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博士學位 論文

In *vitro* biomechanical evaluation of various fixation methods of sagittal split ramus osteotomy in mandibular setback

朝鮮大學校 大學院

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하악 후퇴를 위한 하악지 시상분할 골절단술의 다양한 고정법에 대한 생역학적 *in vitro* 평가

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국문 초록

하악 후퇴를 위한 하악지 시상분할 골절단술의 다양한 고정법에 대한 생역학적 *in vitro* 평가

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목적: 하악지 시상분할 골절단술(Sagittal split ramus osteotomy)은 하악골의 선천성 또는 후천성 기형을 치료하기 위한 악교정 수술법이다. 수술시 안정된 내고정을 필요로 하며, 고정판(miniplate)을 이용한 단피질(monocortical) 고정법이나 양피질 나사(bicortical screw) 고정법, 단피질 고정판 및 양피질 나사 혼성 고정법(hybrid fixation)을 포함한 다양한 고정술식이 이용되고 있다. 내고정법에 대한 많은 연구가 진행되고 있으나 아직까지 흡수성 고정에 대한 연구는 부족하며, 특히 대부분의 연구가 하악골의 전진술에 대한 것으로 이에 본 연구에서는 하악지 시상분할 골절단술을 이용한 하악골 후퇴술시 흡수성 및 타이타늄 고정시스템을 이용한 다양한 고정법에 대해 골편의 변위에 따른 저항력을 비교하고자 하였다.

실험재료 및 방법: 편측 하악골 모형을 하악지 시상분할 골절단술을 이용하여 5mm 후퇴시킨 후 8가지의 방법(n=10)의 내고정을 시행하였다; (A) 흡수성 monocortical group, (B) 타이타늄 monocortical group, (C) 흡수성 hybrid group; 흡수성 miniplate 및 bicortical screw, (D) 타이타늄 hybrid group; 타이타늄 miniplate 및 bicortical screw, (E) 흡수성 mixed hybrid group; 타이타늄 miniplate 및 흡수성 bicortical screw, (F) 타이타늄 mixed hybrid group; 흡수성 miniplate 및 타이타늄 bicortical screw, (G) 흡수성 bicortical group; 3개의 역L자형 흡수성 bicortical screws, (H) 타이타늄 bicortical group; 3개의 역L자형 타이타늄 bicortical screws. 고정된 악골 모형은 근심골편이 움직이지 않도록 맞춤 제작한 지그에 고정되었다. 만능물성시험기를 이용하여 원심 골편의 전치부 절단연에

5mm/분의 속도로 원심골편의 절단연이 10mm 변위시까지 압축력을 가하였다. 5mm와 10mm에서의 압축력을 분산분석과 다중비교분석(Tukey's test)을 통해 평가하였다($P < 0.05$).

결과: 분산분석 결과 5mm와 10mm 변위 모두에서 그룹간 유의할 만한 차이가 나타났다 ($P < 0.001$). 10mm까지 변위시 가장 낮은 저항값을 보인 그룹은 흡수성 monocortical 그룹(A)이었으며, 변위당 저항값 또한 가장 낮았다. 타이타늄 bicortical 그룹(H)이 가장 높은 저항값을 보였으며, 변위당 저항값 또한 가장 높았다. 반면, 흡수성 bicortical 그룹(G)은 타이타늄 hybrid 그룹(D)보다 유의성 있는 낮은 값을 보였다($P < 0.05$). Monocortical 그룹에서는 흡수성(A)과 타이타늄 그룹(B)간 유의할 만한 차이가 없었으나, bicortical 그룹과 hybrid 그룹에서는 흡수성 그룹(C, G)이 타이타늄 그룹(D, H)보다 유의할만하게 낮은 값을 보였다. 흡수성 hybrid 그룹(C)은 흡수성 bicortical 그룹(G)보다 5mm와 10mm 모두에서 유의성 있는 낮은 값을 보였다. 이와 달리 타이타늄 hybrid 그룹(D)은 5mm 변위시에는 타이타늄 bicortical 그룹(H)보다 유의할만하게 낮은 값을 보였으나, 10mm 변위시에는 유의할만한 차이가 없었다. mixed hybrid 그룹(E, F)에서는 F그룹이 높은 값을 보였으나, 통계학적 유의성은 없었다. 흡수성 hybrid 그룹(C)은 monocortical 그룹(A, B)보다는 유의성 있는 높은 값을 보였다. 그러나, monocortical 그룹을 제외한 그룹(D~H)보다는 낮은 값을 보였으며, E그룹과는 유의한 차이가 없었으나, 다른 그룹(D, F, G, H)과는 유의한 차이가 있었다.

