Original Article

Comparison of Static and Dynamic Compressive Strength between Two Mini-implants: An *In-vitro* Study

Anchisa Weerasubpong[1], Wareeratn Chengprapakorn[1], Pravej Serichetaphongse[1]

[1]Esthetic Restorative and Implant Dentistry International Program, Faculty of Dentistry, Chulalongkorn University, Bangkok, Thailand

Abstract

This study was conducted to observe and evaluate the difference in static and dynamic loadings between two mini-implant systems; one system is designed and manufactured as Chulalongkorn's mini-implant products (RetenDent), the other is Korean mini-implant products (MS denture® system, OSSTEM). This *in vitro* study was designed to use compressive loadings as a masticatory force. This compressive force was angulated to the implant at 30° from its vertical axis according to ISO 14801 guidelines Ten specimens from each group were subjected to static load tests. Subsequently, five cyclic loadings were calculated from static compressive strength These loads include 320N, 275N, 230N, 185N, and 140N. Three specimens were randomly selected and tested at each loading condition, a total of 15 specimens for each mini-implant system. The number of survived cycles and fatigue limit were measured and analyzed. The Independent *T*- test was utilized to obtain the statistical differences of the static compressive strength, while descriptive statistics was utilized to compare the difference of dynamic loading between two mini-implant systems. The average static compressive strengths of RetenDent and OSSTEM mini-implants were 462.969 ± 16.73N and 403.407 ± 25.55N, respectively. Overall, RetenDent demonstrated a higher number of survived cycles except at 320N loading condition compared to OSSTEM. The fatigue limit of RetenDent and OSSTEM mini-implants was defined at 185N and 140N, respectively. RetenDent demonstrated a statistically higher static compressive strength. Both of the mini-implant systems had higher compressive strength than mean masticatory force in the anterior and premolar regions and RetenDent also has a higher dynamic compressive strength than the maximum bite force for a complete denture.

Keywords : Compressive strength, Cyclic, Mini-implants, OSSTEM, RetenDent

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Correspondence to :

Anchisa Weerasubpong, Esthetic Restorative and Implant Dentistry International Program, Faculty of Dentistry, Chulalongkorn University, 34 Henri-Dunant Rd., Pathumwan, Bangkok, 10330 Thailand. Tel: 081-623-3993 E-mail: anchisa.we@gmail.com

Introduction

As a developing country, Thailand has been facing a multitude of challenges as the elderly population expands rapidly since 2010 due to better medical healthcare. According to the 2017 report of the National Committee for the Elderly (NCE), the number of Thai elderly was 11 million out of 65.5 million accounting for 17 % of the total population. It is anticipated that with a continuous growth at this rate, Thailand will completely experience the aging society in 2021 as the percentage of citizens aged 60 years old and above will exceed 20 % of the total population.[1] The definition of the elderly varies among countries. Some suggest 65 years of age as the cut-off criteria, while others consider 60 years of age. Retirement is usually used as the standard cut-off criteria to define the term 'elderly' in each country. Besides numerous systemic diseases, elderly people usually suffered from poor quality of life. The most commonly used quality of life measures in elderly people is a combination of the quality of eyesight, hearing ability and denture wearing. One survey reported that 23 percent of the elderly wore dentures.[1] Thus, edentulous problem in elderly people is considered to be an important issue that should be managed.

Previous studies have reported that numerous health problems can be associated with tooth loss, including obesity, gastroesophageal reflux disease, noninsulin-dependent diabetes mellitus, hypertension, heart failure, chronic kidney disease, and sleeping disorder.[2-4] The conventional denture has been a gold standard protocol for replacing missing teeth in the past. However, many undesired problems have been reported, such as ill-fitting of the lower denture due to lack of bone support.[5] Trying to gain more retention, clinicians reduce the vertical dimension to make the denture more stable. Reducing vertical dimension results in angular cheilitis problems. Another method to gain more retention is making a zero-cusp occlusion, which strongly affects the chewing efficiency of the denture. A number of digestive problems may include gastric disease, diabetes, malnutrition, as well as temporomandibular disorder. Another commonly reported difficulty is discomfort. The thickness of the denture can interrupt the speech ability of the denture wearer. Improper design and thickness could lead to a change in articulation.[6,7]

