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# Biomechanical Evaluation of Locking Reconstruction Plates Fixed with Three Versus Four Screws Perside for Lateral Segmental Defects of Mandible with A Servohydraulic Testing Method: An *In Vitro* Study

## Mandibular Lateral Segmental Defektin Her İki Tarafına Üçer veya Dörder Vida ile Sabitlenen Kilitli Rekonstrüksiyon Plaklarının Servohidrolik Test Metodu ile Biyomekanik Değerlendirmesi: *In Vitro* Çalışma

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**ABSTRACT Objective:** Surgical treatments of neoplasias may result in segmental loss of mandible with limited remaining bone stumps. Locking recontruction plates are being used to bridge mandibular discontinuities caused by resections. The aim of this study is to evaluate biomechanical resistance of mostly recommended numbers of screws when locking systems were used for lateral segmental defects. **Material and Methods:** This *in vitro* study was conducted on polyurethane mandibles with simulated lateral segmental defects extending to angulus. 13 synthetic polyurethane mandibles were used in this study. Mandibles were fixed with four screws and three screws on each segment in Group I and II, respectively. Mean yield displacement, yield load, loading values at 1, 3, 5 mm diplacement and displacement at 80 N, 100 N, 200 N, 300 N loading were compared among the 2 groups. **Results:** Group I withstood significantly greater average force before failure than that of Group II (p=0,000). There was no statistically significant difference in displacement at failure between groups. There was no statistically significant difference in loading at 1 mm displacement between 2 groups. **Conclusion:** Fixation with 3 screws on each side of such lateral segmental defects does not provide sufficient stability. Therefore minimum 4 screws should be adopted.

**Keywords:** Mandibular reconstruction; mouth neoplasms; jaw neoplasms

**ÖZET Amaç:** Neoplazilerin cerrahi tedavisi, çene kemiğinde geniş segmental kayıplara neden olup, kalan çene kemiği miktarını kısıtlamaktadır. Mandibula rezeksiyonu sonucunda meydana gelen devamlılık defektlerinin köprülenmesinde, kilitli rekonstrüksiyon plakları kullanılmaktadır. Bu çalışmanın amacı, lateral segmental defektlerin rekonstrüksiyonunda kilitli plaklar kullanıldığında sıklıkla önerilen vida sayılarının biyomekanik dayanımının değerlendirilmesidir. **Gereç ve Yöntemler:** Bu *in vitro* çalışma, angulusa uzanan lateral segmental defektlerin simule edildiği poliüretan mandibulalar üzerinde yürütülmüştür. Bu çalışmada, 13 poliüretan mandibula model kullanılmıştır. Grup I ve Grup II'deki modellerde mandibula segmentleri sırasıyla her segmente dörder vida ve üçer vida ile fikse edilmiştir. İki grubun maksimum yer değişikliği, maksimum kuvvet, 1, 3, 5 mm displasmana neden olan kuvvetler ve 80, 100, 200, 300 N kuvvet altında displasman değerleri karşılaştırılmıştır. **Bulgular:** Grup I'de başarısızlığa neden olan kuvvet ortalaması, Grup II'ye göre anlamlı olarak daha fazladır. İki grup arasında, maksimum yer değişikliği miktarları açısından anlamlı bir fark bulunmamıştır. İki grup arasında 1 mm deplasmana neden olan kuvvet miktarları da anlamlı bir fark göstermemiştir. **Sonuç:** Bu çalışmadaki gibi lateral segmental defektlerde, defektin 2 yanına üçer vida yeterli stabiliteyi sağlayamamıştır. Bu nedenle minimum dörder vida uygulanması benimsenmelidir.

**Anahtar Kelimeler:** Mandibular rekonstrüksiyon; ağız neoplazileri; çene neoplazmaları

Bridging mandibular discontinuities caused by tumour resections with reconstruction plates provide a better functional and aesthetic outcome for patients.[1] Locking reconstruction plates which provide advantages over conventional plates have been emerged recently. The locking plates are character-

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ized with having extra threads on both plate holes and screws that results with lock up of plate and screw.[2] Locking systems provide higher long-term stability than conventional systems.[3]

Use of ideal length and number of screws to obtain rigid internal fixation is a corcerned issue of maxillofacial surgery field in clinical practice. Haug investigated if resistance of conventional reconstruction plates to masticatory loading were effected by numbers of screws per side.[4] Such experiments that evaluate the affective factors on biomechanical durability under masticatory forces were carried on bovine bones.[4,5] Three screws and four screws perside are suggested numbers for an acceptable stability.[2]

Limited number of biomechanical investigations have been published regarding screw numbers for segmental defects. The aim of this biomechanical study is to find out if number of screws is an effective factor to stabilize lateral segmental defect including angulus when locking systems are used.

