ORİJİNAL ARAŞTIRMA ORIGINAL RESEARCH

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Preliminary Investigation of the Biomechanics of Unilateral Chewing Comparing Two Testing Models: *In Vitro* Study

İki Farklı Test Modelinin Karşılaştırılarak Tek Taraflı Çiğnemenin Biyomekaniğinin Öncü Araştırması: *İn Vitro* Çalışma

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ABSTRACT Objective: This article reports a preliminary study undertaken to investigate the biomechanics of unilateral chewing due to lateral segmental defects extending to angulus, introducing modified designs of 3-point and 2 point testing models. Data concerning test set-ups used in biomechanic studies of mandible in the literature have been analysed. **Material and Methods:** Load/displacement data were gathered for the mandibles with the same defect and reconstructed with reconstruction plate in a standart way. Standard models underwent unilateral loading with two different test set-up. The first set-up was consistent with 3 point testing model (Group I) while the second set-up was simulating 2 point testing model (Group II). Furthermore, literature related with *in vitro* studies of mandible were searched and testing set-ups used in these studies were evaluated. **Results:** The mean displacement for Group I was 12.11 mm (±3.36), Group II was 19.56 (±0.92) mm. Group II had significantly greater (p=0.000) displacement when compared with Group I. The mean force before failure for Group I was 850.3 N (±136.1 N), Group II was 1117.83 N (±107.3 N). Models tested with two point system failed at significantly greater force (p=0.000), **Conclusion:** Three point testing model was more efficient and reflecting the chewing forces better under unilateral loading. Many biomechanic studies in the literature adopted three point system for their studies.

Keywords: Mandible reconstruction; jaw neoplasms; mouth neoplasms

ÖZET Amaç: Bu makale, angulusa uzanan lateral segmental defekt sebebiyle meydana gelen tek taraflı çiğnemenin biyomekaniğini araştırarak, 2 nokta ve 3 nokta test modellerinin modifiye dizaynlarının denendiği öncü çalışmayı rapor etmektedir. Mandibulanın biyomekanik çalışmalarında kullanılan deney düzeneği bilgileri de analiz edilmiştir. **Gereç ve Yöntemler:** Aynı standart defekt oluşturulmuş ve rekonstrüksiyon plağı ile aynı standart yöntem ile rekonstrükte edilmiş mandibulalarda yük/displasman verileri elde edilmiştir. Standart modeller 2 farklı deney düzeneğinde sabitlenerek tek taraflı yüklemeye maruz bırakılmıştır. Birinci deney düzeneği (Grup I) 3 nokta test modeli ile uyumlu iken 2. deney düzeneği (Grup II) 2 nokta test modelini simüle etmektedir. Ayrıca mandibulanın *in vitro* çalışmaları ile ilgili literatür taranarak, bu çalışmalarda kullanılan deney düzenekleri değerlendirilmiştir. **Bulgular:** Ortalama yer değişikliği Grup I'de 12,11 mm (±3,36), Grup II'de 19,56 (±0,92) mm olarak bulunmuştur. Grup II Grup I ile karşılaştırıldığında istatistiksel olarak anlamlı oranda daha fazla displasman göstermiştir (p=0,000). Başarısızlığa neden olan ortalama maksimum kuvvet Grup I'de 850,3 N (±136,1 N), Grup II'de 1117,83 N (±107,3 N) olarak bulunmuştur. İki nokta sisteminde teste tabi tutulan modeller anlamlı olarak daha fazla kuvvet dayanımı göstermiştir (p=0,000). **Sonuç:** Üç nokta test modeli daha etkindir ve tek taraflı yüklemede çiğneme kuvvetlerini daha iyi taklit edebilmektedir. Birçok biyomekanik çalışmada, deneylerinde 3 nokta test modelini benimsemişlerdir.

