The Impact of Notches on the Fracture Strength of Complete Upper Dentures: A Novel Biomechanical Approach

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Abstract

This paper focuses on introducing a new biomechanical method for estimating the fracture strength of complete upper dentures (CUDs) and evaluating which notch mode has the greatest impact on their strength reduction. Forty identical CUDs were constructed according to a previously applied methodology, and it was divided into four groups of ten specimens. This is dependent on the location and size of the notches in the labial region of the denture. The upper grip of a universal testing machine was replaced by a newly designed and constructed loading element for simulating the intraoral denture loading conditions. The fracture load and the deflection at fracture were measured, while the fracture energy was calculated (product of the load to the deflection) under compression. The measurement of fracture energy through the present novel method leads to more precise outcomes. The highest impact on the reduction of CUDs strength was for the combination group 4 with both the midline (incisal) diastema and deepened labial fraenal notch. Nevertheless, it gradually reduced for group 2 with midline (incisal) diastema, group 3 with deep labial fraenal notch, and group 1 with initial-shallow labial fraenal notch (P<0.001). The conditions for groups 2 and 4 strongly require reinforcement of the denture bases.

Keywords: Complete upper dentures, Fracture energy, Fracture strength, Incisal diastema, Labial fraenal notch

Introduction

The fracture of complete upper dentures (CUDs) is still an unsolved problem for clinicians (Polyzois et al., 1996; Morris et al., 1985; Saraf et al., 2013; Shimizu et al., 2005).

The deformation of such prostheses leading to fractures has its origin from a complex mechanical phenomenon which is dependent on many factors. The viscoelasticity of edentulous mucosa and its non-uniform thickness, the absence of an exact axis of symmetry, the variation in values and magnitude of loading, the thickness diversity in CUDs, and the torsional deformation of the CUDs during function in coexistence with the bending deflection are some of the mechanical factors that make the study of this issue difficult (Lambrecht & Kydd, 1962; Reddy et al., 2013; Prombonas et al., 2013).

The CUD base is subjected to various stresses during function, namely compressive, tensile, shear, and torsion that may lead to fracture. In order to withstand these stresses, the denture base material must possess good mechanical properties, and one of the most important is the fracture strength (Polyzois et al., 1996; Morris et al., 1985; Saraf et al., 2013; Shimizu et al., 2005).

Consequently, a method of assessing the effect of notches on the strength of CUDs is to measure the denture fracture strength. Many researchers have used a simplified method for studying the fracture strength of CUDs. They measured the fracture strength of the denture acrylic base without artificial teeth. The load is applied on the tissue surface of the denture base midline, in the area that corresponds to the premolar and first molar region (Polyzois et al., 1996; Morris et al., 1985; Saraf et al., 2013; Shimizu et al., 2005; Reddy et al., 2013; Sowmya et al., 2013). However, this method presents several weaknesses (Polyzois et al., 1996; Saraf et al., 2013).

Brittle materials that are normally used to fabricate dentures, such as polymethylmethacrylate (PMMA), exhibit greater compression strength (150 MPa) than tensile strength (80.4 MPa) and shear strength (122 MPa). Furthermore, they are sensitive to the presence of surface notches (O´Brien, 2002).

Despite wide clinical success to date, there has been limited fundamental understanding of the biomechanical consequences induced by surface notches which, among all the above mentioned factors, have a significant effect on the mechanical behavior of denture (Saraf et al., 2013; Morris et al., 1985; Polyzois et al., 1996; Shimizu et al., 2005; Hedzelek & Gaidus, 2006; Seo et al., 2006; Reddy et al., 2013; Sowmya et al., 2013; Al-Kadi et al., 2015). Although numerous studies refers to the contribution of surface notches to the failure of CUDs, there is considerable disagreement among researchers. In particular, some researchers stated that CUD fractures occurs due to the presence of labial fraenal notches (Morris et al., 1985; Lambrecht & Kydd, 1962; Cilingir et al., 2013; Farmer, 1983; Lamb et al., 1985; Hirajima et al., 2009; Hill et al., 1983), while others occurs due to both labial fraenal notches and midline (incisal) diastemas (Takamiya et al., 2012; Beyli & Fraunhofer, 1981; Matthews & Wain, 1956). The explanation given is that these features lead to eventual fracture by stress concentration (Dhiman & Chowdhury, 2009; Nejatidanesh et al., 2009; Stafford & Griffiths, 1979; Glantz & Stafford, 1983; Vallittu, 1996).

