analysis. *Clinical Oral Implants Research*. *28*(7):765-773.

Group, T. W. (1995). The world health organization quality of life assessment (whoqol): Position paper from the world health organization. *Social Science and Medicine*. *41*(10):1403-1409.

Güler, A., Sumer, M., Sumer, P. & Biçer, I. (2005). The evaluation of vertical heights of maxillary and mandibular bones and the location of anatomic landmarks in panoramic radiographs of edentulous patients for implant dentistry. *Journal of Oral Rehabilitation*. *32*(10):741-746.

Gulizio, M. P., Agar, J. R., Kelly, J. R. & Taylor, T. D. (2005). Effect of implant angulation upon retention of overdenture attachments. *Journal of Prosthodontics*. *14*(1):3-11.

Hama, Y., Kanazawa, M., Minakuchi, S., Uchida, T. & Sasaki, Y. (2014). Reliability and validity of a quantitative color scale to evaluate masticatory performance using color-changeable chewing gum. *Journal of Medical and Dental Sciences*. *61*(1):1-6.

Harrel, S. K. & Nunn, M. E. (2001). The effect of occlusal discrepancies on periodontitis. Ii. Relationship of occlusal treatment to the progression of periodontal disease. *Journal of Periodontology*. *72*(4):495-505.

Harvey, W. L., Hatch, R. A. & Osborne, J. W. (1991). Computerized occlusal analysis: An evaluation of the sensors. *Journal of Prosthetic Dentistry*. *65*(1):89-92.

Hayakawa, I., Watanabe, I., Hirano, S., Nagao, M. & Seki, T. (1998). A simple method for evaluating masticatory performance using a color-changeable chewing gum. *International Journal of Prosthodontics*. *11*(2):173-176.

Health U. D. O. & H., S. (2006). Oral health in America: A report of the surgeon general, Rockville, MD: US Department of Health and Human Services, National Institute of Dental and Craniofacial Research, National Institutes of Health; 2000.no 00-4713.

Heckmann, S. M., Schrott, A., Graef, F., Wichmann, M. G. & Weber, H. P. (2004). Mandibular two-implant telescopic overdentures. *Clinical Oral Implants Research*. *15*(5):560-569.

Heckmann, S. M., Wichmann, M. G., Winter, W., Meyer, M. & Weber, H. P. (2001). Overdenture attachment selection and the loading of implant and denture-bearing area. Part 2: A methodical study using five types of attachment. *Clinical Oral Implants Research*. *12*(6):640-647.

Heydecke, G., Locker, D., Awad, M. A., Lund, J. P. & Feine, J. S. (2003). Oral and general health-related quality of life with conventional and implant dentures. *Community Dentistry and Oral Epidemiology*. *31*(3):161-168.

Hidaka, O., Iwasaki, M., Saito, M. & Morimoto, T. (1999). Influence of clenching intensity on bite force balance, occlusal contact area, and average bite pressure. *Journal of Dental Research*. *78*(7):1336-1344.

Hillis, W. D. (1982). A high-resolution imaging touch sensor. *International Journal of Robotics Research*. *1*(2):33-44.

Hjørting-Hansen, E., Laney, W., Broggini, N., Buser, D., Cochran, D., Garcia, L., Giannobile, W. & Taylor, T. (2007). Glossary of oral and maxillofacial implants. Quintessence Publishing Ltd.

Hoffmann, O., Beaumont, C., Tatakis, D. N. & Zafiropoulos, G.-G. (2006). Telescopic crowns as attachments for implant supported restorations: A case series. *Journal of Oral Implantology*. *32*(6):291-299.

Humphrey, L. T. & Bocaege, E. (2008). Tooth evulsion in the Maghreb: Chronological and geographical patterns. *African Archaeological Review*. *25*(1-2):109.

Humphries, S., Devlin, H. & Worthington, H. (1989). A radiographic investigation into bone resorption of mandibular alveolar bone in elderly edentulous adults. *Journal of Dentistry*. *17*(2):94-96.

Huumonen, S., Haikola, B., Oikarinen, K., Söderholm, A. L., Remes-Lyly, T. & Sipilä, K. (2012). Residual ridge resorption, lower denture stability and subjective complaints among edentulous individuals. *Journal of Oral Rehabilitation*. *39*(5):384-390.

Ichikawa, T., Horiuchi, M., Wigianto, R. & Matsumoto, N. (1996). In vitro study of mandibular implant-retained overdentures: The influence of stud attachments on load transfer to the implant and soft tissue. *International Journal of Prosthodontics*. *9*(4):394-399.

Ishikawa, Y., Watanabe, I., Hayakawa, I., Minakuchi, S. & Uchida, T. (2007). Evaluations of masticatory performance of complete denture wearers using color-changeable chewing gum and other evaluating methods. *Journal of Medical and Dental Sciences*. *54*(1):65-70.

Isidor, F. (1997). Histological evaluation of peri-implant bone at implants subjected to occlusal overload or plaque accumulation. *Clinical Oral Implants Research*. *8*(1):1-9.

Islas-Granillo, H., Borges-Yañez, A., Medina-Solis, C. E., Lucas-Rincón, S. E., de Jesús Navarrete-Hernández, J., Villalobos-Rodelo, J. J., Casanova-Rosado, J. F. & Maupomé, G. (2016). Tooth-loss experience and associated variables among adult mexicans 60 years and older. *Puerto Rico Health Sciences Journal*. *35*(2):88-92.

Iversen, M. M., Graue, M., Leksell, J., Smide, B., Zoffmann, V. & Sigurdardottir, A. K. (2016). Characteristics of nursing studies in diabetes research published over three decades in Sweden, Norway, Denmark, and Iceland: A narrative review of the literature. *Scandinavian Journal of Caring Sciences*. *30*(2):241-249.

Jabbour, Z., Emami, E., Grandmont, P., Rompre, P. & Feine, J. (2012). Is oral health-related quality of life stable following rehabilitation with mandibular two-implant overdentures? *Clinical Oral Implants Research*. *23*(10):1205-1209.

Jacobs, R., Mraiwa, N., van Steenberghe, D., Sanderink, G. & Quirynen, M. (2004). Appearance of the mandibular incisive canal on panoramic radiographs. *Surgical and Radiologic Anatomy*. *26*(4):329-333.

Jacobs, R., Schotte, A., Van Steenberghe, D., Quirynen, M. & Naert, I. (1992). Posterior jaw bone resorption in osseointegrated implant-supported overdentures. *Clinical Oral Implants Research*. *3*(2):63-70.

Jacobs, R., van Steenberghe, D., Nys, M. & Naert, I. (1993). Maxillary bone resorption in patients with mandibular implant-supported overdentures or fixed prostheses. *Journal of Prosthetic Dentistry*. *70*(2):135-140.

Jaul, D. H., McNamara, J. A., Carlson, D. S. & Upton, L. G. (1980). A cephalometric evaluation of edentulous rhesus monkeys (macaca mulatta): A long-term study. *Journal of Prosthetic Dentistry*. *44*(4):453-460.

Jivraj, S., Chee, W. & Corrado, P. (2006). Treatment planning of the edentulous maxilla. *British Dental Journal*. *201*(5):261-279.

Johns, R. B., Jemt, T., Heath, M. R., Hutton, J. E., McKenna, S., McNamara, D. C., van Steenberghe, D., Taylor, R., Watson, R. M. & Herrmann, I. (1992). A multicenter study of overdentures supported by brånemark implants. *International Journal of Oral and Maxillofacial Implant*. *7*(4):98-114.

Johnson, W. (1965). A study of stress distribution in complete upper dentures. *Dental Practice*. *15*:374-379.