With inevitable problems of a conventional denture, other choices of treatment have been proposed. Overdenture on the natural teeth has been applied in dental practice for many years. However, problems arising from dental caries and periodontal disease have weakened the successful outcome of the treatment. Thus, endosseous dental implants have been introduced to assist the denture.[8] In general, severe atrophy of alveolar ridges of the patients is a contraindication for a standard implant (two-piece) placement because of the lack of bone support. On the other hand, a one-piece mini-implant is claimed to be beneficial for this clinical situation. The advantage of using mini-implant over standard diameter implant includes minimal invasive protocol, which results in less bone damage and postoperative discomfort. Moreover, it requires less bone available due to the smaller diameter of the mini-implant. With the smaller diameter, there is no need for bone graft, which could lead to postoperative complications and higher expenses.

Despite several benefits of an implant-retained prosthesis, a study in some European countries revealed that only 2-4 % of the edentulous patients were treated with implants.[9] The main limitation for implant treatment in these elderly patients is the high cost of an implant procedure.[10] Likewise, in Thailand, most dental devices and materials are highly dependent on import products. The costs of an implant placement could be about 30,000-50,000 baht per single tooth in a standard implant. This limits the treatment to certain groups of the population, especially in the rural areas. According to the guidelines in 2002, Thailand's universal health care is provided through three programs: Civil Servant Medical Benefit Scheme (CSMBS), Social Security Scheme, and Universal Health Coverage known as 30 baht health scheme.[11] In these three programs, the insurances do not cover the expenditures of implant therapy. Therefore, the development of implant product with a low price is a matter of interest to make the majority of population in Thailand gain access to an implant treatment.

With the aforementioned problems, research and development group in dental school, Chulalongkorn University has been developing mini-implants to be applied in Thai dental practice, especially in the elderly with poor social status. However, mechanical tests of the material must be performed prior to clinical application. Static and dynamic compressive strength is being tested to ensure that the selected mini-implants are qualified to be used in clinical situations. The objective of this study was to compare the difference in compressive strength between the two mini-implant systems to determine the resistance of the mini-implants to masticatory force and to prove whether overdenture using RetenDent mini-implants is clinically usable in the edentulous patients.

Materials and Methods

All instruments, materials, and testing procedures in this study were done following the criteria and guidelines of ISO14801: 2016(E).[12] Fifty mini-implants from 2 companies (Table1) were used in this study.

Table 1 Mini-implant and components used in the current study

Test lot	Manufacturer	Implant	Lot no.
1	RetenDent mini-implant for overdenture (Chulalongkorn's product)	∅2.5mm/12mm, cylindrical ball shape	L190320
2	MS denture® type implant (OSSTEM)	∅2.5mm/11.5mm, cylindrical ball shape	FMN19F031

Specimen preparation

All specimens were vertically embedded in acrylic blocks (SIVA ANGKUN Co.,Ltd.) following the insertion torque of the manufacturer's recommendation. These acrylic blocks were cylindrical in shape with a young modulus of 3200 Pascal. The distance from the loading point to the level of embedding acrylic supporting the mini-implants was standardized at 11 mm. All specimens were subsequently transferred to the specimen holder that secured the position of each sample at an angle of 30° from its vertical axis. The diameter of the loading member was 2.5 cm. (Fig. 1).