## MATERIAL AND METHODS

### RECONSTRUCTION METHODS AND PREPARATION OF MODELS

Thirteen polyurethane mandibles (B-Tech, Ankara, Turkey) were used in this study. A sample size of 13 models were reported to provide 90% chance of determining biomechanical resistance in that experiment by using power analysis. The instutional review board of University of Katip Çelebi exempted the study from review since it does not require the ethics committee approval for its conduct (18.02.21 and no: 2021/0032). This study follows the Declaration of Helsinki.

Two different screw numbers were used to fix reconstruction plate on the resection area. 2.4 mm locking reconstruction plates were used for both groups and plates were bended by the same investigator with the same manner after marking the defect borders (Trimed, Ankara, Turkey). The plates were shortened to 19 holes for models in Group I. Segments were fixed by using four locking screws of 12 mm length for both side of defect. Seventeen-hole locking reconstruction plate was fixed three titanium locking screws of 12 mm length for both side of defect in Group II (n=6). Perforations were made with 1.8 mm diameter drill and a drill guide (Figure 1).

A standart defect was created for both groups. The defect extended from distal of the left first premolar tooth to same sided mandibular ramus of the polyurethane mandibles to which bended reconstruction plates were fixed. 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-UP

Biomechanical test was carried on by using a servohydraulic testing machine (TST 2500 mxe, MARESTEK Electronic Informatics System Design Ltd, İstanbul, Turkey). Although the outline of test setup was similar to that were used by Gutwald et al. and Schupp et al.[3,6] Loading only to the healthy angulus instead of simultaneous bilateral loading made

**FIGURE 1:** Lateral view of the reconstructed models fixed with 4 screws perside (Group I) (a) and 3 screws perside (Group II) (b).

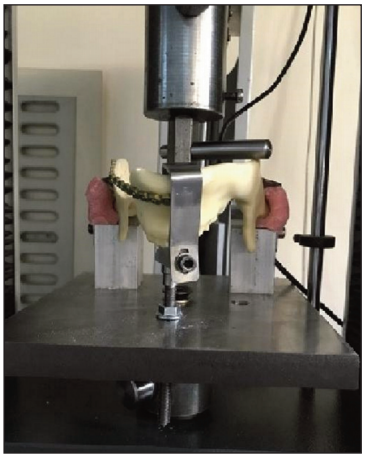

**FIGURE 2:** Set-up of biomechanical loading configuration.

this setup different from mentioned setup systems.[6] A cylindirical rod was fixed to load cell of servohydrolic testing machine and the rod pressed to the contralateral angulus with increasing forces since ipsilateral angulus region was resected (Figure 2). Test setup of this study which was consistent with three point method described by Armstrong et al. allowed occurence of torsional forces as in the *in vivo* unilateral chewing.[7]

Torsional single-cycle bending test under contralateral loading was performed on models of both groups. Yield load and displacement amounts (load or displacement values that results with permanent deformation) were recorded. Permanent deformation was identified as the point at which the slope of the load vs displacement curve lost linear behaviour or plate breakage occurred. An another failure type occured in screw-polyurethane model interface. If this type of failure was experienced before plate breakage and deformation, the load at which screw pullout observed was recorded as the failure load.

Loading were applied to the unilateral angulus of models at a rate of 1 mm/min until failure.

### OUTCOME VARIABLES AND DATA ANALYSIS

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

The collected data were analyzed with SPSS (Statistical Package for the Social Sciences) 15.0 programme. The groups were tested for normal distribution and equality of variances ($p>0.05$). Independent samples t-test were used to compare two groups. The level of statistical significance was accepted as $p<0.05$.

## RESULTS

Seven models with four screw per side (Group I) proved a mean yield displacement of 11.27 mm (±3.6). However, mean yield displacement of the six models with three screws per side (Group II) were reported as 8.4 (±0.43) mm under unilateral loading of mandibles. There was no statistically significant difference in means of displacement amounts at failure between 2 groups ($p=0.081$).

Group I and Group II withstood 638.42 N (±127 N) and 368.6 N (±41.8 N) mean force before failure, respectively. Group I could withstand significantly higher mean force before failure than that of Group II ($p=0.000$) (Table 1).