결론: 타이타늄 hybrid 고정법은 3개의 역L자형 bicortical 고정법에 견주어 견고한 내고정법이라 할 수 있다. 흡수성 hybrid 고정법은 타이타늄에 비해 기계적 안정성은 낮았다. 흡수성 혹은 타이타늄 bicortical screw를 이용한 여러 방법의 hybrid 고정법은 monocortical 고정법에 비해 유의하게 높은 저항값을 보였다. 위와 같은 결과에서 볼 때, 하악지 시상분할 골절단술시 miniplate를 이용한 monocortical 고정법과 더불어 후구치부에 흡수성 혹은 타이타늄 bicrotical screw를 추가 고정하는 방법이 골편 고정에 대한 기계적 안정성을 높임으로써 술 후 악간고정을 단축시킬 수 있는 유용한 고정법이라 생각되었다.

I . Introduction

Sagittal split ramus osteotomy (SSRO) is the most popular orthognathic surgical procedure for treatment of various congenital and developmental deformities of mandible such as mandibular retrognathism, prognathism, and mandibular asymmetry.[1,2] The broad overlapping surface of the split segments increases the amount of cancellous bone contact and promotes bone healing and postoperative mandibular stability.[3] Also, rigid internal fixation can permit early mandibular function possible. Other advantages of SSRO are that its technique is simple and an intraoral approach is possible.[4]

Fixation of proximal and distal segment is needed in SSRO and there are numerous modifications of the fixation methods have been proposed from wire osteosynthesis to rigid fixation systems using various plates and screws for provision of stability.[5-7] Fixation should be stable during the healing period and tolerant to masticatory forces after surgery.[8] When fixation is stable on SSRO, it may be stable procedure that has less relapse.[9] Adequate fixation can provide sufficient resistance to the displacing forces that encourage micromovements across the osteotomy site.[10] Rigid fixation provides skeletal stability after the osteotomy, fast bony healing, early recovery of mandibular function, good oral hygiene, better nutritional support, and easier airway maintenance.[6,11,12] Among many rigid fixation methods, the widely used systems for the fixation of the SSRO are bicortical screws and miniplates with monocortical screws.[13-15]

Spiessl[16] introduced rigid fixation in SSRO in 1974 using three bicortical screws with two above and one below the mandibular canal through transcutaneous approach without intermaxillary fixation (IMF). Rigid fixation can prevent excessive stress around fixation screws that may cause bone resorption and screw loosening.[12,17] It has been recognized as a successful method for reducing relapse.

However, temporomandibular dysfunction due to displacement of the condyle and irreversible nerve damage from compression caused by difficulty in maintaining the appropriate gap between segments can occur. And it can make additional scar formation of skin through transcutaneous approach.[6,18] In addition, if a secondary osteotomy is performed in the retromoral region of distal segment, there may be no lingual cortex present to place the bicortical screw.[12]

An advantage of monocortical fixation is that it can be possible with an intraoral approach because transcutaneous puncture is not needed. There is no unnecessary scarring or facial nerve injury. Also, it doesn't need sufficient bulk of bone for fixation. The damage to proximal teeth and inferior alveolar nerve are lessened as compared with the bicortical fixation.[19] If the location of condyle is wrong during surgery, it is easier to readjust and maintain the condyle in the fossa.[7,20,21]

However, disadvantages are that it can not guarantee the sufficient stability and IMF is needed even a short period.[22,23] IMF may causes stress to the patient and leads to muscular atrophy, increase the risk of airway obstruction risk and temporomandibular joint problems.[24] Especially, the pulling action of the medial pterygoid muscle and suprahyoid muscle, may rotate mandible clockwise potentially causing a relapse in open bite patients.[18]

To better understand and improve the biomechanics of SSRO fixation, many experimental investigations have been done to quantify and evaluate fixation methods *in vitro*.[4,6,8,10,15,18,22,23] However, the ideal method of fixation has not yet been established.[4] Specifically, few studies on resorbable monocortical and bicortical fixation have been performed. In addition, most studies are about mandibular advancement surgery and there is little focus on setback surgery.