According to a survey of 489 questionnaires concerning complete denture repairs, the existence of midline (incisal) diastema, deep fraenal notch, and the combination of these two notches affected more than half of the dentures in need of repair. Although the prevalence of midline fracture of dentures with midline (incisal) diastema was higher than those with no diastema, there was no statistical significant difference. Thus, the existence of deep fraenal notch is strongly related to the prevalence of midline fracture (Zissis et al., 1997).

None of the mentioned studies have studied the impact of each one of these notches on the reduction of the fracture strength of CUDs.

Therefore, this paper focuses on introducing a new biomechanical method for measuring the fracture load and fracture energy of CUDs by simulating the intraoral functional loading mechanism to assess their fracture strength. The scope is also an answer to the controversy about which notch mode has the greatest impact on the fracture strength reduction of the CUD. Furthermore, this study provides a basis for understanding the local biomechanical responses of notches on fracture strength of CUDs, which is considered as a further approach to the overall understanding of the biomechanical behavior of CUDs.

Materials and Methods

Specimen Fabrication

Forty identical CUDs were constructed. Two commercial edentulous jaw molds were used (one for the maxilla and one for the mandible) (Edentulous molds, size 55, Columbia Dentoform, Long Island, New York, USA) to fabricate the dentures-specimens of the present study, according to a previously applied methodology and standard procedures (Prombonas et al., 2012; Prombonas et al., 2013; Zarb et al., 1997). The polymerized CUDs' teeth were made of the same material used to construct the denture bases. The acrylic dentures were finished according to standard finishing procedures for acrylic resin denture bases (Zarb et al., 1997). During the grinding and polishing of the acrylic resin dentures, their thickness was measured at seven points on both the labial (lateral incisors' region) and buccal flanges (first molars' region), as well as on the palatal midline, namely the second molar region, the first premolar region, and the anterior region. These measurements were made using an analog thickness gauge with 0.1 mm precision (K series, Schmidt Control Instruments, Waldkraiburg, Germany) to ensure that the bases of all the denture specimens had the same thickness (3.0 ±0.1 mm) (Prombonas et al., 2012; Prombonas et al., 2013).

Fracture Strength Testing: The New Method

Construction of the Solid Mandibular Acrylic Cast

The mandibular waxed denture was duplicated by taking an impression using a silicone putty (Bonasil Putty DMP Dental Industry S.A. Markopoulo Industrial Zone, Greece). Self-curing resin (Paladur, Heraeus Kulzer, Hanau, Frankfurt, Germany) was poured into the lower denture impression producing an acrylic resin mandibular cast.

However, the following methodology was followed to parallel the base of the mandibular cast to the occlusal plane: An aluminum plate was mounted on a surveyor's vertical arm (Kalantidis Co, Athens, Greece) being parallel to the horizontal plane. The lower acrylic resin mandibular cast was mounted below that plate using sticky wax. A plexiglass plate was secured on the surveying table. A small quantity of self-curing resin was placed on the plexiglass plate surface and the working arm was lowered embedding the acrylic resin mandibular cast in the resin. After the acrylic resin had polymerized, the base of the lower acrylic mandibular cast was parallel to the occlusal plane, as shown in Figure 1 below.

Figure 1. *The apparatus used for parallelizing the base of the lower acrylic cast to the occlusal plane.*

The Construction of the Modified Upper Grip

A modified Phywe testing machine (Universal Testing Machine, Phywe System GMBH, Gottingen, Germany) was used to measure the CUDs' fracture strength by simulating the real denture loading conditions during function. Thus, the upper grip of the machine was replaced by a loading element constructed via the following procedure: At first an acrylic replica of the maxillary midline area was constructed using the same commercial edentulous maxillary mold, as mentioned below. Two denture wax sheets (20mm in width) (Tenatex, Associated Dental Products, Wiltshire, UK) were positioned inside the mold of the edentoulus maxilla, on the left and right side of the midline, in an upright position, each at a distance of 7.5 mm bilaterally of the midline. Self-curing acrylic resin (Paladur, Heraeus Kulzer, Hanau, Frankfurt, Germany) was poured in the space between the two wax sheets. After the acrylic resin had polymerized, the midline area acrylic resin replica was removed from the mold. Its dimensions were 20 mm in length, 15 mm in height, and 7.5 mm in width.