Pairwise comparisons revealed that the mean displacement at 80 N, 100 N, 200 N, 300 N loadings of Group II was significantly greater than that of Group I ($p=0.000$) (Figure 3).

Loading values that result in 1, 3, 5 mm displacement were compared. As there was no statistically significant difference in loading at 1 mm displacement between two groups, Group II showed 3 and 5 mm displacements under significantly lower forces comparing with Group I (Figure 4).

**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) | Sig. (2-tailed) |
|---|---|---|---|
| Maximum displacement | 11.27 mm (±3.6) | 8.4 (±0.43) mm | **0.081** |
| Maksimum load | 638.42 N (±127 N) | 368.6 N (±41.8 N) | **0.001** |

SD: Standard deviation.

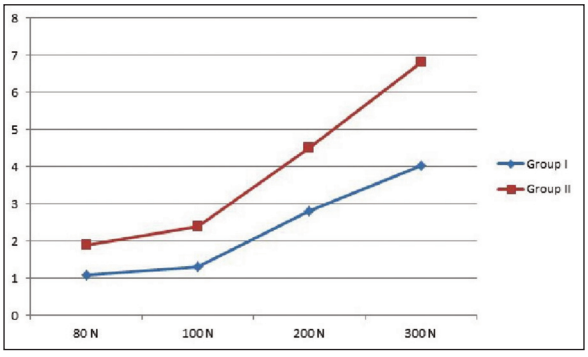


**FIGURE 3:** Displacement of Group I and Group II at increasing loads.

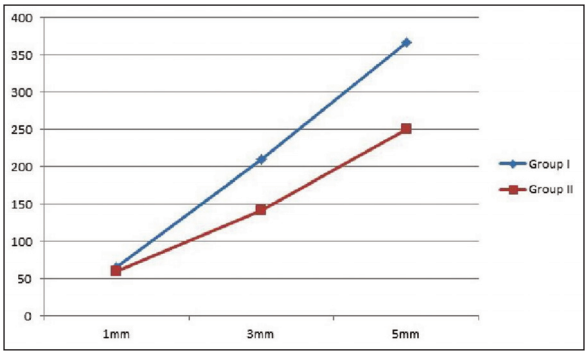


**FIGURE 4:** Load values at 1, 3 and 5 mm displacement.

## DISCUSSION

Screw loosening is a common complication in maxillofacial reconstruction and osteosynthesis cases since excessive stress due to masticatory forces may result in bone resorbtion around the screws.[8,9] Although local stress peak normally will not lead to spontaneous damage to the hardware or screws, fatigue of materials may develop under masticatory forces. Clinical practice confirmed that hardware related complications possibly occur with function under masticatory forces.[9] Isler et al. suggested that locking plates with more screws be employed to avoid complication of screw loosening in their retrospective clinical study.[1] We aimed to improve our understanding of optimal screw numbers with locking recontruction plates required for better biomechanical characterictics in lateral segmental defects of mandible and to reduce the incidence of complications encountered in clinical practice.

Restoration of the mandibular continuity with locking reconstruction plates is favored over conventional reconstruction plates.[3,6,10] Schupp et al. compared biomechanical behaviours of 2.4 and 2.7 mm conventional reconstruction plates and 2.4 locking plates under cyclic loading. Reported results showed that 2.4 mm locking plates were significantly better in term of durability and resistance to fatigue comparing with others.[3] Locking plate fixed with mono-cortical screws has been shown to be more durable than non-locking plating systems for mandibular reconstruction by using finite element analysis.[11] Glória et al. presented a meta-analysis that compared non-locking or locking plates in term of bite force of patients with mandibular fractures. The overall results of that meta-analysis proved that non-locking plates could not perform as sufficient bite forces in the incisor region and molar regions as in the locking plates.[12]

Some published papers discussed the complications due to reconstruction plates.[1,9] Arden et al. reported complications of 31 patients with lateral segmental defect reconstructed with reconstruction plates. The complications included plate exposure and screw loosening, wound infection, plate fracture in order of descending incidence.[13] A retrospective study of 68 patients considering the complications related with reconstruction plates reported screw loosening as the most frequent complication especially in proximal part of plate.[14] Non-locking plates were reported to be related with complication of screw loosening in a retrospective analysis of 23 patients.[1] As proved in literature, locking plates are more advantageous than non-locking ones. Therefore we have investigated if locking plates could show good biomechanic indurance with fewer screws. This study has been conducted on polyurethane type synthetic mandibles. Polyurethane material mimics wet bone since it has similar screw pull-out strength and insertion torque.[15]