The purpose of this study was to compare biomechanical effects of various fixation methods using titanium and resorbable bicortical screws and miniplates with monocortical screws in SSRO for mandibular setback.

Ⅱ. Materials and Methods

A. Materials

Since human or animal mandibles have different bone quality or quantity for each sample, samples can't be standardized. Therefore, synthetic polyurethane hemimandible replicas (model No. 8332; Synbone®, Malans, Switzerland) fabricated with sagittal split osteotomies previously done by the manufacturer which have been successfully used *in vitro* study[22,23,25] were used in this study. The Titanium fixation system (Le Forte; Jeil Medical Corp., Seoul, Korea) and the resorbable fixation system (BioSorb™*FX,* Linvatec Biomaterials Ltd, Tampere, Finland) used in this study. BioSorb™*FX* fixation system is made of self-reinforced (70% L-lactide, 30% DL-lactide) poly lactic acid. The titanium miniplate used for monocortical fixation in this study was 4 holes miniplate with thickness 1mm, width 4.5mm. And resorbable miniplate was 4 holes miniplate with thickness 1.2mm, width 5.5mm. Screws (diameter 2.0mm and length 6mm) for monocortical fixation and screws (diameter 2.4mm and length 14mm) for bicortical fixation were used. The support jig for loading test was customized.

B. Methods

A 5mm setback SSRO was performed and the anterior part of proximal segment and the posterior part of the distal segment were removed to avoid interference. For fixation of 14mm bicortical screw, a medial retromolar region of the distal segment was adjusted. The hemimandibles were divided into 8 groups (n=10) based on the fixation methods used. Experimental groups were divided as the following (Fig. 1).