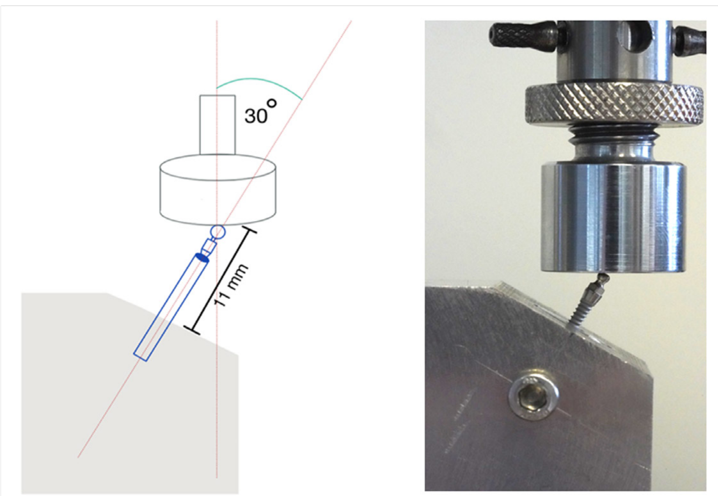

Figure 1 Schematic of the test set up: Mini-implant was mounted in an acrylic block. The specimen holder secured the position of each sample at 30° off-axis

Static compressive test

Twenty specimens, ten from each group, were randomized and subjected to test for static compressive strength. The static test was performed by Universal Testing Machine (Servo Hydraulic System, INSTRON 8872). The compression load was applied to each specimen by a unidirectional vertical platform through a hemispherical loading member with 1mm/min speed until permanent deformation occurred. Failure was defined as a fracture of the implant body. Data were recorded in the extension of mini-implants in relation to compressive load per second and plotted on a graph. The top peak of the graph, which referred to the maximum compressive strength, was recorded for each sample. Merlin software was used to collect and interpret the data.

Fatigue compressive test

Thirty specimens, fifteen from each company, were placed in the same manner with the static testing. The fatigue test was performed in accordance with the guidelines of ISO14801:2016(E) by Universal Testing Machine, INSTRON E1000. Half of the maximum static compressive strength was selected as the first tested load, followed by two ranges of step width (10 % of the estimated maximum endured load) above and below. These loads include 320N, 275N, 230N, 185N, and 140N. Three specimens were tested at each loading condition and subsequently calculated for the average number of survived cycles. The load was pulsated with a sine wave at the frequency of 15 Hz. The amplitude was set at half of the difference between the maximum and the minimum loads. Data were collected and interpreted by Waveform software. The load that reached five million cycles without deformation was defined as the fatigue limit.

SEM and ESD analysis

Scanning Electron Microscope (SEM) and Energy Dispersive Analysis (EDS) (Quanta250, FEI, USA) were used for further analysis of the morphological and chemical characteristics of the mini-implants, respectively. Samples from each group were observed through SEM at two locations including head and body of the mini-implants. The acceleration high voltage (HV) was set at 20 kV. Representative photos were taken at magnifications of 50 and 1,000. Then the EDS analyses were performed to examine the compositions of both samples. The analyses were randomly performed at three different areas for each sample and demonstrate the results in peak height intensities.

Statistical analysis

Statistical Package for Social Sciences (SPSS) software was used for the statistical analysis. Shapiro-Wilk test was performed to validate the normality of the distribution of the data. An Independent *t*-test was utilized to investigate the statistical difference of the static compressive strength between the two mini-implant systems, while descriptive statistics was utilized for dynamic compressive strength testing. A *P*-value below 0.01 was considered as significance in all comparisons.

Results

Static compressive test

The results are as shown in Table 2. The average static compressive strengths of RetenDent mini-implants and OSSTEM mini-implants were 462.97 ± 16.73N and 403.41 ± 25.55N, respectively. RetenDent mini-implants demonstrated statistically higher compressive strength when compared to OSSTEM mini-implants at the significant level of 0.01. Example of specimens with permanent deformation after undergoing static tests are as shown in Fig.2

Table 2 Mean values and standard deviations of static compressive strength (unit:N).