Jonkman, R. E., van Waas, M. A., Plooij, J. & Kalk, W. (1991). Measuring mandibular ridge reduction on oblique cephalometric radiographs. *Journal of Cranio-Maxillofacial Surgery*. *19*(1):27-30.

Kamiyama, M., Kanazawa, M., Fujinami, Y. & Minakuchi, S. (2010). Validity and reliability of a self-implementable method to evaluate masticatory performance: Use of color-changeable chewing gum and a color scale. *Journal of Prosthodontic Research*. *54*(1):24-28.

Kassebaum, N., Bernabé, E., Dahiya, M., Bhandari, B., Murray, C. & Marcenes, W. (2014). Global burden of severe tooth loss: A systematic review and meta-analysis. *Journal of Dental Research*. *93*(7-s):20s-28s.

Kawano, F., Koran III, A., Asaoka, K. & Matsumoto, N. (1993). Effect of soft denture liner on stress distribution in supporting structures under a denture. *International Journal of Prosthodontics*. *6*(1):43-49.

Keller, U. & Haase, C. (1991). Care of edentulous mandible with implant stabilized telescope complete denture. *ZWR*. *100*(9):640-644, 646-647.

Kelly, E. (1972). Changes caused by a mandibular removable partial denture opposing a maxillary complete denture. *Journal of Prosthetic Dentistry*. *27*(2):140-150.

Kerstein, A. D. R. (2011). Healthy and harmonized function via computer-guided occlusal force management. *Cosmetic Dentistry*. *5*:6-12.

Kerstein, R. (2007). Computerized occlusal analysis technology and cerec case finishing. *International Journal of Computerized Dentistry*. *11*(1):51-63.

Kerstein, R. (2008). Articulating paper mark misconceptions and computerized occlusal analysis technology. *Dental Implantology Update*. *19*(6):41-46.

Kerstein, R. B. (2004). Combining technologies: A computerized occlusal analysis system synchronized with a computerized electromyography system. *Journal of Craniomandibular Practice*. *22*(2):96-109.

Kerstein, R. B. (2015). History of the t-scan system development from 1984 to the present day. Handbook of research on computerized occlusal analysis technology applications in dental medicine. IGI Global.1-35.

Kerstein, R. B. & Grundset, K. (2001). Obtaining measurable bilateral simultaneous occlusal contacts with computer-analyzed and guided occlusal adjustments. *Quintessence International*. *32*(1):7-18.

Kerstein, R. B. & Radke, J. (2006). The effect of disclusion time reduction on maximal clench muscle activity levels. *Journal of Craniomandibular Practice*. *24*(3):156-165.

Kerstein, R. B., Thumati, P. & Padmaja, S. (2013). Force finishing and centering to balance a removable complete denture prosthesis using the t-scan iii computerized occlusal analysis system. *Journal of Indian Prosthodontic Society*. *13*(3):184-188.

Keyak, J. H. & Falkinstein, Y. (2003). Comparison of in situ and in vitro CT scan-based finite element model predictions of proximal femoral fracture load. *Medical Engineering and Physics*. *25*(9):781-787.

Khalid, T., Yunus, N., Ibrahim, N., Elkezza, A. & Masood, M. (2016). Patient-reported outcome and its association with attachment type and bone volume in mandibular implant overdenture. *Clinical Oral Implants Research*. *28*(5):535-542.

Khalifa, A. K., Wada, M., Ikebe, K. & Maeda, Y. (2016). To what extent residual alveolar ridge can be preserved by implant? A systematic review. *International Journal of Implant Dentistry*. *2*(1):1-9.

Kim, Y., Oh, T. J., Misch, C. E. & Wang, H. L. (2005). Occlusal considerations in implant therapy: Clinical guidelines with biomechanical rationale. *Clinical Oral Implants Research*. *16*(1):26-35.

Kleis, W. K., Kämmerer, P. W., Hartmann, S., Al-Nawas, B. & Wagner, W. (2010). A comparison of three different attachment systems for mandibular two-implant overdentures: One-year report. *Clinical Implant Dentistry and Related Research*. *12*(3):209-218.

Klemetti, E., Lassila, L. & Lassila, V. (1996). Biometric design of complete dentures related to residual ridge resorption. *Journal of Prosthetic Dentistry*. *75*(3):281-284.

Klemetti, E. & Vainio, P. (1993). Effect of bone mineral density in skeleton and mandible on extraction of teeth and clinical alveolar height. *Journal of Prosthetic Dentistry*. *70*(1):21-25.

Koc, D., Dogan, A. & Bek, B. (2010). Bite force and influential factors on bite force measurements: A literature review. *European Journal of Dentistry*. *4*(2):223–232.

Kohavi, D. (1993). Complications in the tissue integrated prostheses components: Clinical and mechanical evaluation. *Journal of Oral Rehabilitation*. *20*(4):413-422.

Kong, C. V., Yang, Y. & Maness, W. (1991). Clinical evaluation of three occlusal registration methods for guided closure contacts. *Journal of Prosthetic Dentistry*. *66*(1):15-20.

Koos, B., Godt, A., Schille, C. & Göz, G. (2010). Precision of an instrumentation-based method of analyzing occlusion and its resulting distribution of forces in the dental arch. *Journal of Orofacial Orthopedics*. *71*(6):403-410.

Koos, B., Höller, J., Schille, C. & Godt, A. (2012). Time-dependent analysis and representation of force distribution and occlusion contact in the masticatory cycle. *Journal of Orofacial Orthopedics*. *73*(3):204-214.

Koran, A. & Craig, R. (1974). Three-dimensional photo-elastic stress analysis of maxillary and mandibular complete dentures. *Journal of Oral Rehabilitation*. *1*(4):361-369.

Kordatzis, K., Wright, P. S. & Meijer, H. J. (2003). Posterior mandibular residual ridge resorption in patients with conventional dentures and implant overdentures. *International Journal of Oral and Maxillofacial Implant*. *18*(3):447-452.

Korioth, T. & Versluis, A. (1997). Modeling the mechanical behavior of the jaws and their related structures by finite element (FE) analysis. *Critical Reviews in Oral Biology and Medicine*. *8*(1):90-104.

Kreisler, M., Behneke, N., Behneke, A. & d'Hoedt, B. (2003). Residual ridge resorption in the edentulous maxilla in patients with implant-supported mandibular overdentures: An 8-year retrospective study. *International Journal of Prosthodontics*. *16*(3):295-300.

Kreisler, M., Schulze, R., Schalldach, F., d'Hoedt, B., Behneke, A. & Behneke, N. (2000). A new method for the radiological investigation of residual ridge resorption in the maxilla. *Dento Maxillo Facial Radiology*. *29*(6):368-375.

Krennmair, G., Seemann, R., Weinländer, M. & Piehslinger, E. (2011). Comparison of ball and telescopic crown attachments in implant-retained mandibular overdentures: A 5-year prospective study. *International Journal of Oral and Maxillofacial Implant*. *26*(3):598-606.

Kribbs, P. J. (1990). Comparison of mandibular bone in normal and osteoporotic women. *Journal of Prosthetic Dentistry*. *63*(2):218-222.

Krustrup, U. & Petersen, P. E. (2007). Dental caries prevalence among adults in Denmark-the impact of socio-demographic factors and use of oral health services. *Community Dental Health*. *24*(4):225-232.

Kubota, H. (1959). The relation between the position of artificial teeth and the alveolar crest in dentures. *Shikwa Gakuho*. *59*:377-384.

Kumagai, H., Suzuki, T., Hamada, T., Sondang, P., Fujitani, M. & Nikawa, H. (1999). Occlusal force distribution on the dental arch during various levels of clenching. *Journal of Oral Rehabilitation*. *26*(12):932-935.