A. Resorbable monocortical group (resorbable miniplate with 4 monocortical screws)

B. Titanium monocortical group (titanium miniplate with 4 monocortical screws)

C. Resorbable hybrid group (resorbable 1 bicortical screw and miniplate with 4 monocortical screws)

D. Titanium hybrid group (titanium 1 bicortical screw and miniplate with 4 monocortical screws)

E. Resorbable mixed hybrid group (resorbable 1 bicortical screw and titanium miniplate with 4 monocortical screws)

F. Titanium mixed hybrid group (titanium 1 bicortical screw and resorbable miniplate with 4 monocortical screws)

G. Resorbable bicortical group (inverted-L shaped 3 resorbable bicortical screws)

H. Titanium bicortical group (inverted-L shaped 3 titanium bicortical screws)

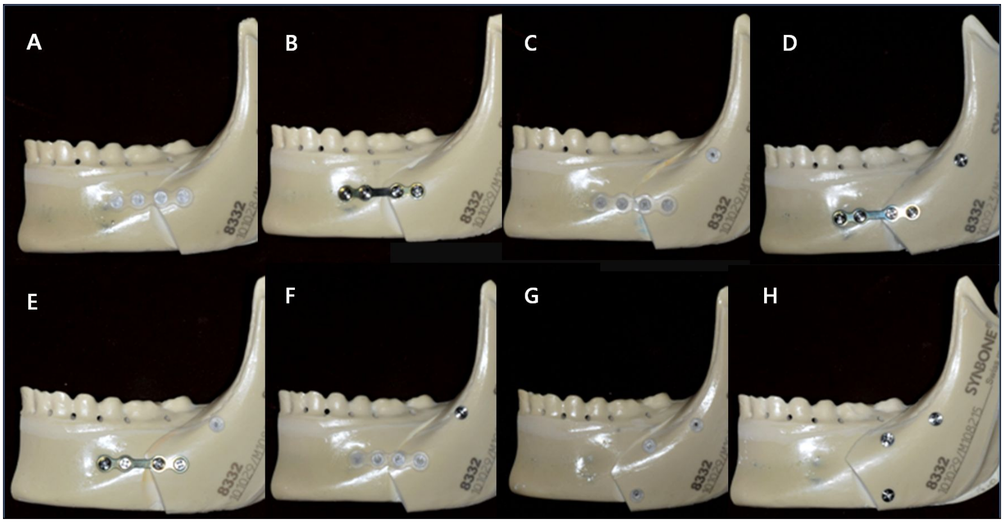

Fig. 1. Hemimandibles fixed with different fixation methods

As described in Brasileiro et al.,[10] for standardization of screws position, the fixation was performed using a transparent acrylic mold and resorbable screws were inserted after tapping. The miniplate was positioned parallel to occlusal plane. In the hybrid group, fixation was performed for one bicortical screw in retromolar region 5mm distant from second molar and three bicortical screws in an inverted–L shape with two above and one below the mandibular canal were fixed in bicortical groups.

C. Loading tests

The hemimandibles fixed with different methods were stabilized in support apparatus (Fig. 2A). In this custom–fabricated support jig, the distal segment can move freely but the condyle and ramus of proximal segment were fixed to avoid moving and it is designed not to move during loading.

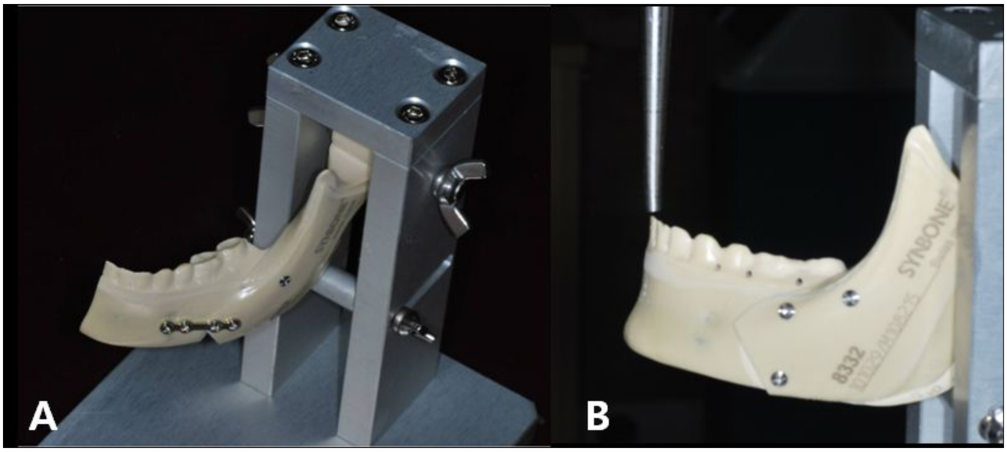

Fig. 2. The loading test A) Custom–fabricated support jig, B) Application of vertical compression force at lower incisor edge of the distal segment

The universal testing machine AG-IS (Shimadzu, Kyoto, Japan) was used for loading tests. A vertical compression force was applied to the lower incisor edge of the distal segment at a rate of 5mm per minute (Fig. 2B) because it is more critical to evaluate incisal loading than lateral loading for *in vitro* evaluation.[10,25] The loading forces in Newtons (N) for incisal displacement of the distal segment from 0mm to 10mm were measured, and the means with standard deviations of the data were calculated. The loading forces (N) for 5mm and 10mm incisal displacement of distal segment were recorded and processed statistically.

D. Statistical analysis

Analysis of variance was performed by the test of normality and test of homogeneity of variances (Levene test, $P > 0.05$). The collected data was compared through ANOVA and HSD Tukey's test for multiple comparison between groups. For statistical analysis, SPSS version 20.0 (SPSS Inc., Chicago, IL, USA) was used and probabilities of less than 0.05 were accepted as significant.

Ⅲ. Results

Analysis of variance using the Levene test showed that data were normally distributed ($P > 0.05$). As results of ANOVA, there was a statistically significant difference among the groups at 5mm and 10mm displacement ($P < 0.001$).