	1	2	3	4	5	6	7	8	9	10	Mean	SD	*P*-value
RetenDent	481.8	452.59	475.15	452.55	477.93	474.25	464.82	460.74	464.79	425.07	462.97	16.73	<0.001
OSSTEM	377.61	413.48	419.33	400.42	350.46	392.06	427.73	432.57	423.94	396.47	403.41	25.55	

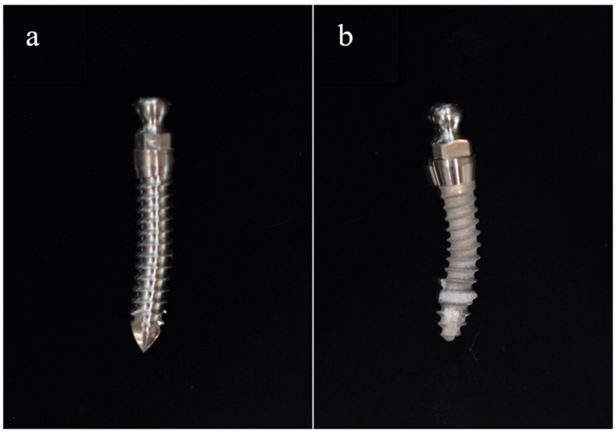

Figure 2 *Samples after static compression test a: RetenDent b: OSSTEM*

Fatigue compressive test

The average number of survived cycles was calculated from three specimens in each loading condition. The results are as shown in Table 3. RetenDent mini-implants demonstrated a higher number of survived cycles at loading conditions of 275N, 230N, 185N, and 140N. However, at 320N, OSSTEM showed a slightly higher number of survived cycles. The data were plotted in the load-cycle diagram for comparison according to ISO 14801 guidelines. (Fig. 3) The fatigue limits of RetenDent and OSSTEM mini-implants were 185N and 140N, respectively.

Table 3 *Average number of survived cycles until failure (unit: cycles)*

	320N	275N	230N	185N	140N
RetenDent	3,423	8,912	55,707	5,000,000	5,000,000
OSSTEM	3,697	5,354	9,203	19,231	5,000,000