Kumar, T. A., Naeem, A., Verma, A., Mariyam, A., Krishna, D. & Kumar, P. K. (2016). Residual ridge resorption: The unstoppable. *Indian Journal of Applied Research*. *2*(2):169-171.

Kuoppala, R., Näpänkangas, R. & Raustia, A. (2013). Quality of life of patients treated with implant-supported mandibular overdentures evaluated with the oral health impact profile (OHIP-14): A survey of 58 patients. *Journal of Oral and Maxillofacial Research*. *4*(2):e4 doi:10.5037/jomr.2013.4204.

Lamb, D., Ellis, B. & Van Noort, R. (1985). The fracture topography of acrylic dentures broken in service. *Biomaterials*. *6*(2):110-112.

Lambrecht, J. R. & Kydd, W. L. (1962). A functional stress analysis of the maxillary complete denture base. *Journal of Prosthetic Dentistry*. *12*(5):865-872.

Langer, Y. & Langer, A. (1991). Root-retained overdentures: Part I-biomechanical and clinical aspects. *Journal of Prosthetic Dentistry*. *66*(6):784-789.

Langer, Y., Langer, A. & Maurice, T. (2000). Tooth-supported telescopic prostheses in compromised dentitions: A clinical report. *Journal of Prosthetic Dentistry*. *84*(2):129-132.

Lassila, V., Holmlund, I. & Koivumaa, K. K. (1985). Bite force and its correlations in different denture types. *Acta Odontologica Scandinavica*. *43*(3):127-132.

Laurell, L., Hugoson, A., Håkansson, J., Pettersson, B., Sjöström, L., Berglöf, F. & Berglöf, K. (1989). General oral status in adults with rheumatoid arthritis. *Community Dentistry and Oral Epidemiology*. *17*(5):230-233.

Laurina, L. & Soboleva, U. (2006). Construction faults associated with complete denture wearers' complaints. *Stomatologija*. *8*(2):61-64.

Lechner, S. & Roessler, D. (2001). Strategies for complete denture success: Beyond technical excellence. *Compendium of Continuing Education in Dentistry (Jamesburg, NJ: 1995)*. *22*(7):553-559; quiz 560.

Lee, S., Lee, S., Huh, K., Yi, W., Heo, M. & Choi, S. (2012). The effects of location of alveolar crest on the vertical bone heights on panoramic radiographs. *Dentomaxillofacial Radiology*. *41*(2):117.

Lekovic, V., Camargo, P. M., Klokkevold, P. R., Weinlaender, M., Kenney, E. B., Dimitrijevic, B. & Nedic, M. (1998). Preservation of alveolar bone in extraction sockets using bioabsorbable membranes. *Journal of Periodontology*. *69*(9):1044-1049.

Li, W., Lin, D., Rungsiyakull, C., Zhou, S., Swain, M. & Li, Q. (2011). Finite element based bone remodeling and resonance frequency analysis for osseointegration assessment of dental implants. *Finite Elements in Analysis and Design*. *47*(8):898-905.

Liedberg, B. & Öwall, B. (1995). Oral bolus kneading and shaping measured with chewing gum. *Dysphagia*. *10*(2):101-106.

Liu, J., Pan, S., Dong, J., Mo, Z., Fan, Y. & Feng, H. (2013). Influence of implant number on the biomechanical behaviour of mandibular implant-retained/supported overdentures: A three-dimensional finite element analysis. *Journal of Dentistry*. *41*(3):241-249.

Liu, S., Liu, Y., Xu, J., Rong, Q. & Pan, S. (2014). Influence of occlusal contact and cusp inclination on the biomechanical character of a maxillary premolar: A finite element analysis. *Journal of Prosthetic Dentistry*. *112*(5):1238-1245.

Locker, D. (1988). Measuring oral health: A conceptual framework. *Community Dental Health*. *5*(1):3-18.

Locker, D. (2009). Self-esteem and socioeconomic disparities in self-perceived oral health. *Journal of Public Health Dentistry*. *69*(1):1-8.

Locker, D. & Allen, P. F. (2002). Developing short-form measures of oral health-related quality of life. *Journal of Public Health Dentistry*. *62*(1):13-20.

Locker, D. & Millar, W. J. (2005). Edentulism and denture use. *Health Reports*. *17*(1):55.

Madléna, M., Hermann, P., Jáhn, M. & Fejérdy, P. (2008). Caries prevalence and tooth loss in Hungarian adult population: Results of a national survey. *BioMed Central Public Health*. *8*(1):364.

Maeda, Y., Sogo, M. & Tsutsumi, S. (2005). Efficacy of a posterior implant support for extra shortened dental arches: A biomechanical model analysis. *Journal of Oral Rehabilitation*. *32*(9):656-660.

Maeda, Y., Tsutsumi, S., Okada, M., Ishii, K., Nokubi, T. & Okuno, Y. (1986). Rebase and stress distribution in maxillary complete denture patients. *Journal of Osaka University Dental School*. *26*:113-122.

Maeda, Y. & Wood, W. (1989). Finite element method simulation of bone resorption beneath a complete denture. *Journal of Dental Research*. *68*(9):1370-1373.

Majumder, S., Roychowdhury, A. & Pal, S. (2005). Biomechanical analysis of human pelvis under muscolo-skeletal load using 3d finite element method. *International Journal of Applied Mechanics and Engineering*. *10*(4):647-665.

Maness, W. (1987a). Computerized occlusal analysis: A new technology. *Quintessence International*. *18*:287-292.

Maness, W. L. (1987b). Computerized occlusal analysis: A new technology. *Quintessence International*. *18*:287-292.

Maness, W. L. & Podoloff, R. (1989). Distribution of occlusal contacts in maximum intercuspation. *Journal of Prosthetic Dentistry*. *62*(2):238-242.

Manly, R. S. & Braley, L. C. (1950). Masticatory performance and efficiency. *Journal of Dental Research*. *29*(4):448-462.

Marinescu, R., Daegling, D. J. & Rapoff, A. J. (2005). Finite-element modeling of the anthropoid mandible: The effects of altered boundary conditions. *Anatomical*

Record Part A: Discoveries in Molecular, Cellular, and Evolutionary Biology. *283*(2):300-309.

Maruo, Y., Nishigawa, G., Irie, M., Oka, M., Hara, T., Suzuki, K. & Minagi, S. (2010). Stress distribution prevents ischaemia and bone resorption in residual ridge. *Archives of Oral Biology*. *55*(11):873-878.

Matsui, Y., Ohno, K., Michi, K., Hata, H., Yamagata, K. & Ohtsuka, S. (1996). The evaluation of masticatory function with low adhesive color-developing chewing gum. *Journal of Oral Rehabilitation*. *23*(4):251-256.

Matthews, E. & Wain, E. (1956). Stresses in denture bases. *British Dental Journal*. *100*(7):167-171.

McCarthy, C., Patel, R., Wragg, P. & Brook, I. (2003). Dental implants and onlay bone grafts in the anterior maxilla: Analysis of clinical outcome. *International Journal of Oral and Maxillofacial Implant*. *18*(2):238.

McCord, J. (2000). Impression making. *British Dental Journal*. *188*(09):484.

McGivney, G. P., Haughton, V., Strandt, J. A., Eichholz, J. & Lubar, D. (1986). A comparison of computer-assisted tomography and data-gathering modalities in prosthodontics. *International Journal of Oral and Maxillofacial Implant*. *1*(1):55-68.

Medina-Solís, C. E., Pérez-Núñez, R., Maupomé, G. & Casanova-Rosado, J. F. (2006). Edentulism among Mexican adults aged 35 years and older and associated factors. *American Journal of Public Health*. *96*(9):1578-1581.