A rectangular metallic base (50×20×15 mm) was constructed and welded to a screw (24 mm in diameter) of which the thread would be screwed onto the upper part of the universal testing machine. On the bottom and lateral surfaces of this rectangular base, small undercut cavities were generated using a special engineering drill. This rectangular base was mounted on the vertical arm of a surveyor, being horizontal (Kalantidis Co, Athens, Greece), using self-curing resin (Paladur, Heraeus Kulzer, Hanau, Frankfurt, Germany). The midline area acrylic resin replica was positioned on its corresponding site on the intaglio (inner) surface of one of the CUDs. The CUD was positioned in central occlusion with the acrylic resin mandibular cast. The acrylic resin mandibular cast, being parallel to the horizontal plane, was secured on the surveying table. A quantity of self-curing resin (Paladur, Heraeus Kulzer, Hanau, Frankfurt, Germany) was prepared and positioned on the upper surface of the midline area acrylic resin replica, whereas the surveyor's vertical arm was lowered to that point where the metallic rectangular base was embedded into the acrylic resin. Figure 2 shows the stabilization of the vertical arm with full polimerization of acrylic resin.

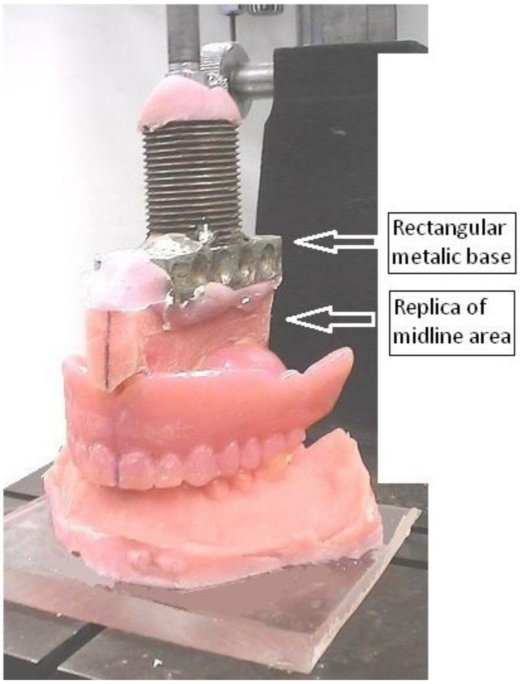

Figure 2. *The construction of the modified upper grip of the universal testing machine. The incorporation of the rectangular metallic base into the acrylic replica of the midline area.*

While the midline area acrylic resin replica was in place, the rest of the inner (intaglio) surface of the denture was filled in with silicone putty (Bonasil Putty DMP Dental Industry S.A. Markopoulo Industrial Zone, Greece). Following polymerization, these two silicone matrices adhered to the midline area acrylic resin replica using cyanoacrylate adhesive (Three Bond, Minamiosawa, Hachiojishi, Tokyo, Japan). The resultant hybrid cast, constituting of acrylic in the region along the midline and silicone in the remaining areas, was the upper loading element of the specimens. This loading element was screwed onto the upper part of the universal testing machine as shown in Figure 3. Each denture specimen loaded on this element was subjected to a pure bend since the midline of the hybrid mold is rigid, while its right and left areas are resilient.

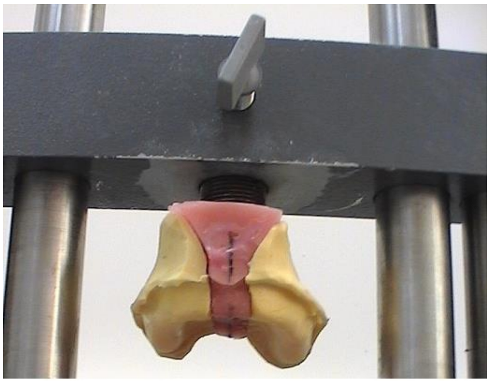

Figure 3. *The resultant hybrid cast (the upper loading element of the specimens), made of acrylic resin and silicone putty, screwed onto the upper part of the universal testing machine.*

Each CUD specimen was placed in centric occlusion with the acrylic resin mandibular cast, whereas the hybrid cast (being screwed onto the upper part of the machine) was positioned on the intaglio surface of the CUD in such a manner that the midline coincided with the loading axis of the testing machine.