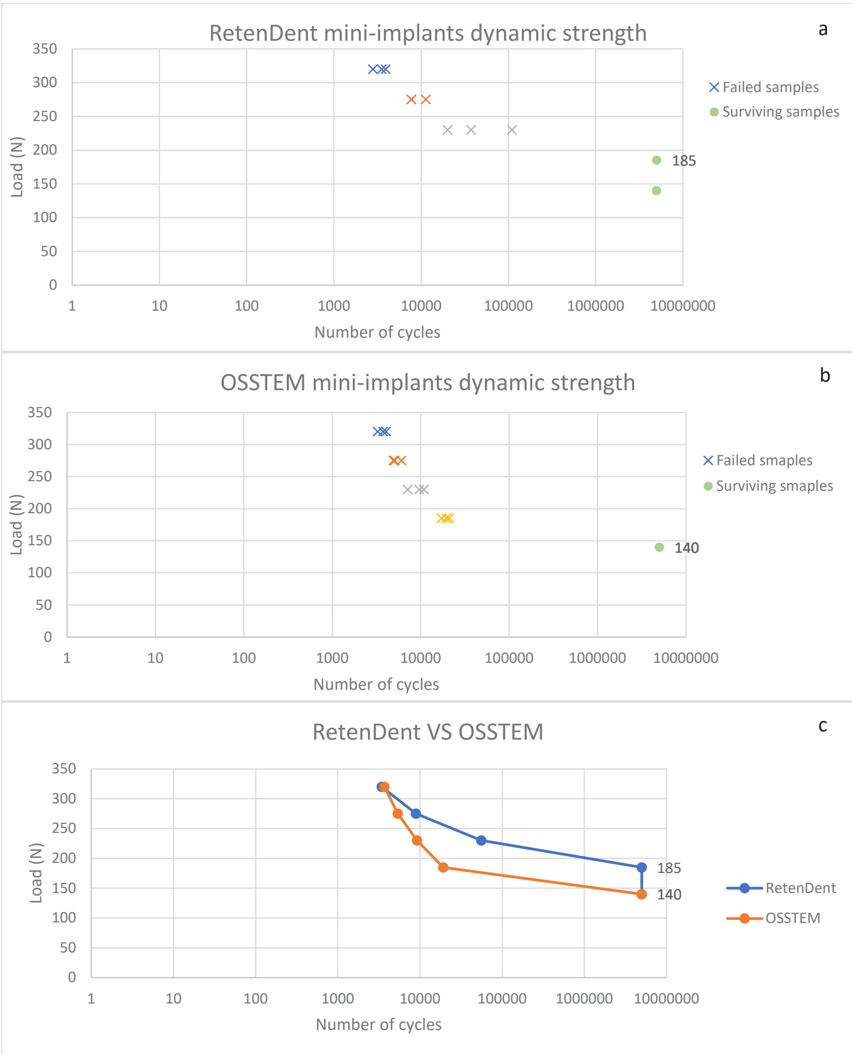

Figure 3 *Load-cycle diagram a: RetenDent b: OSSTEM c: RetenDent compare to OSSTEM mini-implant*

SEM and EDS analysis

The SEM images of the mini-implants are shown in Figure 4. At the head of the mini-implants, it showed a homogenous smooth mechanical surface, while the body of the mini-implants demonstrated the irregular roughness which is the results from surface modification in order to enhance osseointegration process of the mini-implants. Moreover, the picture also demonstrated different thread designs between the two mini-implants systems. RetenDent's thread design is similar to reverse buttress shape while OSSTEM's is similar to regular buttress thread shape. EDS spectra of both samples which were measured at 3 different locations are shown in Figure 5. Both samples demonstrated similar results as Ti represented the major components of the materials. The results also revealed the presence of Aluminium (Al) and Vanadium (V).

(a) RetenDent

(b) OSSTEM

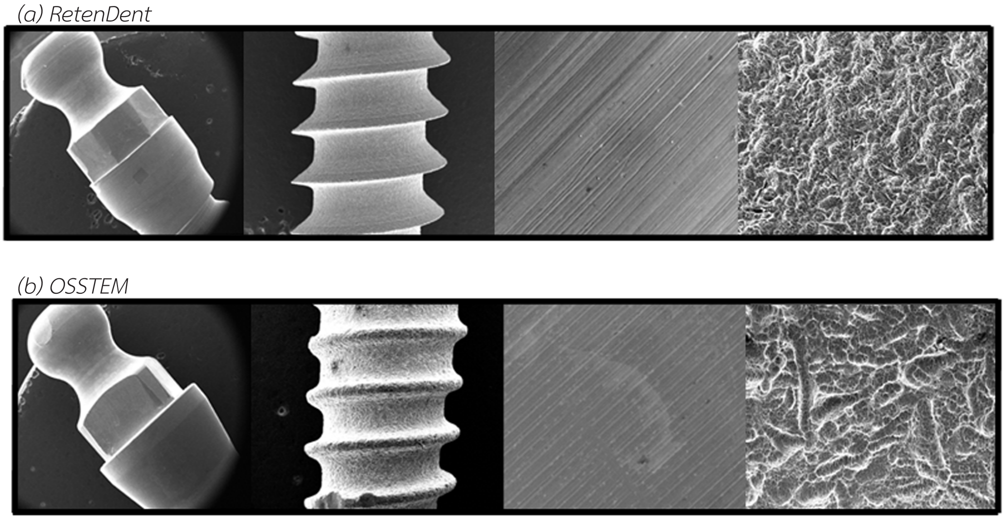

Figure 4 *Images obtained by scanning electron microscopy (a) RetenDent (b) OSSTEM (From left to right: Head 50x, Body50x, Head 1000x, Body 1000x magnification)*

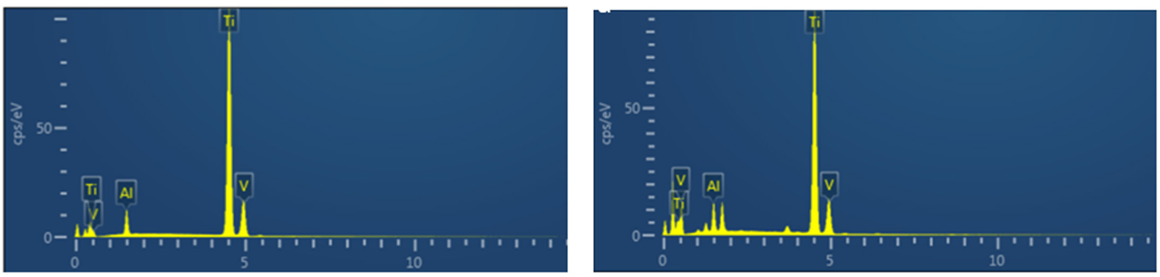

Figure 5 *Example of energy dispersive spectroscopy spectra obtained by chemical analysis of (a) RetenDent and (b) OSSTEM*