Anahtar Kelimeler: Mandibula rekonstrüksiyonu; çene neoplazmları; ağız neoplazmları

Biomechanical studies to get better understanding of fixation systems have been carried on ortognathic, trauma or segmental defect models. Fixation systems were tested with chewing forces after securing the models in a set-up. Researchers developed 2 point and 3 point test set-ups basicly although a few

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more systems that modified these two main systems were published in the literature. Vertical loading was simulated actually in studies, whereas lateral and rotational forces may be encountered clinically especially in segmental defect cases whom might chew unilaterally or have lost majority of chewing muscles on related side due to surgical resection.

Biomechanical studies carried on models with segmental defects were predominantly tested with three point test set-up and under bilateral loading.[1,2] Rendenbach et al. compared fixation systems on reconstruction models with 2 point test set-up under unilateral loading.[3]

The aim of this preliminary biomechanical study is to compare two point system and three point system for standart models with segmental defect that would undergo unilateral chewing and to find out which one is simulating reality better. Furthermore, we reviewed the literature about the testing set-ups used in biomechanic studies of mandible.

MATERIAL AND METHODS

The Ethics Committee of University of Kâtip Çelebi exempted the study from review since it does not require the ethics committee approval for its conduct (18.02.21 and no.2021/0033). Twelve synthetic polyurethane mandibles (B-Tech, Ankara, Turkey) were used in this study. This study follows the Declaration of Helsinki.

Two different experiment set-up methods were compared for the same models. In both testing groups, a 2.4 mm locking reconstruction plate (Trimed, Ankara, Turkey) was used and manually bent by the same investigator to the reconstruction model after marking the defect border. The plates were shortened to 19 insertion holes. Fixation was performed using four titanium locking screws of 12 mm length for both side of defect. Perforations were made with 1.8 mm diameter drill and a drill guide.

A standart defect was created for both groups. The defect extended between the left first premolar tooth and left mandibular ramus of the polyurethane mandibles to which bended reconstruction plates were applied. Although applied defect simulated the ostectomies performed during the surgical treatments of benign tumours or neoplasias, this type of defect that include angulus was rare that has been tested biomechanically.

BIOMECHANICAL TEST SET-UPS

A servohydraulic testing machine (TST 2500 mxe, MARESTEK Electronic Informatics System Design Ltd, Istanbul, Turkey) was used for this biomechanical test. The outline of the first test set-up (Group I) was similar to that of the Schupp et al. and Gutwald et al.'s test set-up.[2,3] A stainless steel sylindrical rod was fixed to load cell of the servohydrolic testing machine and the rod pressed to the contralateral angulus with increasing forces since ipsilateral angulus region was resected (Figure 1).

Second test set-up (Group II) was constructed like the system applied by Rendenbach et al. Both condyles and ramus region were fixed with screws and metal support. Loading was applied to contralateral dental support in which two point system was simulated (Figure 1). These two different set-ups were compared under unilateral loading.

Loads were generated at a rate of 1 mm/min until failure of sample. Outcomes of experiment were recorded for each sample.

Loading was carried on until failure or plastic deformation of models. Permanent deformation was identified as the point at which the slope of the load vs displacement curve became non-linear. Plate breakage, model failure or screw pull-out were other accepted failure mechanisms. The load at which these failure types observed was used as the failure load.

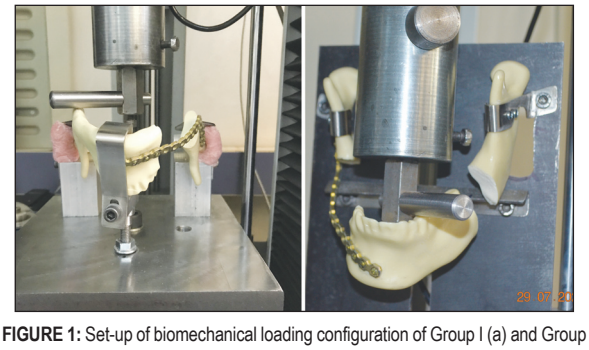

FIGURE 1: Set-up of biomechanical loading configuration of Group I (a) and Group II and failure of model (b).