An *in vitro* biomechanical study evaluated optimum screw numbers to obtain acceptable durability in cases of atrophic fractures of mandible fixed with locking systems. One, two, three, four, five, six, seven and eight screws per side of fracture were tested and compared with each other. Loading values at 1, 3, 5 mm displacement and maximum load were evaluated parameters. While resistance values in-

creased till 4 screws perside, values showed no more significant increase beyond 4 screws. Fixation with 3 screws and 4 screws perside gave relatively better resistance values.[2] We have evaluated maximum load and displacement, loading values at 1, 3, 5 mm displacement and displacement values at 80, 100, 200, 300 N loading in lateral segmental defects of mandible in the present study.

Haug conducted an *in vitro* biomechanical study on bovine bones with linear fracture in which non-locking reconstruction plates with various screw numbers were used for fixation. While insistent increase in durability of system were reported with increased screw numbers up to four screws on each segment, resistance of osteosyntesis showed no more significant increase above 4 screws. At four screws on each segment the plate was maximally secured to bone therefore masticatory forces could be transferred from bone to reconstruction plate.[4] However another study using locking reconstruction plates and screws reported similar resistance beyond three screws. Plate and screw type were not the only variables as there are differences in methodology and models considering these two studies.[2,4] There is an aggrement on screw number fewer than 3 could not provide sufficient resistance and screw number more than 4 have not increase resistance.[2,4,16] Although, the idea of 3-4 screws on each segment was supported by some authors, extensive segmental lesions are on debate since complications related with hardware occur in clinical practice.

In the present study, three locking screws per segment and four locking screws per segment applied to locking plates in fixation of lateral segmental defect were compared. The mean load values that cause 1 mm displacement for 3 screw per segment with locking reconstruction plate was reported as 62.8 N and for 4 screw per segment with reconstruction plate was reported as 68 N by Pereira-Filho et al.[2] In the current study, loading values of the same displacement amounts for Group I and II were 65.1 and 59.3 N, respectively. The mean load values that cause 3 mm displacement for 3 screw per segment with locking reconstruction plate was reported as 118.5 N, and for 4 screw per segment with reconstruction plate was reported as 134.9 N by Pereira-Filho et al.[2] However, equivalent values in our study for Group I and Group II was reported as 210 N and 142 N. Although no significant difference was found between two groups in term of loading amount that caused 1 mm displacement similarly to the study of Pereira-Filho et al., when considering loading amounts for 3 and 5 mm displacement, there are significant differences between fixing with 3 screws (Group II) and 4 screws (Group I) in our study. However, Pereira-Filho et al. proved that to be no difference between three and four screws in terms of loading amount for 3 and 5 mm displacement.[2] Inconsistencies in some issues between results of our and Pereira-Filho et al.'s study may have caused by differences in testing setup, defect tested by two study or materials' specialities.

Bujtár et al. investigated combinations of mono/bi cortical screws and non-locking/locking plates on hemimandibulectomy, corpus, symphyseal and subtotal defects through using finite element analysis. Three screws on either side of defect were reported to be adaquate for segmental defects except extensive defects.[11] We evaluated biomechanical resistance of fixing with three screws vs four screws on extensive lateral segmental defects including angulus region in our study. As a result, in contrast to some studies, fixing with three screws does not give sufficient indurance comparing with fixing with four screws on segmental defects extend to angulus. Although, limited surface area of proximal segment following a standard neoplasia resection extending up to entrance of mandibular canal and including coronoid process obligate the surgeons to use of fewer screws, alternative plates with ideal number of screws should be preferred instead of commercial plates with fewer screws. Customized plates with various kinds of plate design fixed with four screws in limited remaining bone areas following extensive neoplasia surgeries have been suggested by researchers.[17,18]

## CONCLUSION

In conclusion, although many variables such as screw lenght, screw diameter, defect size, defect location, bone composition could be discussed, mostly applied and suggested screw numbers have been evaluated on frequently encountered segmental defect in our

study. As considered screw loosening, plate fracture complications, fixing with three screws is not a useful option for mentioned defects.