A. The values of loading force to displacement

The average loads, standard deviations and multiple comparisons of significant difference among groups at 5mm and 10mm displacement were summarized in Table 1 and 2. The titanium bicortical group (H) demonstrated as the most rigid of the groups while the resorbable monocortical group (A) had the lowest mechanical resistance among all group (Fig. 3). The contrast of mean loading values among groups in 5mm displacement does not differ greatly from the contrast of values in 10mm displacement. The titanium bicortical group (H) showed a steeper increase in load-displacement curves from 0mm to 10mm, while resorbable monocortical group showed a slight increase in load-displacement curves.

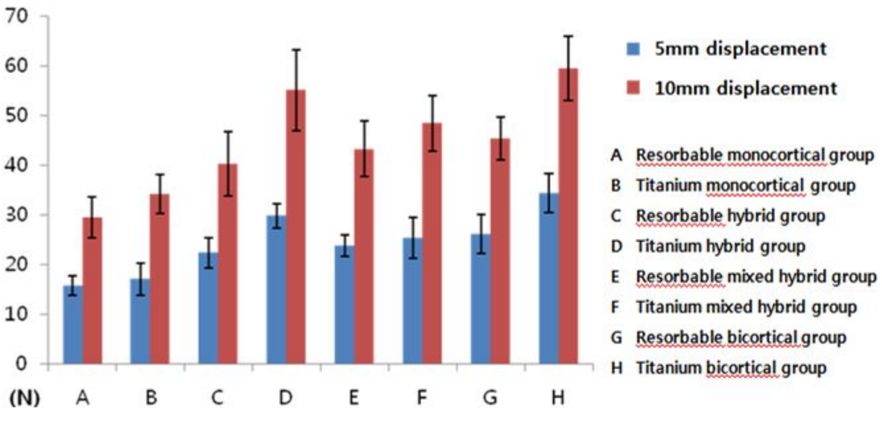

Fig. 3. Mean loading values and standard deviations

Table 1. The mean loading force values for 5mm vertical displacement and statistical analysis summary among groups using Tukey's test

	Group description	Mean ± SD (N)	Comparison between groups*
A	Resorbable monocortical group	15.71±1.97	C, D, E, F, G, H
B	Titanium monocortical group	17.07±3.23	C, D, E, F, G, H
C	Resorbable hybrid group	22.31±2.99	A, B, D, F, G, H
D	Titanium hybrid group	29.74±2.48	A, B, C, E, F, H
E	Resorbable mixed hybrid group	23.67±2.15	A, B, D, H
F	Titanium mixed hybrid group	25.29±4.05	A, B, C, D, H
G	Resorbable bicortical group	26.11±3.94	A, B, C, H
H	Titanium bicortical group	34.36±3.98	A, B, C, D, E, F, G

* Significant difference between the groups (HSD Tukey's test, $P < 0.05$).

A: resorbable miniplate with 4 monocortical screws, B: titanium miniplate with 4 monocortical screws, C: resorbable 1 bicortical screw and miniplate with 4 monocortical screws, D: titanium 1 bicortical screw and miniplate with 4 monocortical screws, E: resorbable 1 bicortical screw and titanium miniplate with 4 monocortical screws, F: titanium 1 bicortical screw and resorbable miniplate with 4 monocortical screws, G: inverted-L shaped 3 resorbable bicortical screws, H: inverted-L shaped 3 titanium bicortical screws

B. The comparison of resorbable and titanium fixation system

The loads of titanium hybrid group (D) were higher than resorbable hybrid group (C) and the loads of titanium bicortical group (H) were higher than resorbable bicortical group (G) significantly ($P <$ 0.05). However, there was no significant differences between titanium monocortical group (B) and resorbable monocortical group (A)($P >$ 0.05) although loads of group B were higher than group A. The group F showed more stable the group E when comparing mixed hybrid group, but these results were not statistically significant ($P >$ 0.05). In comparison by bicortical screw, group D which added titanium bicortical screw had statistically significant higher stability compared with group E which added resorbable bicortical screw ($P < 0.05$). Also, the loads of group F were significantly higher than group C ($P < 0.05$). These results mean the titanium bicortical screw has a higher resistance compared with resorbable bicortical screw.