OUTCOME VARIABLES AND DATA ANALYSIS

Mean yield displacement, yield load (failure load), were recorded by using data generated on test machine. Moreover displacement amounts at 80 N, 100 N, 200 N, 300 N, 400N, 500N loading and load for displacements of 1, 3, 5 mm were quantified for both groups.

The collected data were statistically analysed with SPSS (Statistical Package for the Social Sciences) 15.0 programme. To compare two different test set-up, independent samples t test was used. The level of statistical significance was accepted as $p<0.05$.

RESULTS

Six models which were tested in three point set-up (Group I) showed a mean yield displacement of 12.11 mm (±3.36). However, the six models which were tested in two point set-up (Group II) showed a mean yield displacement of 19.56 (±0.92) mm when loading force was applied to contralateral side of mandible. There was a statistically significant difference in means of displacement amounts at failure between two groups (p=0.000) (Table 1).

Standart models tested in Group I and Group II withstood 850.3 N (±136.1 N) and 1117.83 N (±107.3 N) average force before failure, respectively. Group II could with stand significantly greater mean force before failure than that of Group I (p=0.004) (Table 1).

Pairwise comparisons revealed that the mean displacements at 80N, 100N, 200N, 300N, 400N, 500N loadings of two point set-up (Group II) was significantly greater than that of three point set-up (Group I) ($p<0.05$) (Figure 2).

Loading values that result with 1, 3, 5 mm displacement were compared. Models in Group II showed 1, 3 and 5 mm displacements under significantly lower forces comparing with Group I (Figure 3).

Plate deformation and breakage of the screw were seen in two models in Group I. Screw pullout was registered as failure modality for remaining 4 models in Group I. Model fracture was the main modality of failure in Group II.

TABLE 1: Peak load and displacement values for Group I and Group II and comparison of two groups.

	Group I (mean±SD)	Group II (mean±SD)	Significance level (2-tailed)
Maximum displacement	12.11 mm (±3.36)	19.56 (±0.92)	0.000
Maximum load	850.3 N (±136.1 N)	1117.83 N (±107.3)	0.004

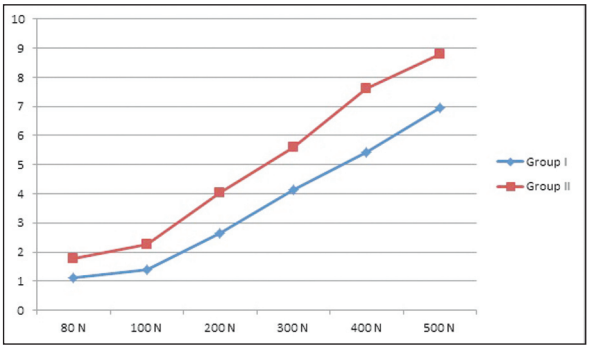

FIGURE 2: Displacement of Group I and Group II at increasing loads.

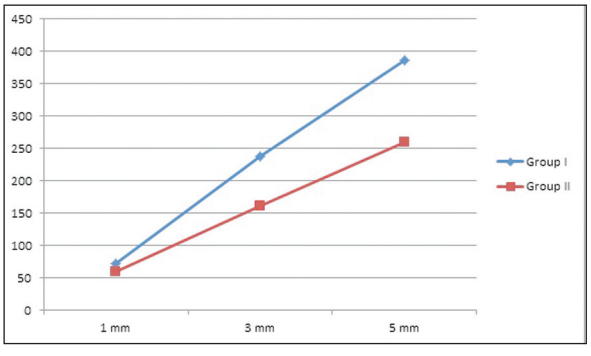

FIGURE 3: Load values at 1, 3 and 5 mm displacement.