Meijer, H. J., Raghoebar, G. M., Van't Hof, M. A., Geertman, M. E. & Van Oort, R. P. (1999). Implant-retained mandibular overdentures compared with complete dentures; a 5-years' follow-up study of clinical aspects and patient satisfaction. *Clinical Oral Implants Research*. *10*(3):238-244.

Mendes, D. C., de Oliveira Poswar, F., de Oliveira, M. V. M., Haikal, D. S., da Silveira, M. F., de Barros Lima Martins, A. M. & De Paula, A. M. B. (2012). Analysis of socio-demographic and systemic health factors and the normative conditions of oral health care in a population of the Brazilian elderly. *Gerodontology*. *29*(2):e206-e214.

Menicucci, G., Mossolov, A., Mozzati, M., Lorenzetti, M. & Preti, G. (2002). Tooth–implant connection: Some biomechanical aspects based on finite element analyses. *Clinical Oral Implants Research*. *13*(3):334-341.

Mercado, F., Marshall, R. I., Klestov, A. & Bartold, P. (2001). Relationship between rheumatoid arthritis and periodontitis. *Journal of Periodontology*. *72*(6):779-787.

Mercier, P. & Lafontant, R. (1979). Residual alveolar ridge atrophy: Classification and influence of facial morphology. *Journal of Prosthetic Dentistry*. *41*(1):90-100.

Merdji, A., Bouiadjra, B. B., Achour, T., Serier, B., Chikh, B. O. & Feng, Z. (2010). Stress analysis in dental prosthesis. *Computational Materials Science*. *49*(1):126-133.

Merickske-Stern, R. (1990). Clinical evaluation of overdenture restorations supported by osseointegrated titanium implants: A retrospective study. *International Journal of Oral and Maxillofacial Implant*. *5*(4):375-383.

Mericske-Stern, R. (2003). Prosthodontic management of maxillary and mandibular overdentures. *Implant Overdentures: The Standard of Care for Edentulous Patients. Chicago, IL: Quintessence Pub. Co*.pp83-98.

Mericske-Stern, R., Hofmann, J., Wedig, A. & Geering, A. H. (1993). In vivo measurements of maximal occlusal force and minimal pressure threshold on overdentures supported by implants or natural roots: A comparative study, part 1. *International Journal of Oral and Maxillofacial Implant*. *8*(6):641-649.

Millar, W. J. & Locker, D. (2007). Smoking and oral health status. *Journal of the Canadian Dental Association*. *73*(2):155-162.

Millstein, P. & Maya, A. (2001). An evaluation of occlusal contact marking indicators: A descriptive quantitative method. *Journal of the American Dental Association*. *132*(9):1280-1286.

Millstein, P. L. (1985). An evaluation of occlusal indicator wax. *Journal of Prosthetic Dentistry*. *53*(4):570-572.

Miura, H., Watanabe, S., Isogai, E. & Miura, K. (2001). Comparison of maximum bite force and dentate status between healthy and frail elderly persons. *Journal of Oral Rehabilitation*. *28*(6):592-595.

Moini, M. R. & Neff, P. A. (1991). Reproducibility of occlusal contacts utilizing a computerized instrument. *Quintessence International*. *22*(5):357-360.

Molligoda, M., Berry, D. & Gooding, P. (1986). Measuring diurnal variations in occlusal contact areas. *Journal of Prosthetic Dentistry*. *56*(4):487-492.

Morra, E. A. & Greenwald, A. S. (2005). Polymer insert stress in total knee designs during high-flexion activities: A finite element study. *Journal of Bone and Joint Surgery*. *87*(s2):120-124.

Muddugangadhar, B., Amarnath, G., Sonika, R., Chheda, P. S. & Garg, A. (2015). Meta-analysis of failure and survival rate of implant-supported single crowns, fixed partial denture, and implant tooth-supported prostheses. *Journal of International Oral Health*. *7*(9):11-17.

Murray, M., Smith, P., Watts, D. & Wilson, N. (1999). Occlusal registration: Science or art? *International Dental Journal*. *49*(1):41-46.

Naert, I., Gizani, S., Vuylsteke, M. & Van Steenberghe, D. (1998). A 5-year randomized clinical trial on the influence of splinted and unsplinted oral implants in the mandibular overdenture therapy. Part i: Peri-implant outcome. *Clinical Oral Implants Research*. *9*(3):170-177.

Närhi, T. O., Geertman, M. E., Hevinga, M., Abdo, H., Kalk, W., Nijmegen, T. N., of Groningen, U. & Groningen, T. N. (2000). Changes in the edentulous maxilla in persons wearing implant-retained mandibular overdentures. *Journal of Prosthetic Dentistry*. *84*(1):43-49.

Narva, K. K., Lassila, L. V. & Vallittu, P. K. (2005). Flexural fatigue of denture base polymer with fiber-reinforced composite reinforcement. *Composites Part A: Applied Science and Manufacturing*. *36*(9):1275-1281.

Narva, K. K., Vallittu, P. K., Helenius, H. & Yli-Urpo, A. (2001). Clinical survey of acrylic resin removable denture repairs with glass-fiber reinforcement. *International Journal of Prosthodontics*. *14*(3):219-224.

Nelsen, K., Tayles, N. & Domett, K. (2001). Missing lateral incisors in iron age south-east Asians as possible indicators of dental agenesis. *Archives of Oral Biology*. *46*(10):963-971.

Newton, J., Yemm, R., Abel, R. & Menhinick, S. (1993). Changes in human jaw muscles with age and dental state. *Gerodontology*. *10*(1):16-22.

Nguyen, K., Rincon, J. & Bickel, M. (2007). Association of strong premature contacts and tooth mobility using t-scan. *Australian Dental Journal*. *52*(s4):49-49.

Nishimura, I., Hosokawa, R. & Atwood, D. A. (1992). The knive-edge tendency in mandibular residual ridges in women. *Journal of Prosthetic Dentistry*. *67*(6):820-826.

Obeid, A., Stafford, G. & Bates, J. (1982). Clinical studies of strain behaviour of complete dentures. *Journal of Biomedical Engineering*. *4*(1):49-54.

Ohashi, M., Woelfel, J. B. & Paffenbarger, G. C. (1966). Pressures exerted on complete dentures during swallowing. *The Journal of the American Dental Association*. *73*(3):625-630.

Okiyama, S., Ikebe, K. & Nokubi, T. (2003). Association between masticatory performance and maximal occlusal force in young men. *Journal of Oral Rehabilitation*. *30*(3):278-282.

Olivieri, F., Kang, K.-h., Hirayama, H. & Maness, W. L. (1998). New method for analyzing complete denture occlusion using the center of force concept: A clinical report. *Journal of Prosthetic Dentistry*. *80*(5):519-523.

Olthoff, L., Van Der Bilt, A., Bosman, F. & Kleizen, H. (1984). Distribution of particle sizes in food comminuted by human mastication. *Archives of Oral Biology*. *29*(11):899-903.

Oprea, B., Cernusca-Mitariu, S., Dragomir, R., Boitan, M., Fleacă, R. & Cernuşcă-Miţariu, M. (2014). Computer assistance harnessed in modern dentistry treatments. *Acta Medica Transilvanica*. *19*(2):298-301.

Oral Health Division, M. o. H. M. (2011). National oral health plan for Malaysia 2011-2020.1-29.

Oshida, Y., Miyazaki, M., Osman, H. & Xirouchaki, L. (1994). Development of photo-sensing bulge ductility tester. *Bio-Medical Materials and Engineering*. *5*(2):125-139.