Table 2. The mean loading force values for 10mm vertical displacement and statistical analysis summary among groups using Tukey's test

	Group description	Mean ± SD (N)	Comparison between groups*
A	Resorbable monocortical group	29.37±4.09	C, D, E, F, G, H
B	Titanium monocortical group	34.15±3.95	C, D, E, F, G, H
C	Resorbable hybrid group	40.25±6.45	A, B, D, F, G, H
D	Titanium hybrid group	55.07±8.09	A, B, C, E, F, G
E	Resorbable mixed hybrid group	43.26±5.63	A, B, D, H
F	Titanium mixed hybrid group	48.39±5.57	A, B, C, D, H
G	Resorbable bicortical group	45.36±4.31	A, B, C, D, H
H	Titanium bicortical group	59.48±6.51	A, B, C, E, F, G

* Significant difference between the groups (HSD Tukey's test, $P < 0.05$).

A: resorbable miniplate with 4 monocortical screws, B: titanium miniplate with 4 monocortical screws, C: resorbable 1 bicortical screw and miniplate with 4 monocortical screws, D: titanium 1 bicortical screw and miniplate with 4 monocortical screws, E: resorbable 1 bicortical screw and titanium miniplate with 4 monocortical screws, F: titanium 1 bicortical screw and resorbable miniplate with 4 monocortical screws, G: inverted-L shaped 3 resorbable bicortical screws, H: inverted-L shaped 3 titanium bicortical screws

C. The comparison by fixation methods

The monocortical groups (A and B) had statistically significant lower mechanical resistance compared with other groups ($P < 0.05$). Resorbable hybrid group (C) were significantly lower than resorbable bicortical group (G) at 5mm and 10mm displacement ($P < 0.05$). No significant difference existed between resorbable bicortical group (G) and mixed hybrid groups (E and F) ($P > 0.05$). On the other hand, the difference between titanium hybrid group (D) and titanium bicortical group (H) was not statistically significant at 10mm displacement ($P > 0.05$) and load values of groups D and H were significantly higher than other groups ($P < 0.05$).

IV. Discussion

The hybrid technique was first suggested by Schwartz and Relle[26] in 1996. This hybrid technique is a fixation method that combines the advantages of bicortical screw and miniplate with monocortical screw and includes fixation with monocortical screws at lateral surface of mandibular body and bicortical screw in the retromolar region.[26] Brasileiro et al[10,27] described a detailed method and the advantages of hybrid technique. The proximal segment and distal segment were fixed using miniplate and monocortical screws. After releasing the intermaxillary fixation, check the occlusion, mandibular position, and condylar seating. Then perform additional fixation at the retromolar region with single bicortical screw. The retromolar region is excellent in bone quality and width and it is possible through an intraoral approach so it is the most recommended as a fixation position of bicortical screw.[28] Van Sickels et al reported that there is no great advantage to add more than one bicortical screw to miniplate with the monocortical screw.[25] The advantages of hybrid technique are as follows;[10,27] 1) excellent mechanical resistance 2) low condylar torque 3) low incidence of injury of inferior alveolar nerve 4) intraoral approach.

Micromotion at the osteotomy site causes miniplate failure and this micromotion can be reduced using a hybrid technique which adds a single bicortical screw.[14] Many studies have reported that mechanical resistance of hybrid technique was significantly increased than compared to miniplate with monocortical screws.[15,27,29] Also, as the stress concentrated on the miniplate is distributed,[4] the entire fixation system is stabilized.[15] This is because the displacement of segments are prevented by resisting the bicortical screw in the retromolar region to the axial and shear stress.[15] A triangular configuration using 3 bicortical screws is excellent for resisting displacing movements[17,30] and an inverted-L shape fixation is known to be most stable in the laboratory environment.[6,29] By Brasileiro et al,[10] adding 1 bicortical screw in the retromolar region with the monocortical fixation technique showed the same stabilization as an inverted-L fixation. And they described this hybrid technique is simple and stable and optimizes the resistance. In this study, the titanium bicortical screws group showed higher values than titanium hybrid group, but there were no significant differences between two groups at 10mm displacement.