DISCUSSION

In vitro testing of osteosynthesis systems has been done by using human cadaver mandibles, sheep mandibles, polyurethane mandibles. To compare the results with literature available and to obtain consistent values, standardization of each variable is a must. Then polyurethane mandibles are a leap forward than animal or cadaver mandibles to serve a standart substratum for biomechanical studies. Many studies support polyurethane substrates for biomechanical investigations since it is proved that polyurethane showed similar biomechanic properties with native bone.[4] To investigate the biomechanic behaviours of

experimental systems, reproducible *in vitro* testing method simulating chewing in the best way needs to be developed. Three point model is an agreed method to test materials for sagittal split osteotomy and angulus fractures.[5-7]

Previously published studies have used a 2-point loading model in which proximal end of the plated specimen is secured while a force is applied to the distal end, opposite end of defect line in another words (a cantilevered beam model).[8-10] Two point system was criticized that it could not replicate assymetric bending or torsional movements of the human mandible when in function and the complex interactions among bone and muscle.[11] As a consequence, Armstrong is the first to define 3 point system which is simulating chewing as if it is a isometric contraction like nature.[12] However, loading was generated in vertical direction as in the 2 point model. A study which compares the stability of three different locking osteosynthesis systems used four point bending system. Four point bending system which was tried on straight block instead of mandible shaped substrate has been developed by modifying three point model.[13]

In the current study, we aimed to find ideal experimental set-up for lateral segmental defects which undergo unilateral forces. Two main set-up systems, three point model and two point model, under unilateral loading were compared. The results published by Fontana et al. showed 2,3 mm plate withstood 737.8N (±72.5 N) force before failure in three point system under bilateral loading.[14] In the current study, models with larger defects reconstructed with 2,4 mm locking reconstruction plate which were tested with three point system under unilateral loading gave 850.3 N (±136.1 N) maximum loading amount. Slightly higher values that is obtained in our study could be explained with loading side or difference in plate thickness. In our study, models that were tested in two point system could withstand 1117.83 N (±107.3) N before failure. Although the same reconstruction models were used, a statistically significant difference have been found in term of strength. This could be explained both with difference in failure modalities and difference in load distrubution between two groups. Screw pullout was predominantly observed in Group I as main failure modality was model fracture in Group II. Screw pull-out came earlier than the model fractures and two point testing model conduct the load to model instead of distrubuting the chewing force to hardware and screws.

The mean displacements were reported as 5.79 (±0.89) mm and 6.03 (±1.59) mm for 2,3 mm reconstruction plate and 2,7 mm reconstruction plate, respectively.[14] In our study, maximum displacement amount was 12.11 mm (±3.36) for Group I as the defect size is longer than the previous study of Fontana et al. and unilateral loading was applied to models in our study.[14] In Group II, significantly higher displacement values at mentioned loading amounts and at failure were reported.

However, Doty et al. reported incomparable higher yield displacement amounts such as 94±15, 99.8±0.3 and 99.7±0.4 mm for 2,4 low profile reconstruction plates, 2,4 reconstruction plates and 3,0 locking reconstruction plates in lateral segmental defects of mandible respectively.[15] Inconsistency between displacement values reported by Doty et al. and of the present study and could be explained with difference in testing set-up. Doty et al. applied a different kind of two point method in which only one condyle was fixed and contralateral loading was applied.[15] This kind of set-up conflict with the nature since the condyle could not allow such high diplacement in case of chewing. However, in biomechanical studies, the most important point is to standardization of experimental set-up in itselves for whole groups of a study to obtain comparable values. Although standardization of testing set-up among groups of each different study could be obtained, a seek for ideal and uniform set-up which simulates unilateral chewing best is ongoing. Two point system in reverse position as described by Dickard and Klotch is an another modification of 2 point system.[16]

Since the main aim of this study is to compare experimental set-ups, we have chosen some studies to compare that have similar variables but used two different experimental set-ups. Ribeiro-junior et al. verified the resistance to displacement of miniplate fixation methods after SSRO with 3 point testing method.[5,6] Oguz et al. compared similar fixation systems after SSRO with 2 point testing method.[17]

Avarage load for 3 mm displacement in models fixated with 4 hole miniplate and screws were 49,2 N and 16,9 N respectively, in Ribeirojunior et al's and Oguz et al's studies.[5,6,17] Furthermore, avarage force for 3 mm displacement in models fixated with 4 hole locking systems were reported as 55,2 N and 24,6 N respectively, in 3 point testing model and 2 point testing model.[5,6,17] The biomechanical tests performed by using a two-point model (cantilevered beam model) gave higher displacement values which is against the nature of isometric like chewing contractions.