Each denture specimen was loaded under compression at a crosshead speed of 5 mm/min (Saraf et al., 2013; Morris et al., 1985; Polyzois et al., 1996; Reddy et al., 2013).

The prepared CUDs-specimens were tested for their fracture threshold via the universal testing machine to obtain two values, the load at which CUDs fracture (fracture load in kN) and the amount of deflection at fracture (fracture deflection in mm). These two values were recorded by the chart recorder of the machine. Using these two values, a third value that is the fracture energy was calculated as the product of the load to the deflection, in J (N × m) (Seo et al., 2006).

A typical denture fracture pattern is shown in Figure 4.

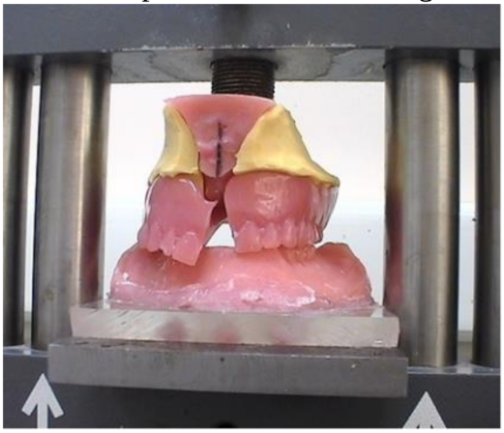

Figure 4. *The fracture of the CUD-specimen in two pieces, along the midline as in the intraoral conditions.*

Statistical Analysis

Having a low number of specimens per group (ten), nonparametric tests were applied for the statistical analysis using standard statistical software (SPSS version 15.0 for Windows, Chicago, Illinois, USA). The Kruskal–Wallis test was used to assess variations of the means among the four groups (notch conditions). The Mann-Whitney test for two independent samples was used to determine the significance of differences in the fracture load magnitudes between all possible pairs of notch conditions, with a probability level of $P = 0.05$.

Results

Descriptive statistics were calculated. The mean, range, and standard deviation of the maximum fracture load (kN), deflection at fracture (mm), and fracture energy (J) for the four groups of this study are given in Table 1.

Table 1. *Results of fracture load, fracture energy and deflection at fracture of complete upper dentures-specimens (n =10)*

	GROUP 1	GROUP 2	GROUP 3	GROUP 4
FRACTURE LOAD (kN)				
Mean	4.15	2.27	2.73	1.94
Range	0.40	1.20	1.65	1.35
St. Deviation	0.13	0.39	0.51	0.55
FRACTURE ENERGY (J)				
Mean	7.91	3.16	4.56	2.56
Range	3.06	1.80	3.30	3.44
St. Deviation	1.02	0.59	1.10	1.19
DEFLECTION AT FRACTURE (mm)				
Mean	1.90	1.39	1.66	1.26
Range	0.56	0.52	0.53	0.82
St. Deviation	0.19	0.14	0.17	0.27

Highly significant variance of means was found among the four groups for fracture load, fracture energy, and deflection at fracture (Kruskal–Wallis test, $P<0.001$).

It is clear from Table 1 that group 1 (complete denture with shallow initial fraenal notch) showed the highest mean value in fracture load (fracture strength) as well as in fracture energy, compared to group 2 (incisal diastema between central incisors), group 3 (deep labial fraenal notch), and group 4 (combination of deep labial fraenal notch and diastema) (statistical significance regarding all the above mentioned pairwise comparisons $P<0.001$).

The results revealed statistically significant differences in means for fracture energy between the groups 2 and 3 ($P=0.005$) as well as 3 and 4 ($P=0.002$) but not between groups 2 and 4 ($P=0.218$). As far as it concerns the differences in means for fracture load, these were statistically significant only between groups 3 and 4 ($P=0.007$). No statistically significant difference was found for the fracture load between the groups 2 and 3 as well as 2 and 4 ($P = 0.063$ and $P = 0.123$ respectively).

Group 4 (combination of midline (incisal) diastema and labial fraenal notch deepening) had the lowest mean values among the four groups of notches, for both fracture load and fracture energy. These mean values presented a statistically significant difference when compared to those of group 3, but did not present a statistically significant difference when compared to group 2.

Considering deflection, high statistically significant variance of means was found among the four groups (Kruskal-Wallis test $P<0.001$). The maximum mean deflection was recorded for group 1 (1.90 mm) whereas the minimum for group 4 (1.26 mm). Pairwise comparisons of the mean deflection values among all groups showed statistically significant difference ($P \leq 0.009$), except for the pair of groups 2 and 4 ($P = 0.529$).