The displacement of condyle can be prevented during bicortical screw fixation because the fixation of miniplate is performed first. Additionally, the neurovascular compression caused by excessive contacts between segments can be minimized. Since the bicortical screw is located in the upward of inferior alveolar nerve, this also avoids injury to the nerve.[27,31] The single bicortical screw fixation in the retromolar region does not need transcutaneous approach using trocar, it can avoid nerve injury or skin scar and the operation time can be shortened.[15]

However, this hybrid technique has limitation. If there is interference between the proximal segment and the distal segment, the medial aspect of the proximal segment needs to be trimmed or a second osteotomy should be performed at the retromolar region of distal segement.[12,32] This is important factor to prevent the displacement of condyle and relapse due to interference. However, in this case if there is no bone to fix the bicortical screw to retromolar region, the hybrid technique can not be used.[10] In addition, revision of the bony contact, careful placement of the bicortical screws or shifting to plate fixation should be performed in the facial asymmetry cases which needs differential movement and rotation.[30]

It was previously reported that bicortical screws are more mechanically resistant than the miniplate with monocortical screws in a number of *in vitro* biomechanical evaluations.[4,15,27,29,33] Anucul et al[34] reported that bicortical screw was an average of 3 times more resistant than miniplate fixation and Brasileiro et al[10] reported bicortical fixation was at least 40% more rigid than the monocortical fixation for vertical or lateral loads. Pereira Filho et al[35] demonstrated that the bicortical screw presented the greatest values of loading resistance and demonstrated that the miniplate had 60% lower resistance compared to bicortical screws. Several biomechanical studies have shown that miniplate fixation with monocortical screws is not as stable as other techniques.[11,25,31] In this study, resorbable bicortical group had 55% higher resistance and titanium bicortical group had 73% higher resistance than each monocortical groups.

Shearing force is the greatest impacts to the stability of the segments after SSRO.[10] The excessive shear force in monocortical plate fixation may transform the mandibular segment postoperatively and cause decreased stability leading to nonunion or incomplete union.[10,36] If movement across the osteotomy site occurs, fixation failure can occur by migration of the screws and bending of a bone plate.[12] Because the symphysis is displaced inferiorly and posteriorly due to pulling action of suprahyoid muscle and occlusal loading, the distal segment is rotated in clockwise direction. Also, since the ramus is rotated upward and forward due to the influence of masticatory muscles, the proximal segment becomes counterclockwise rotated.[10,12] For this, the fixed area with miniplate receives a force that makes mandible twisting between segments.[4] The bicortical fixation can resist to such shearing stress than monocortical fixation.[37] This mechanical resistance of bicortical fixation is possible because of wide contact between bone segments.[15]

On the other hand, the proximal segment is rotated inward leading to condylar positional change so it represents a large condylar torque in bicortical fixation.[13,38] Low resistance of miniplate has an advantage in that it has clinically low compression between segments and low condylar torque.[4] Joss and Vassalli[7] reported that bicortical screws showed only slight differences regarding stability compared with miniplates in the short term but higher long−term relapse rates were seen in bicortical screws fixation resulting in pain and malocclusion than in miniplates fixation through clinical articles review. In clinical studies, despite the high resistance of bicortical screw there are no great differences of stability between bicortical screw and the miniplate with monocortical screw[7,24,36,39−41] and the failure tendency of miniplate fixation was not increased.[40,42] It can obtain enough stability only with miniplate fixation[4] because of significant reduction of masticatory force after surgery.[43] Also, the short−term stability was guaranteed by rigid fixation but long−term stability was caused by functional and neuromuscular factors, it can be achieved by functionally stable fixation such as miniplate fixation.[22]

Titanium is a gold standard fixation material that is widely used currently because of excellent stiffness, strength and biocompatibility.[6,44] However, it requires secondary surgery for removal and it has the disadvantages of screw loosening, shear stresses causing bone resorption around screw, sensitivity to temperature, artifact on radiograph, allergic reactions, chemical carcinogenesis and restriction of growth.[45,46]