Bayram et al. and Esen et al. have investigated same materials (2 mm 4 hole miniplate fixation) on angulus fractures of sheep hemimandibles by using 3 point system and 2 point experimental set-up, respectively.[18,19] Both of them have reported mean displacement values under 20 and 60 N loading. While Bayram et al. reported 0,46 mm displacement value at 60 N loading, Esen et al. reported 2,68 mm displacement at the same loading amount.[18] As mentioned before, 2 point system gave higher displacement values under certain forces.

Biomechanic studies of segmental defects of mandible are more complicated than studies investigating SSRO or fractures. The models which were used in studies investigating SSRO were 2-dimensional. The researchers used hemimandibles to simplify experiment.[20-22] However, it seems impossible for mandibles with segmental defect in which hardwares have already crossed the midline or there were limited area to apply load cell.[2,3] As a consequence, segmental defect studies have been run on whole mandibles instead of hemimandibles trying to represent 3-dimensional clinical environment in the best way. Use of hemi-mandible models in studies of SSRO was criticized since insufficient demonstration of mandible movements may as well result with error in load distrubution. To overcome this problem, a six-point biomechanical test unit was presented.[23] Cilasun et al. suggested adding a piece to set-up to allow the rotation of the condylar segment in a transverse plane. However, lateral movements could not be displayed even with this detail.[24]

In biomechanical studies, loads were generated in vertical direction in both 2 point and 3 point systems.[25,26] Futhermore, studies investigating biomechanical behaviour of test materials on lateral segmental defects of mandible applied vertical forces to models. Although 30-70% load distrubution for resected-unresected side were used by researchers, load characteristic was again vertical.[1] However, lateral and rotational forces should be considered and simulated by an ideal set-up to obtain better results.

In the current study, we compared two point testing set-up and three point testing set-up for lateral segmental defects under unilateral forces. Three point testing set-up simulate torsional, rotational forces better than two point set-up. Screw pull-out was the main failure reason in three point testing system which is indicating torsional forces could be applied. Screws closest to and farthest from the resection margin on the proximal residual segment appeared to be most prone to loosening in a photoelastic study.[27] In our priliminary study, it is observed that screws farthest from resection margin on proximal side have been pulled out under loading. Then the first set-up in the current study which was a modified kind of 3 point system is simulating *in vivo* better than the second one. However, in our study model, fractures in contralateral angulus have been observed as a failure mechanism in Group II which is unexpected kind of failure *in vivo*. Screw pull-out is more realistic failure type which is indicating overloading on screws.

CONCLUSION

The main weaknesses of testing set-ups are that only vertical loading was simulated. However, complex bilateral movement of the mandible, especially during unilateral chewing, may affect the biomechanical results. In the current study, it is claimed that 3 point system with unilateral loading is simulating lateral bending movements or rotational forces better than 2 point system. However, data obtained from biomechanical studies should be supported by clinical outcomes to direct conclusions about fixation systems.

Higher displacement values that are obtained in 2 point testing set-up conflicts with the nature of chewing. As isometric like contractions exist during chewing a bolus between teeth, increase of loading rather than displacement should be encountered in biomechanic studies. However, in two point testing

set-up, higher displacement values have been obtained which has no counterpart in clinic.

Source of Finance

During this study, no financial or spiritual support was received neither from any pharmaceutical company that has a direct connection with the research subject, nor from a company that provides or produces medical instruments and materials which may negatively affect the evaluation process of this study.

Conflict of Interest

No conflicts of interest between the authors and / or family members of the scientific and medical committee members or members of the potential conflicts of interest, counseling, expertise, working conditions, share holding and similar situations in any firm.

Authorship Contributions

This study is entirely author's own work and no other author contribution.

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