Figures 5, 6, and 7 are bar graphs for fracture load, fracture energy and deflection at fracture, respectively. The horizontal lines link the groups whose average values differ statistically to a significant level.

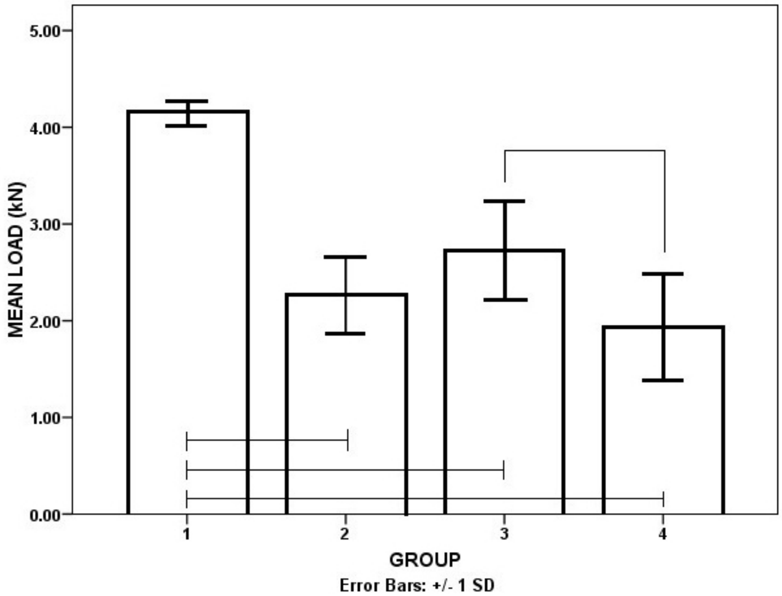

Figure 5. *The mean values of load at fracture among the four groups and the pairs of groups with statistically significant differences (connection with horizontal lines).*

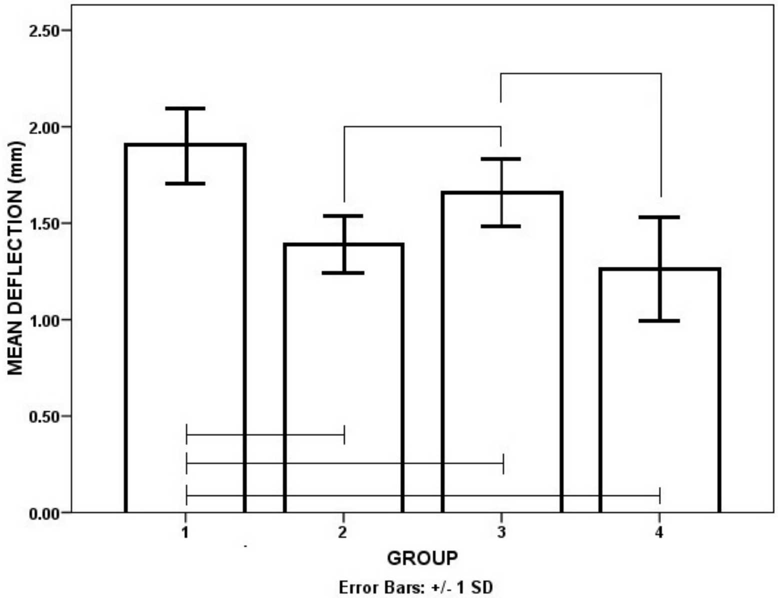

Figure 6. *The mean values of deflection at fracture and the pairs of groups with statistically significant differences (connection with horizontal lines).*