Österberg, T., Dey, D. K., Sundh, V., Carlsson, G. E., Jansson, J.-O. & Mellström, D. (2010). Edentulism associated with obesity: A study of four national surveys of 16 416 Swedes aged 55–84 years. *Acta Odontologica Scandinavica*. *68*(6):360-367.

Özdemir, A. K., Özdemir, H. D., Polat, N. T., Turgut, M. & Sezer, H. (2006). The effect of personality type on denture satisfaction. *International Journal of Prosthodontics*. *19*(4):364-370.

Pan, S., Awad, M., Thomason, J. M., Dufresne, E., Kobayashi, T., Kimoto, S., Wollin, S. D. & Feine, J. S. (2008). Sex differences in denture satisfaction. *Journal of Dentistry*. *36*(5):301-308.

Pan, S., Dagenais, M., Thomason, J. M., Awad, M., Emami, E., Kimoto, S., Wollin, S. D. & Feine, J. S. (2010). Does mandibular edentulous bone height affect prosthetic treatment success? *Journal of Dentistry*. *38*(11):899-907.

Panchbhai, A. S. (2013). Quantitative estimation of vertical heights of maxillary and mandibular jawbones in elderly dentate and edentulous subjects. *Special Care in Dentistry*. *33*(2):62-69.

Panigrahi, D., Satpathy, A., Patil, A. & Patel, G. (2015). Occlusion and occlusal indicating materials. *International Journal of Applied Dental Sciences*. *1*(4):23-26.

Pasciuta, M., Grossmann, Y. & Finger, I. M. (2005). A prosthetic solution to restoring the edentulous mandible with limited interarch space using an implant-tissue-supported overdenture: A clinical report. *Journal of Prosthetic Dentistry*. *93*(2):116-120.

Patyk, A., Lotzmann, U., Scherer, C. & Kobes, L. (1989). Comparative analytic occlusal study of clinical use of t-scan systems. *98*(9):752-755.

Pellizzer, E. P., Verri, F. R., Falcón-Antenucci, R. M., Goiato, M. C. & Gennari Filho, H. (2010). Evaluation of different retention systems on a distal extension removable partial denture associated with an osseointegrated implant. *Journal of Craniofacial Surgery*. *21*(3):727-734.

Peltzer, K., Hewlett, S., Yawson, A. E., Moynihan, P., Preet, R., Wu, F., Guo, G., Arokiasamy, P., Snodgrass, J. J. & Chatterji, S. (2014). Prevalence of loss of all teeth (edentulism) and associated factors in older adults in China, Ghana, India, Mexico, Russia and South Africa. *International Journal of Environmental Research and Public Health*. *11*(11):11308-11324.

Pera, P., Bassi, F., Schierano, G., Appendino, P. & Preti, G. (1998). Implant anchored complete mandibular denture: Evaluation of masticatory efficiency, oral function and degree of satisfaction. *Journal of Oral Rehabilitation*. *25*(6):462-467.

Pjetursson, B. E., Thoma, D., Jung, R., Zwahlen, M. & Zembic, A. (2012). A systematic review of the survival and complication rates of implant-supported fixed dental prostheses (fdps) after a mean observation period of at least 5 years. *Clinical Oral Implants Research*. *23*(s6):22-38.

Poggie, R. A., Turgeon, T. R. & Coutts, R. D. (2007). Failure analysis of a ceramic bearing acetabular component. *Journal of Bone and Joint Surgery*. *89*(2):367-375.

Porter Jr, J. A., Petropoulos, V. C. & Brunski, J. B. (2002). Comparison of load distribution for implant overdenture attachments. *International Journal of Oral and Maxillofacial Implant*. *17*(5):651-662.

Prombonas, A. E. & Vlissidis, D. S. (2006). Comparison of the midline stress fields in maxillary and mandibular complete dentures: A pilot study. *Journal of Prosthetic Dentistry*. *95*(1):63-70.

Purbrick, J. A. (1981). A force transducer employing conductive silicone rubber. *Proceedings of the 1st International Conference on Robot Vision and Sensory Controls*.73-80.

Rees, J., Huggett, R. & Harrison, A. (1990). Finite element analysis of the stress-concentrating effect of fraenal notches in complete dentures. *International Journal of Prosthodontics*. *3*(3):238-240.

Regli, C. P. & Gaskill, H. L. (1954). Denture base deformation during function. *Journal of Prosthetic Dentistry*. *4*(4):548-554.

Regli, C. P. & Kydd, W. L. (1953). A preliminary study of the lateral deformation of metal base dentures in relation to plastic base dentures. *Journal of Prosthetic Dentistry*. *3*(3):326-330.

Reiber, T., Fuhr, K., Hartmann, H. & Leicher, D. (1989). Recording pattern of occlusal indicators. I. Influence of indicator thickness, pressure, and surface morphology. *Deutsche Zahnarztliche Zeitschrift*. *44*(2):90-93.

Reisine, S. T. (1988). The impact of dental conditions on social functioning and the quality of life. *Annual Review of Public Health*. *9*(1):1-19.

Renvert, S., Persson, R. E. & Persson, G. R. (2013). Tooth loss and periodontitis in older individuals: Results from the Swedish national study on aging and care. *Journal of Periodontology*. *84*(8):1134-1144.

Ribeiro, M. T. F., Rosa, M. A. C. d., Lima, R. M. N. d., Vargas, A. M. D., Haddad, J. P. A. & Ferreira e Ferreira, E. (2011). Edentulism and shortened dental arch in Brazilian elderly from the national survey of oral health 2003. *Revista de Saúde Pública*. *45*(5):817-823.

Rieger, M., Mayberry, M. & Brose, M. (1990). Finite element analysis of six endosseous implants. *Journal of Prosthetic Dentistry*. *63*(6):671-676.

Rismanchian, M., Bajoghli, F., Mostajeran, Z., Fazel, A. & Eshkevari, P. (2009). Effect of implants on maximum bite force in edentulous patients. *Journal of Oral Implantology*. *35*(4):196-200.

Roccia, F., Diaspro, A., Nasi, A. & Berrone, S. (2008). Management of sport-related maxillofacial injuries. *Journal of Craniofacial Surgery*. *19*(2):377-382.

Russell, S. L., Gordon, S., Lukacs, J. R. & Kaste, L. M. (2013). Sex/gender differences in tooth loss and edentulism. *Dental Clinics*. *57*(2):317-337.

Rutkunas, V., Mizutani, H., Peciuliene, V., Bendinskaite, R. & Linkevicius, T. (2008). Maxillary complete denture outcome with two-implant supported mandibular overdentures. A systematic review. *Stomatologija*. *10*(1):10-15.

Sadamori, S., Kotani, H., Abekura, H. & Hamada, T. (2007). Quantitative analysis of occlusal force balance in intercuspal position using the dental prescale system in patients with temporomandibular disorders. *International China Journal Dentistry*. *7*:43-47.

Sağlam, A. (2002). The vertical heights of maxillary and mandibular bones in panoramic radiographs of dentate and edentulous subjects. *Quintessence International*. *33*(6):433-438.

Salvador, M. C. G., Valle, A. L. d., Ribeiro, M. C. M. & Pereira, J. R. (2007). Assessment of the prevalence index on signs of combination syndrome in patients treated at Bauru school of dentistry, University of Sao Paulo. *Journal of Applied Oral Science*. *15*(1):9-13.

Saraçoğlu, A. & Özpinar, B. (2002). In vivo and in vitro evaluation of occlusal indicator sensitivity. *Journal of Prosthetic Dentistry*. *88*(5):522-526.

Sato, S., Fueki, K., Sato, H., Sueda, S., Shiozaki, T., Kato, M. & Ohyama, T. (2003). Validity and reliability of a newly developed method for evaluating masticatory function using discriminant analysis. *Journal of Oral Rehabilitation*. *30*(2):146-151.