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*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.*


## REFERENCES


1. Isler SC, Keskin Yalcin B, Cakarer S, Cansiz E, Gumusdal A, Keskin C. The use of reconstruction plates to treat benign mandibular pathological lesions: A retrospective clinical study. J Stomatol Oral Maxillofac Surg. 2018;119(5):379-83. [Crossref] [PubMed]
2. Pereira-Filho VA, da Silva BN, Nunes Reis JM, Spin-Neto R, Real Gabrielli MF, Monnazzi MS. Effect of the number of screws on the stability of locking mandibular reconstruction plates. Int J Oral Maxillofac Surg. 2013;42(6):732-5. [Crossref] [PubMed]
3. Schupp W, Arzdorf M, Linke B, Gutwald R. Biomechanical testing of different osteosynthesis systems for segmental resection of the mandible. J Oral Maxillofac Surg. 2007;65(5): 924-30. [Crossref] [PubMed]
4. Haug RH. Effect of screw number on reconstruction plating. Oral Surg Oral Med Oral Pathol. 1993;75(6):664-8. [Crossref] [PubMed]
5. Haug RH. The effects of screw number and length on two methods of tension band plating. J Oral Maxillofac Surg. 1993;51(2):159-62. [Crossref] [PubMed]
6. Gutwald R, Jaeger R, Lambers FM. Customized mandibular reconstruction plates improve mechanical performance in a man dibular reconstruction model. Comput Methods Biomech Biomed Engin. 2017;20(4): 426-35. [Crossref] [PubMed] [PMC]
7. Armstrong JE, Lapointe HJ, Hogg NJ, Kwok AD. Preliminary investigation of the biomechanics of internal fixation of sagittal split osteotomies with miniplates using a newly designed in vitro testing model. J Oral Maxillofac Surg. 2001;59(2):191-5. [Crossref] [PubMed]
8. Sugiura T, Yamamoto K, Murakami K, Kawakami M, Kang YB, Tsutsumi S, et al. Biomechanical analysis of miniplate osteosynthesis for fractures of the atrophic mandible. J Oral Maxillofac Surg. 2009;67(11):2397-403. [Crossref] [PubMed]
9. Atilgan S, Erol B, Yardimeden A, Yaman F, Ucan MC, Gunes N, et al. A three dimensional analysis of reconstruction plates used in different mandibular defects. Biotechnology & Biotechnological Equipment. 2010;24(2):1893-6. [Crossref]
10. Haug RH, Street CC, Goltz M. Does plate adaptation affect stability? A biomechanical comparison of locking and nonlocking plates. J Oral Maxillofac Surg. 2002;60(11):1319-26. [Crossref] [PubMed]
11. Bujtár P, Simonovics J, Váradi K, Sándor GK, Avery CM. The biomechanical aspects of reconstruction for segmental defects of the mandible: a finite element study to assess the optimisation of plate and screw factors. J Craniomaxillofac Surg. 2014;42(6):855-62. [Crossref] [PubMed]
12. Glória JCR, Fernandes IA, Silveira EMD, Souza GM, Rocha RL, Galvão EL, et al. Comparison of bite force with locking plates versus non-locking plates in the treatment of man dibular fractures: a meta-analysis. Int Arch Otorhinolaryngol. 2018;22(2):181-9. [Crossref] [PubMed] [PMC]
13. Arden RL, Rachel JD, Marks SC, Dang K. Volume-length impact of lateral jaw resections on complication rates. Arch Otolaryngol Head Neck Surg. 1999;125(1):68-72. [Crossref] [PubMed]
14. Yi Z, Jian-Guo Z, Guang-Yan Y, Ling L, Fu-Yun Z, Guo-Cheng Z. Reconstruction plates to bridge mandibular defects: a clinical and experimental investigation in biomechanical aspects. Int J Oral Maxillofac Surg. 1999;28(6): 445-50. [Crossref] [PubMed]
15. Bredbenner TL, Haug RH. Substitutes for human cadaveric bone in maxillofacial rigid fixation research. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2000;90(5):574-80. [Crossref] [PubMed]
16. Ellis E 3rd, Miles BA. Fractures of the mandible: a technical perspective. Plast Reconstr Surg. 2007;120(7 Suppl 2):76S-89S. [Crossref] [PubMed]
17. Narra N, Valášek J, Hannula M, Marcián P, Sándor GK, Hyttinen J, et al. Finite element analysis of customized reconstruction plates for mandibular continuity defect therapy. J Biomech. 2014;47(1):264-8. [Crossref] [PubMed]
18. Demir E, Yalçın G, Kalaycı A, Sağlam H. Biomechanical evaluation of caudally and buccally screwed customized reconstruction plates for lateral segmental defects of man dible. Br J Oral Maxillofac Surg. 2020. [Crossref] [PubMed]