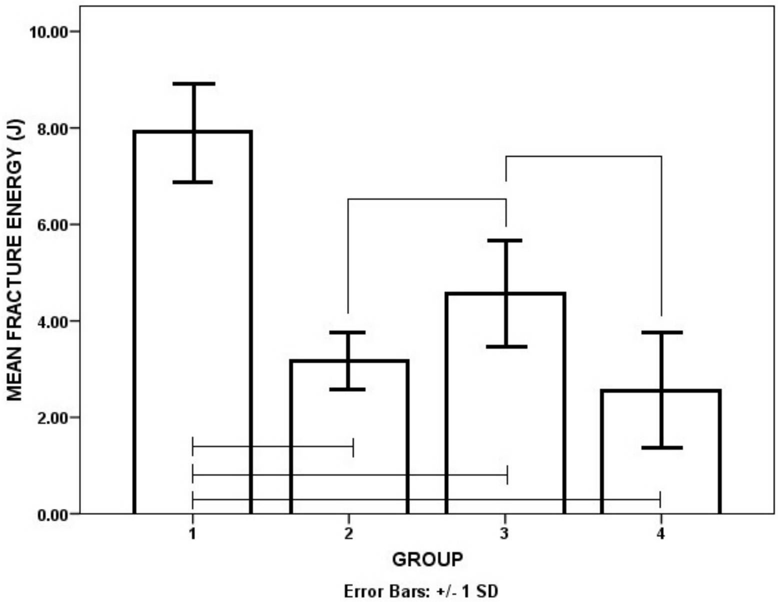

Figure 7. *The mean values of fracture energy among the four groups and the pairs of groups with statistically significant differences (connection with horizontal lines).*

Discussion

In the present study, the fracture strength, deflection at fracture, and fracture energy of CUDs were measured.

Regarding the latter, some researchers have used the formula "fracture energy = ½ × fracture load × deflection", in kgr/cm units (Morris et al., 1985; Reddy et al., 2013; Sowmya et al., 2013). Other researchers avoided calculating the fracture energy, estimating the fracture strength based only on the fracture load measurement (Saraf et al., 2013; Polyzois et al., 1996; Shimizu et al., 2005; Hedzelek & Gaidus, 2006; Al-Kadi et al., 2015). In the present study, the fracture energy was calculated as the product of fracture load and deflection at fracture, as mentioned by previous studies (Seo et al., 2006).

Measurement of CUDs' fracture energy by this novel biomechanical methodology presented in our study (simulation of intraoral loading mechanism) has not been reported to the available literature. Therefore, direct comparison cannot be made. Nevertheless, according to the available literature, the measured fracture load ranged between 0.69 and 1.16 kN (Saraf et al., 2013), 0.79 and 2.01 kN (Shimizu et al., 2005), 0.7 and 0.9 kN (Polyzois et al., 1996), 0.7 and 1.3 kN (Seo et al., 2006), or 0.56 and 1.89 kN (Al-Kadi et al., 2015). These values are typically lower than those measured in this study, given that the load was applied at one particular point resulting in high load concentration and leading to rapid failure of the denture.

Other researchers have also stated that measuring the deflection and fracture strength of identical plain acrylic denture bases (with no teeth) by loading them on an arbitrary point of the intaglio surface (methodology used in previous studies) had several weaknesses (Saraf et al., 2013; Polyzois et al., 1996). This is verified by the mode of fracture observed in some of these studies, where the bases fractured in three pieces (Morris et al., 1985; Sowmya et al., 2013). This fracture mode is never (or extremely rarely) encountered in the functional fracture (due to fatigue) of CUDs in the oral cavity.

The CUD presents uniqueness as a loadable structure due to some distinct features like: lack of symmetry, fluctuating cross-section, complexity of applied loads during normal function in both magnitude and direction, and non-uniformity of load distribution throughout the specimen (Lambrecht & Kydd, 1962; Prombonas et al., 2012; Prombonas et al., 2013; Reddy et al., 2013).

In order to simulate the above mentioned functional load conditions of CUDs, a new biomechanical approach for measuring the fracture strength of CUDs was applied in this study. This explains why all CUDs-specimens of the present study were fractured in two pieces along the midline, as it happens when fractured in the oral cavity. An additional reason that the specific design of the midline area acrylic resin replica was implemented in the study was to simulate the rigidity of the palatal raphe compared to the flexibility that the rest of the palatal area presents (Zarb et al., 1997).

It was shown that the presence of notches (group 1 compared to groups 2, 3, and 4) drastically reduced the fracture load and fracture energy, as well as the deflection at fracture of the CUDs-specimens.

Among the groups 2 and 3, group 2 (after generating a midline (incisal) diastema (7mm) by grinding in between the two central incisors) showed lower fracture load and fracture energy compared to group 3 (deepening the initial labial fraenal notch by 2 mm to a total notch length of 7 mm). However, this difference was statistically significant only for fracture energy. According to previous work, the impact of notches in the fracture of CUDs was not clear, namely the frequency of midline fracture of dentures with incisal diastema was higher than those without diastema, with no statistical significance, whereas the existence of deep labial fraenal notch was strongly related to the frequency of midline fracture (Zissis et al., 1997).