Saub, R., Locker, D. & Allison, P. (2005). Derivation and validation of the short version of the Malaysian oral health impact profile. *Community Dentistry and Oral Epidemiology*. *33*(5):378-383.

Saub, R., Locker, D., Allison, P. & Disman, M. (2007). Cross-cultural adaptation of the oral health impact profile (OHIP) for the Malaysian adult population. *Community Dental Health*. *24*(3):166-175.

Scandrett, F. R., Tebo, H. G., Miller, J. T. & Quigley, M. B. (1973). Radiographic examination of the edentulous patient: Part i. Review of the literature and preliminary report comparing three methods. *Oral Surgery, Oral Medicine, Oral Pathology*. *35*(2):266-274.

Schelb, E., Kaiser, D. A. & Brukl, C. E. (1985). Thickness and marking characteristics of occlusal registration strips. *Journal of Prosthetic Dentistry*. *54*(1):122-126.

Schropp, L., Wenzel, A., Kostopoulos, L. & Karring, T. (2003). Bone healing and soft tissue contour changes following single-tooth extraction: A clinical and radiographic 12-month prospective study. *International Journal of Periodontics and Restorative Dentistry*. *23*(4):313-324.

Scott, B., Forgie, A. & Davis, D. (2006). A study to compare the oral health impact profile and satisfaction before and after having replacement complete dentures constructed by either the copy or the conventional technique. *Gerodontology*. *23*(2):79-86.

Semyari, H., Heravi, M., Shayegh, S., Azar, R. & Bastami, F. (2013). Comparison of quality of life between Iranians using two implant-retained overdenture prosthesis and conventional complete denture. *Avicenna Journal of Dental Research*. *5*(2):e20971.

Sennerby, L., Carlsson, G. E., Bergman, B. & Warfvinge, J. (1988). Mandibular bone resorption in patients treated with tissue-integrated prostheses and in complete-denture wearers. *Acta Odontologica*. *46*(3):135-140.

Serhal, C. B., Jacobs, R., Flygare, L., Quirynen, M. & Van Steenberghe, D. (2002). Perioperative validation of localization of the mental foramen. *Dentomaxillofacial Radiology*. *31*(1):39-43.

Sertgöz, A. & Güvener, S. (1996). Finite element analysis of the effect of cantilever and implant length on stress distribution in an implant-supported fixed prosthesis. *Journal of Prosthetic Dentistry*. *76*(2):165-169.

Sevimay, M., Turhan, F., Kiliçarslan, M. & Eskitascioglu, G. (2005). Three-dimensional finite element analysis of the effect of different bone quality on stress distribution in an implant-supported crown. *Journal of Prosthetic Dentistry*. *93*(3):227-234.

Shafi, A. A., Kadir, M. R. A., Sulaiman, E., Kasim, N. H. A. & Kassim, N. L. A. (2013). The effect of dental implant materials and thread profiles-a finite element and statistical study. *Journal of Medical Imaging and Health Informatics*. *3*(4):509-513.

Shah, F. K., Gebreel, A., Habib, A. A. & Porwal, A. (2012). Comparison of immediate complete denture, tooth and implant-supported overdenture on vertical dimension and muscle activity. *Journal of Advanced Prosthodontics*. *4*(2):61-71.

Shahmiri, R., Aarts, J. M., Bennani, V., Atieh, M. A. & Swain, M. V. (2013). Finite element analysis of an implant-assisted removable partial denture. *Journal of Prosthodontics*. *22*(7):550-555.

Shamdol, Z., Ismail, N. M., Hamzah, N. T. & Ismail, A. R. (2008). Prevalence and associated factors of edentulism among elderly Muslims in Kota Bharu, Kelantan, Malaysia. *Journal of the Islamic Medical Association of North America*. *40*(4):143-148.

Sharma, A., Rahul, G. R., Poduval, S. T., Shetty, K., Gupta, B. & Rajora, V. (2013). History of materials used for recording static and dynamic occlusal contact marks: A literature review. *Journal of Clinical and Experimental Dentistry*. *5*(1):e48-e53.

Sheiham, A. & Croog, S. H. (1981). The psychosocial impact of dental diseases on individuals and communities. *Journal of Behavioral Medicine*. *4*(3):257-272.

Sheiham, A. & Steele, J. (2001). Does the condition of the mouth and teeth affect the ability to eat certain foods, nutrient and dietary intake and nutritional status amongst older people? *Public Health Nutrition*. *4*(3):797-803.

Shinogaya, T., Bakke, M., Thomsen, C., Vilmann, A. & Matsumoto, M. (2000). Bite force and occlusal load in healthy young subjects-a methodological study. *The European Journal of Prosthodontics and Restorative Dentistry*. *8*(1):11-15.

Shinogaya, T., Bakke, M., Thomsen, C., Vilmann, A., Sodeyama, A. & Matsumoto, M. (2001). Effects of ethnicity, gender, and age on clenching force and load distribution. *Clinical Oral Investigations*. *5*(1):63-68.

Shinogaya, T. & Matsumoto, M. (1998). Evaluation of prosthodontic treatment by occlusal force distribution: A methodological study. *European Journal of Prosthodontics and Restorative Dentistry*. *6*(3):121-125.

Slade, G. (1997a). Measuring oral health and the quality of life. Department of Dental Ecology, School of Dentistry, University of North Carolina.93-104.

Slade, G. D. (1997b). Derivation and validation of a short-form oral health impact profile. *Community Dentistry and Oral Epidemiology*. *25*(4):284-290.

Slot, W., Raghoebar, G. M., Vissink, A., Huddleston Slater, J. J. & Meijer, H. J. (2010). A systematic review of implant-supported maxillary overdentures after a mean observation period of at least 1 year. *Journal of Clinical Periodontology*. *37*(1):98-110.

Smith, D. (1961). The acrylic denture. Mechanical evaluation mid-line fracture. *British Dental Journal*. *110*(8):257-267.

Smith GA, L. W., Grant AA. (1983). Magnetic retention units for overdentures. *Journal of Oral Rehabilitation*. *10*(6):481-488.

Solomons, Y. F. (2000). Mandibular implant-supported overdentures: A prospective evaluation of the burden of prosthodontic maintenance with 3 different attachment systems. *International Journal of Prosthodontics*. *13*(3):246-253.

Stafford, G. & Glantz, P.-O. (1991). Intraoral strain gauge measurements on complete dentures: A methodological study. *Journal of Dentistry*. *19*(2):80-84.

Stewart, A. L., Hays, R. D. & Ware, J. E. (1988). The mos short-form general health survey: Reliability and validity in a patient population. *Medical Care*. *26*(7):724-735.

Sukegawa, S., Kanno, T., Akamatsu, H., Shibata, A., Takahashi, Y. & Furuki, Y. (2016). Surgical management of severe bruxism and masseteric hypertrophy in the patient with repeated implant failures: A case report. *Journal of Oral and Maxillofacial Surgery, Medicine, and Pathology*. *28*(5):416-420.

Swart, J. & Allard, R. (1985). Subperiosteal onlay augmentation of the mandible: A clinical and radiographic survey. *Journal of Oral and Maxillofacial Surgery*. *43*(3):183-187.

Takahashi, T., Gonda, T. & Maeda, Y. (2015). Influence of reinforcement on strains within maxillary implant overdentures. *International Journal of Oral and Maxillofacial Implants*. *30*(6):1327-1332.

Takamiya, A. S., Monteiro, D. R., Marra, J., Compagnoni, M. A. & Barbosa, D. B. (2012). Complete denture wearing and fractures among edentulous patients treated in university clinics. *Gerodontology*. *29*(2):e728-e734.