Discussion

Several studies reported that denture wearer preferences in overdenture were higher when compared to the conventional complete denture and fixed prosthesis due to better denture stability, easy cleaning, and maintenance.[13,14] However, severe atrophy of the alveolar ridges of patients is a contraindication for standard implant placement. Standard implant (two-piece) protocol requires at least 6 millimeters buccolingual width dimension of the alveolar process. This specific buccolingual dimension is rarely found in the edentulous patients, especially in the lower jaw. Therefore, the mini-implant overdenture (one-piece) is recommended to replace the standard implant. The mini-implants of 2.5 mm in diameter requires only 4.5 mm of bone thickness which is normally available in the lower jaw. Moreover, this one-piece design provides a better strength compared to the standard hollow implants.

OSSTEM mini-implant products were selected to be the benchmarked mechanical properties since several studies reported that OSSTEM mini-implants were successful in clinical application and demonstrated high patient satisfaction.[15,16] Static and dynamic compressive strengths were selected as a representative for the mechanical testing.

In this study, both mini-implants of each system were embedded in the acrylic blocks with standardization of 11 mm distance between the supporting point and the loading point, resulting in an equal moment arm (lxsin30) of 5.5 mm. The result demonstrated that the mean static compressive strength of RetenDent mini-implants was 462.97N, which was statistically higher when compared with that of the OSSTEM mini-implants (403.41N) at the significant level of 0.01. The reason for this might due to the different materials used in the manufacturing process. Analyzed through EDS, both mini-implants demonstrated the presence of Vanadium (V) and Aluminum (Al) elements suggesting that Ti6Al4V is the alloy material of both mini-implant systems. The manufacturer of OSSTEM only stated that the alloy material of the products is Titanium but did not specific grade type of the material. On the other hand, the manufacturer of RetenDent mini-implant claims that the alloy material of the products is Ti6Al4V ELI (grade23) following the ASTM F 136 Titanium specification.[17]

Two types of Titanium that are commonly used in the implant dentistry are cpTi4 and Ti-6Al-4V. Several studies reported that Ti-6Al-4V was a preferable material for mini-implants since it provided superior mechanical properties when compared with cpTi4.[18,19] However, some studies reported the risk of toxicity from Vanadium in the Ti-6Al-4V alloy and the mismatch of the elastic modulus between the implant and the bones.[20,21] Thus, modification of titanium alloy compositions with extra low interstitials (ELI) has been developed. The Ti6Al4V ELI contains lower levels of interstitials, which results in better mechanical and thermal properties. These properties include fracture and corrosion resistance, wear, and cryogenic properties.[22]

Another different factors between these two mini-implant systems are the thread shape and design. Study by Lee *et al* reported that different types of thread had no effect on the compressive strength of the material. On the other hand, different thread shape and depth could affect the stress distribution and primary stability.[23] Study by Oswal *et al.* found that Minimum Von Mises stresses were seen with the reverse buttress thread design at the cortical bone.[24] Study by Ahmad *et al.* also reported that the reverse buttress had a favorable outcome as it provides better stability and increases the ability of osseointegration process. [25]

Surface treatment is another factor that has an effect on osseointegration. According to manufacturer's information, both RetenDent and OSSTEM were treated by sandblasted and acid etching technique (SA). Elkhaweldi *et al.* reported that SL had a higher survival rate compared to RBM method, especially in the area of poor quality of bone. [26] Study by Im *et al.* also reported that the initial stability of SL was higher than RBM, but not statistically different.[27]