From the present study, it can be assumed that the fracture energy measurement (as the product of two physical quantities), compared to fracture load, is more sensitive on estimating the statistical differences, leading to more precise outcomes.

Furthermore, by considering groups 1, 2 and 3, it was shown that the presence of incisal diastema (group 2) lowers the fracture strength to a significant level compared to the presence of a labial fraenal notch regardless of whether it is shallow or deep. This leads to the assumption that the incisal diastema has the greatest impact on reducing the fracture strength of CUDs, compared to the other two types of notches (groups 1 and 3). Furthermore, this finding is in agreement with a previous study where it has been shown that it is less likely that a failure crack in a CUD will be initiated from the fraenal notch region. This is due to the compressive nature of the principal stresses and the low value of the maximum shear stress in this region (Prombonas et al., 2012).

The combination of midline (incisal) diastema and labial fraenal notch deepening (group 4) had the lowest mean values among the four groups of notches, for both fracture load and fracture energy. These mean values presented a statistically significant difference when compared to those of group 3 but did not present a statistically significant difference when compared to group 2. The above finding showed that among the three notch conditions (groups 2, 3 and 4), the incisal diastema generation (group 2) decreases the fracture strength to a statistically significant low level (compared to group 3) which is close to the fracture strength level shown when combining the deepening of the labial fraenal notch and the midline (incisal) diastema generation (group 4). These two conditions (groups 2 and 4) strongly require reinforcement of the denture bases.

Answering to the scope of the present study, concerning the impact of each one of the notch conditions on the reduction of the fracture strength of the CUD, the highest was for the combination of the labial fraenal notch deepening and the midline (incisal) diastema generation (group 4). Also, it gradually reduced for the midline (incisal) diastema generation (group 2), the labial fraenal notch deepening (group 3), and the shallow (initial) fraenal notch (group 1). The above findings are also an answer to the existing controversy of which notch mode, among the incisal diastema and the fraenal notch, presents the highest impact on the reduction of CUDs strength.

The current findings reveal the necessity of CUD reinforcement in cases that involve deep labial fraenal notch but especially in the case of midline (incisal) diastema or its combination with deep labial fraenal notch.

Conclusion

The new biomechanical approach applied in this study for measuring the fracture strength of the CUD is an excellent simulation of the denture load in the oral cavity. In estimating statistically the differences in fracture strength of CUD, the measurement of fracture energy through the present novel biomechanical method is more sensitive than the measurement of fracture load, leading to more precise outcomes.

The midline (incisal) diastema and the combination of a deep labial fraenal notch with a midline (incisal) diastema lowers the strength significantly compared to the shallow labial fraenal notch. Thus, such conditions require reinforcement of the denture bases.

References:

1. Ali Al-Kadi, F.K., Abdulkareem, J.F. & Al-jmoor, C.A. (2015). Fracture strength of palatal denture base constructed from different acrylic denture base materials. European Scientific Journal; 11:354-364.
2. Beyli, M.S. & von Fraunhofer, JA. (1981). An analysis of causes of fracture of acrylic resin dentures. J. Prosthet. Dent.; 46:238-241.
3. Cilingir, A., Bilhan, H., Baysal, G., Sunbuloglu, E. & Bozdag, E. (2013). The impact of frenulum height on strains in maxillary denture bases. J. Adv. Prosthodont; 5:409-415.
4. Dhiman, R.K. & Chowdhury, S.R. (2009). Midline Fractures in Single Maxillary Complete Acrylic vs Flexible Dentures. Med. J. Armed Forces India; 65:141-145.
5. Farmer, J.B. (1983). Preventive prosthodontics: Maxillary denture fracture. J. Prosthet. Dent.; 50:172-175.
6. Glantz, P.O. & Stafford, G.D. (1983). Clinical deformation of maxillary complete dentures. J. Dent.; 11:224–230.