Takenaka, M., Mine, K., Tsuchimochi, K. & Shimada, K. (2001). Tooth removal during ritual tooth ablation in the jomon period. *Indo-Pacific Prehistory Association*. *21*:49-52.

Tallgren, A. (1972). The continuing reduction of the residual alveolar ridges in complete denture wearers: A mixed-longitudinal study covering 25 years. *Journal of Prosthetic Dentistry*. *27*(2):120-132.

Tallgren, A., Lang, B., Walker, G. & Ash, M. (1980). Roentgen cephalometric analysis of ridge resorption and changes in jaw and occlusal relationships in immediate complete denture wearers. *Journal of Oral Rehabilitation*. *7*(1):77-94.

The glossary of prosthodontic terms. (2017). *Journal of Prosthetic Dentistry*. *117*(5):e1-e105.

Thomason, J., Kelly, S., Bendkowski, A. & Ellis, J. (2012). Two implant retained overdentures-a review of the literature supporting the McGill and York consensus statements. *Journal of Dentistry*. *40*(1):22-34.

Thomason, J., Lund, J., Chehade, A. & Feine, J. (2003). Patient satisfaction with mandibular implant overdentures and conventional dentures 6 months after delivery. *International Journal of Prosthodontics*. *16*(5):467-473.

Thomason, J. M., Feine, J., Exley, C., Moynihan, P., Müller, F., Naert, I., Ellis, J. S., Barclay, C., Butterworth, C. & Scott, B. (2009). Mandibular two implant-supported overdentures as the first choice standard of care for edentulous patients-the York consensus statement. *British Dental Journal*. *207*(4):185-186.

Thomson, W. M. (2012). Monitoring edentulism in older New Zealand adults over two decades: A review and commentary. *International Journal of Dentistry*. *2012*:375407-375407.

Throckmorton, G., Rasmussen, J. & Caloss, R. (2009). Calibration of t-scan® sensors for recording bite forces in denture patients. *Journal of Oral Rehabilitation*. *36*(9):636-643.

Torres, B., Costa, F., Modena, C., Cota, L., Cortes, M. & Seraidarian, P. (2011). Association between personality traits and quality of life in patients treated with conventional mandibular dentures or implant-supported overdentures. *Journal of Oral Rehabilitation*. *38*(6):454-461.

Trakas, T., Michalakis, K., Kang, K. & Hirayama, H. (2006). Attachment systems for implant retained overdentures: A literature review. *Implant Dentistry*. *15*(1):24-34.

Trivedi, S. (2014). Finite element analysis: A boon to dentistry. *Journal of Oral Biology and Craniofacial Research*. *4*(3):200-203.

Tugwell, P., Bennett, K., Sackett, D. & Haynes, B. (1984). Relative risks, benefits, and costs of intervention. *Tropical and Geographical Medicine*.1097-1113.

Tymstra, N., Raghoebar, G., Vissink, A. & Meijer, H. (2011). Maxillary anterior and mandibular posterior residual ridge resorption in patients wearing a mandibular implant-retained overdenture. *Journal of Oral Rehabilitation*. *38*(7):509-516.

Uchida, H., Kobayashi, K. & Nagao, M. (1989). Measurement in vivo of masticatory mucosal thickness with 20 MHz b-mode ultrasonic diagnostic equipment. *Journal of Dental Research*. *68*(2):95-100.

Uram-Tuculescu, S., Cooper, L. F., Foegeding, E. A., Vinyard, C. J., De Kok, I. J. & Essick, G. (2015). Electromyographic evaluation of masticatory muscles in dentate patients versus conventional and implant-supported fixed and removable denture wearers--a preliminary report comparing model foods. *International Journal of Prosthodontics*. *28*(1):79-92.

Uzun, G. & Hersek, N. (2002). Comparison of the fracture resistance of six denture base acrylic resins. *Journal of Biomaterials Applications*. *17*(1):19-28.

Vairo, G. & Sannino, G. (2013). Comparative evaluation of osseointegrated dental implants based on platform-switching concept: Influence of diameter, length, thread shape, and in-bone positioning depth on stress-based performance. *Computational and Mathematical Methods in Medicine*. *2013*:1-15 http://dx.doi.org/10.1155/2013/250929.

Vallittu, P. (1996). Fracture surface characteristics of damaged acrylic-resinbased dentures as analyzed by sem-replica technique. *Journal of Oral Rehabilitation*. *23*(8):524-529.

Vallittu, P., Lassila, V. & Lappalaine, R. (1996). The effect of notch shape and self-cured acrylic resin repair on the fatigue resistance of an acrylic resin denture base. *Journal of Oral Rehabilitation*. *23*(2):108-113.

Vallittu, P. K., Alakuijala, P., Lassila, V. P. & Lappalainen, R. (1994). In vitro fatigue fracture of an acrylic resin-based partial denture: An exploratory study. *Journal of Prosthetic Dentistry*. *72*(3):289-295.

Vallittu, P. K., Lassila, V. P. & Lappalainen, R. (1993). Evaluation of damage to removable dentures in two cities in Finland. *Acta Odontologica Scandinavica*. *51*(6):363-369.

Van Kampen, F., Van Der Bilt, A., Cune, M., Fontijn-Tekamp, F. & Bosman, F. (2004). Masticatory function with implant-supported overdentures. *Journal of Dental Research*. *83*(9):708-711.

Van Oosterwyck, H., Duyck, J., Vander Sloten, J., Van der Perre, G., De Coomans, M., Lieven, S. & Puers, R. (1998). The influence of bone mechanical properties and implant fixation upon bone loading around oral implants. *Clinical Oral Implants Research*. *9*(6):407-418.

Van Waas, M. (1983). Ridge resorption in denture wearers after vestibuloplasty and lowering of the floor of the mouth, measured on panoramic radiographs. *Dentomaxillofacial Radiology*. *12*(2):115-121.

Van Waas, M. A. (1990). The influence of psychologic factors on patient satisfaction with complete dentures. *Journal of Prosthetic Dentistry*. *63*(5):545-548.

Varón de Gaitán, A. C., Bustamante Mesa, J. C., Hoyos Galvis, A. C., Zapata Suárez, A. F. & Plaza Ruíz, S. P. (2014). Tomographic determination of residual ridges shape and size prevalence in edentate patients. *Revista Facultad de Odontología Universidad de Antioquia*. *25*(2):265-282.

Vermylen, K., Collaert, B., Lindén, U., Björn, A. L. & De Bruyn, H. (2003). Patient satisfaction and quality of single-tooth restorations. *Clinical Oral Implants Research*. *14*(1):119-124.

Veyrune, J., Tubert-Jeannin, S., Dutheil, C. & Riordan, P. (2005). Impact of new prostheses on the oral health related quality of life of edentulous patients. *Gerodontology*. *22*(1):3-9.

Wafa'a, R., Swelem, A. A. & Radi, I. A. (2017). The effect of 2 versus 4 implants on implant stability in mandibular overdentures: A randomized controlled trial. *Journal of Prosthetic Dentistry*.doi: 10.1016/j.prosdent.2016.1012.1008.

Wain, E. (1957). Stresses in denture bases. *Dental Practice*. *8*:37-41.

Walton, J. & MacEntee, M. (1994). Problems with prostheses on implants: A retrospective study. *Journal of Prosthetic Dentistry*. *71*(3):283-288.

Walton, J. N. & MacEntee, M. I. (1993). A retrospective study on the maintenance and repair of implant-supported prostheses. *International Journal of Prosthodontics*. *6*(5):451-455.