The compressive fatigue testing is the simulation of daily functions and is accepted as the foremost and suitable test strategy to get the information closet to the clinical circumstance. In this study, five loads were selected to compare the number of cycles between these two mini-implants, including 320N, 275N, 230N, 185N, and 140N. These loads were selected as 230N representing half of the maximum static compressive strength of the material, and 45N was determined as the step width of the maximum load. The specimens were positioned at a 30-degree off-axis which simulated clinically severe single tooth bending.[28] Literature review shows that adults have a chewing frequency of around 2700 times a day, which is equal to 10 million times per year.[29] However, chewing cycles are not always active in normal oral conditions. According to ISO14801, five million cycles are considered as a standard for cyclic testing. The results demonstrated that both RetenDent and OSSTEM mini-implants showed similar results in that the number of survived cycles were increased with decreasing level of load. RetenDent mini-implants showed a higher number of survived cycles when compared with OSSTEM mini-implants at the same loading condition. Only at 320N that OSSTEM did demonstrate a slightly higher number of survived cycles. The reason for this is the collar size of the mini-implants. OSSTEM has a larger collar which is around 3.2 mm when compared with RetenDent, which has a collar size of around 2.8 mm. This collar part receives the load and transfers it to the body. At 320N, the 2.8 mm collar size cannot withstand the load. As a result, it breaks at the lower number of cycles than OSSTEM. However, the area for the mini-implants placement is limited around the premolar to premolar region since the purpose of the mini-implant is to retain prosthesis. Previous studies reported that the mean masticatory force at the molar region ranged from 107 to 156N, 39 to 66N on the premolars and 11 to 33N on the front teeth.[30] Therefore, 320N is beyond the mean masticatory force at the premolar region.

By comparing the results with a study by Heo *et al.,* which tested mini-implants from Dentis, Daegu, Korea, it showed that the diameter of the mini-implant was 2.5 mm and the length was 13 mm. The test method was similar to this study. The results demonstrated that the maximum static compressive strength was 149 ± 6.1N.[31] Dentis was made of cpTi4. Thus, it yielded a lower compressive strength value when compared with Ti6Al4V and Ti6Al4VELI material at the same diameter and tested conditions. The fatigue limit of Dentis was analyzed at 60N, which accounted for around 40 percent of its maximum static compressive strength. This percentage is comparative to RetenDent. OSSTEM's mean static load is around 403N, and its fatigue load is limit to around 140N. This accounts for around 35 percent of its maximum compressive strength. However, the large range of the step width must be considered, as the load between the ranges could be the definite fatigue limit of the materials.

The most concerning problem for the mini-implants is their mechanical properties to withstand the force since several studies reported a high risk of fracture in the reduced diameter of the implants.[32,33] The maximum bite force is usually used as an indicator to evaluate oral cavity function. Several factors have an effect on this value, including gender, age, periodontal and dental status. As mentioned above, the compressive strength of both mini-implants is higher than the mean masticatory force around the placement area of the mini-implants. Moreover, studies reported that completely edentulous patients had reduced masticatory force up to only 20 %–40 % of that of healthy dentate persons.[34] This is due to decreased muscle activity as older people tend to have weak neuromuscular control.[35] Studies reported that the maximum bite strength for a complete denture was around 155N, with an average masticatory force of 43N.[36] Compared with this study's results, RetenDent's static and dynamic compressive strength is greater than this value. Therefore, RetenDent mini-implants are likely to have capabilities in need for application in clinical practice to retain prostheses.

Limitations

This study was an *in-vitro* study. It cannot simulate the actual intraoral environment. The load was applied only in a single direction. Temperature and humidity was not similar to the actual clinical situation. Future studies might consider artificial saliva baths and thermocycling.

Conclusions

RetenDent mini-implants are statistically higher in static compressive strength compared with OSSTEM mini-implants. Both RetenDent and OSSTEM mini-implants have higher static compressive strength than mean masticatory force in anterior and premolar regions

RetenDent has a higher dynamic compressive strength than OSSTEM and also has a higher number of survived cycles in all loading conditions except at 320N loads.

RetenDent's static and dynamic compressive strength was greater than maximum bite force for a complete denture.

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