7. Hedzelek, W. & Gajdus, P. (2006). Comparison of mechanical strength of palatal denture bases made from various plastic materials. Int. J. Prosthodont; 19:193-194.
8. Hill, E.G., Bates, J.F., Lewis, T.T. & Rees, N. (1983). Fracture toughness of acrylic denture base. Biomaterials; 4:112-120.
9. Hirajima, Y., Takahash, H. & Minakuchi, S. (2009). Influence of a denture strengthener on the deformation of a maxillary complete denture. Dent. Mater. J.; 28:507–512.
10. Lamb, D.J., Ellis, B. & van Noort, R. (1985). The fracture topography of acrylic dentures broken in service. Biomaterials; 6:110-112.
11. Lambrecht, J.R. & Kydd, W.L. (1962). A functional stress analysis of the maxillary complete denture base. J. Prosthet. Dent; 12:865-872.
12. Matthews, E. & Wain, E.A. (1956). Stresses in denture bases. Br. Dent. J.; 100:167-171.
13. Morris, J.C., Khan, Z. & von Fraunhofer, J.A. (1985). Palatal shape and the flexural strength of maxillary denture bases. J. Prosthet. Dent.; 53:670-673.
14. Nejatidanesh, F., Peimannia, E. & Savabi, O. (2009). Effect of labial frenum notch size and palatal vault depth on stress concentration in a maxillary complete denture: a finite element study. J. Contemp. Dent. Pract.; 10:59-66.
15. O'Brien, W.J. (2002). Dental materials and their selection, 3d edn. Chicago: Quintessence Publications Co. Inc; p.p. 1–17. 352. 369. 375.
16. Polyzois, G.L., Andreopoulos, A.G. & Lagouvardos, P.E. (1996). Acrylic resin denture repair with adhesive resin and metal wires: effects on strength parameters. J. Prosthet. Dent.; 75 :381-87.
17. Prombonas, A.E., Vlissidis, D.S., Paralika, M.A. & Poulis, N.A. (2012). The stress state of the fraenal notch region in complete upper dentures. Med. Eng. Phys.; 34 :1477–1482.
18. Prombonas, A.E., Paralika, M.A. & Poulis, N.A. (2013). Investigation of the torsional deformation of the complete upper denture: A pilot study. J. Biomed. Sci. Eng.; 6:443-448.
19. Reddy, B.M., Himabindu, M., Padmaja, B.I., Sunil, M. & Reddy, N.R. (2013). Palatal vault depth influence on the flexural strength of two heat cure acrylic denture base resins: an in vit30ro study. J. Contemp. Dent. Pract.; 14:1131-1136.
20. Saraf, V.R., Shetty, V., Anandakrishna, G.N. & Rairam, S.G. (2013). Comparison of mechanical strength of palatal denture bases made from three commercially available high impact acrylic resin denture base materials in different palatal vault configuration – An invitro study. J. Oral Health Res.; 4:1-7.

21. Seo, R.S., Murata, H., Hong, G., Vergani, C.E. & Hamada, T. (2006). Influence of thermal and mechanical stresses on the strength of intact and relined denture bases. J. Prosthet. Dent. 2006 ; 96:59-67.
22. Shimizu, H., Tsue, F., Obukuro, M., Kido, H., Takahashi, Y. & Ohmura, H. (2005). Fracture strength of metal-based complete maxillary dentures with a newly designed metal framework. Int. Chin. J .Dent.; 5:35-38.
23. Sowmya, S., Dhakshaini, M.R., Gujjari, A.K., Ravi, M.B. & Raghavendra Swamy, K.N. (2013). Palatal Vault Depth Influence on the Flexural Strength of Two Heat Cure Acrylic Denture Base Resins - An *In vitro* Comparative Study. World Appl. Sci. J.; 21:1290-1294.
24. Stafford, G.D. & Griffiths, D.W. (1979). Investigation of the strain produced in maxillary complete dentures in function. J. Oral Rehabil.; 6:241–256.
25. Takamiya, A.S., Monteiro, D.R., Marra, J., Compagnoni, M.A. & Barbosa, DB. (2012). Complete denture wearing and fractures among edentulous patients treated in university clinics. Gerodontology; 29:728–734.
26. Vallittu, P.K. (1996). Fracture surface characteristics of damaged acrylic-resin-based dentures as analysed by SEM-replica technique. J. Oral Rehabil.; 23:524–529.
27. Zarb, G.A., Bolender, C.I., & Carlsson, G.E. (1997). Boucher's prosthodontic treatment for edentulous patients, 11th edn. St. Louis: C.V. Mosby; p.p. 332.346.
28. Zissis, A.J., Polyzois, G.L. & Yannikakis, S.A. (1997). Repairs in complete dentures: results of a survey. Quintessence Dent. Technol.; 20:149-155.