Wang, L., Zheng, L., Li, C., Dong, S., Lan, A. & Zhou, Y. (2013). Adrenomedullin delivery in microsphere-scaffold composite for remodeling of the alveolar bone following tooth extraction: An experimental study in the rat. *Biomedical engineering online*. *12*(1):99.

Weinberg, L. A. (1993). The biomechanics of force distribution in implant-supported prostheses. *International Journal of Oral and Maxillofacial Implants*. *8*(1):451-455.

WHO. (1995). Constitution of the world health organization.1-18.

Wical, K. E. & Swoope, C. C. (1974). Studies of residual ridge resorption. Part I. Use of panoramic radiographs for evaluation and classification of mandibular resorption. *Journal of Prosthetic Dentistry*. *32*(1):7-12.

Wick, J. (2010). Oral health in the long-term care facility. *The Consultant Pharmacist®*. *25*(4):214-224.

Wilding, R., Levin, I. & Pepper, R. (1987). The use of panoramic radiographs to measure alveolar bone areas. *Journal of Oral Rehabilitation*. *14*(6):557-567.

Winkler, S. (1988). Essentials of complete denture prosthodontics. Year Book Medical Pub. 2nd ed. Littleton, Mass: PSG Pub Co, 1988.

Wismeijer, D., Vermeeren, J. I. & van Waas, M. A. (1992). Patient satisfaction with overdentures supported by one-stage tps implants. *International Journal of Oral and Maxillofacial Implant*. *7*(1):168-177.

Woelfel, J. B., Kreider, J. A. & Berg, T. (1962). Deformed lower ridge caused by the relining of a denture by a patient. *Journal of the American Dental Association*. *64*(6):763-769.

Woelfel, J. B., Winter, C. M. & Igarashi, T. (1976). Five-year cephalometric study of mandibular ridge resorption with different posterior occlusal forms. Part i. Denture construction and initial comparison. *Journal of Prosthetic Dentistry*. *36*(6):602-623.

Wright, P. S., Glantz, P. O., Randow, K. & Watson, R. M. (2002). The effects of fixed and removable implant-stabilized prostheses on posterior mandibular residual ridge resorption. *Clinical Oral Implants Research*. *13*(2):169-174.

Xie, Q. & Ainamo, A. (1999). Association of edentulousness with systemic factors in elderly people living at home. *Community Dentistry and Oral Epidemiology*. *27*(3):202-209.

Xie, Q., Ainamo, A. & Tilvis, R. (1997a). Association of residual ridge resorption with systemic factors in home-living elderly subjects. *Acta Odontologica Scandinavica*. *55*(5):299-305.

Xie, Q., Wolf, J. & Ainamo, A. (1997b). Quantitative assessment of vertical heights of maxillary and mandibular bones in panoramic radiographs of elderly dentate and edentulous subjects. *Acta Odontologica*. *55*(3):155-161.

Yamamura, M., Takahashi, A., Aoki, H., Takeuchi, N., Endo, Y., Tamaki, K., Sano, Y., Fujiwara, S., Fujita, T. & Kusunoki, S. (1990). A study on display and accuracy of occlusal contacts by means of t-scan system. *Kanagawa shigaku. Journal of the Kanagawa Odontological Society*. *25*(2):236-241.

Yavuzyilmaz, E., Yamalik, N., Çalgüner, M., Ersoy, F., Baykara, M. & Yeniay, I. (1992). Clinical and immunological characteristics of patients with rheumatoid arthritis and periodontal disease. *Journal of Nihon University School of Dentistry*. *34*(2):89-95.

Yeh, C.-K. & Rodan, G. A. (1984). Tensile forces enhance prostaglandin e synthesis in osteoblastic cells grown on collagen ribbons. *Calcified Tissue International*. *36*(1):S67-S71.

Yunus, N., Masood, M., Saub, R., Al-Hashedi, A. A., Taiyeb Ali, T. B. & Thomason, J. M. (2015). Impact of mandibular implant prostheses on the oral health-related quality of life in partially and completely edentulous patients. *Clinical Oral Implants Research*. *27*(7):904-909.

Yunus, N., Saub, R., Bai Taiyeb Ali, T., Mohd Salleh, N. & Rustum Baig, M. (2014). Patient-based and clinical outcomes of implant telescopic attachment–retained mandibular overdentures: A 1-year longitudinal prospective study. *International Journal of Oral and Maxillofacial Implant*. *29*(5):1149-1156.

Zarb, G. A. & Bolender, C. L. (1997). Boucher's prosthodontic treatment for edentulous patients. (vol. 275, p. 191). C.V.

Zhang, S. (1992). The analysis of the maxillary complete denture and its underlying supporting tissues with three dimensional finite element method under the vertical occlusal force in centric occlusion. *Chinese Journal of Stomatology*. *27*(1):6-8, 61.

Zhou, X., Zhao, Z., Zhao, M. & Fan, Y. (1999). The boundary design of mandibular model by means of the three-dimensional finite element method. *West China Journal of Stomatology*. *17*(1):29-32.

Ziebert, G. J. & Donegan, S. J. (1979). Tooth contacts and stability before and after occlusal adjustment. *Journal of Prosthetic Dentistry*. *42*(3):276-281.

Zuccari, A., Oshida, Y., Okamura, M. & Moore, B. (1996). Bulge ductility of several occlusal contact measuring paper-based and plastic-based sheets. *Bio-Medical Materials and Engineering*. *7*(4):265-270.

LIST OF PUBLICATIONS AND PAPERS PRESENTED

Published papers

1- Khuder, T., Yunus, N., Sulaiman, E., Ibrahim, N., Khalid, T., & Masood, M. (2017). Association between occlusal force distribution in implant overdenture prostheses and residual ridge resorption. Journal of Oral Rehabilitation, 44(5), 398-404.

2- Khuder, T., Yunus, N., Sulaiman, E., & Dabbagh, A. (2017). Finite element analysis and clinical complications in mandibular implant-overdentures opposing maxillary dentures. Journal of the Mechanical Behavior of Biomedical Materials, 75, 97-104.

Conference papers

1- Event: The Regional Conference on Maxillofacial Prosthodontics, 8^{th}-10^{th} August 2016, Faculty of Dentistry, University of Malaya, Malaysia.

Category: Poster Presentation.

Title: Occlusal Analysis Of Implant-Supported Prostheses Using Computerized T-scan III System.

Rewards: Awarded the (Special Mention) in Poster Presentation.

2- **Event:** The 2^{nd} International Conference on Innovative Dentistry (ICID), 13^{th}-14^{th} August 2016, The Royal Chulan Damansara Hotel, Petaling Jaya, Selangor, Malaysia.

Category: Poster Presentation.

Title: Occlusal Forces and Bone Resorption in Mandibular Implant-Supported Overdentures.

Rewards: Awarded the (1st Runner-Up) in Poster Presentation.

3- **Event:** International Association for Dental Research Malaysian Section (South-East Asian Division), Hotel Armada Petaling Jaya, Selangor on the 18th March 2017.

Category: Oral Presentation.

Title: Strain Distribution and Prostheses Complications with Mandibular Implant-Supported Overdentures.

4- **Event:** International Association for Dental Research Malaysian Section (South-East Asian Division), Holiday Villa Subang, Selangor on the 24th Feb 2018.

Category: Oral Presentation.

Title: Effect of Mandibular Prosthesis type on the strain distribution within Maxillary Complete Dentures.

5- **Event:** University of Malaya three minutes thesis (UM3MT) competition, faculty of dentistry university of Malaya Kuala lumper, on the 3rd April 2018.

Category: Oral Presentation.

Title: Clinical, Radiological and In Vitro Strain Investigations In Mandibular Implant Overdentures.

Other Events

Event: IME SOLIDWORKS innovation day 2017.