Resorbable osteosynthesis materials have the advantages of radiolucency and reduced stress shielding because of a progressive decrease in strength and stiffness. However, it has lower mechanical strength than titanium and insufficient clinical scientific evidence, so resorbable osteosynthesis has not yet replaced its metallic counterpart.[47] Surgeons also hesitate to use resorbable system for orthognathic patients because of longer operation time, micromovement of fixed bone caused by low initial stability, foreign body reaction, high cost, risk of infection.[48]

Cilasun et al[49] reported that there were no significant differences in stability when comparing poly-L-lactic acid/polyglycolic acid (PLLA/PGA) resorbable bicortical screws and titanium bicortical screws in the fresh sheep hemimandibles for fixation in SSRO. Ferretti and Reyneke[50] also mentioned that resorbable screws can be used instead of titanium screws in SSRO. There were no significant differences between titanium screws group and resorbable screws group in 8 years long-term clinical study.[47] Paeng et al[48] reported that bicortical resorbable screws showed clinically stable outcome in skeletal stability after SSRO but it is weak in open bite tendency and it showed vertically less stable result than titanium screws. In addition, they used five resorbable screws and four titanium screws for fixation. And they suggested that the bony contact between segments is important in resorbable screw fixation and if the bony contact is minimal, the stability of resorbable screws is reduced. In this study, the resorbable bicortical screws group showed significantly lower values than titanium bicortical screws group and titanium hybrid group. The values of loading force of resorbable bicortical screws group were rather lower than titanium mixed group (titanium bicortical screw and resorbable miniplate with monocortical screws group) although there was no significant difference.

Since this study is an *in vitro* evaluation of various fixation methods using resorbable plate and bicortical screw, it has limits that it can not reproduce the stress direction of actual patient and anatomic structures including muscle interaction. And the stability of segments after SSRO is influenced by many factors clinically. Simply increase of mechanical stability does not ensure good results. And this study only focused on the stress of the fixation material itself. Also, a property of matter of resorbable and titanium fixation system varies according to manufacturer. However, this study is meaningful as a first step for clinical use of hybrid technique fixation with resorbable osteosynthesis and it is considered to have clinical evaluation for hybrid technique using the resorbable plate and bicortical screw through further clinical study.

V. Conclusion

The purpose of this study was to compare and evaluate various fixation methods biomechanically including titanium and resorbable fixation systems of sagittal split ramus osteotomy in mandibular setback. The incisal loading force (N) for 5mm and 10mm displacement of distal segment were analyzed using synthetic polyurethane hemimandible replicas. Based on the results of this study, it was concluded that:

1. The titanium hybrid technique showed no significant difference of resistance with the inverted L shape bicortical fixation technique which was known to have the greatest resistance.
2. There was no significant differences between titanium monocortical group and resorbable monocortical group although resorbable groups had lower resistance than titanium groups.
3. The resorbable fixation technique including hybrid and bicortical fixation was still lower resistance than titanium.
4. The hybrid technique provided increased resistance regardless of fixation materials.

These results indicate that the hybrid technique using resorbable or titanium bicortical screw is stable and useful fixation methods of sagittal split ramus osteotomy in mandibular setback.

References

1. Wolford LM. The sagittal split ramus osteotomy as the preferred treatment for mandibular prognathism. J Oral Maxillofac Surg 2000;58:310-2.
2. Yang X-W, Long X, Yeweng S-J, Kao C-T. Evaluation of mandibular setback after bilateral sagittal split osteotomy with the Hunsuck modification and miniplate fixation. J Oral Maxillofac Surg 2007;65:2176-80.
3. Böckmann R, Schön P, Frotscher M, Eggeler G, Lethaus B, Wolff KD. Pilot study of modification of the bilateral sagittal split osteotomy (BSSO) in pig mandibles. J Craniomaxillofac Surg 2011;39:169-72.
4. Sato FRL, Asprino L, Consani S, de Moraes M. Comparative biomechanical and photoelastic evaluation of different fixation techniques of sagittal split ramus osteotomy in mandibular advancement. J Oral Maxillofac Surg 2010;68:160-66.
5. Oba Y, Yasue A, Kaneko K, Uchida R, Shioya sono A, Moriyama K. Comparison of stability of mandibular segments following the sagittal split ramus osteotomy with poly-l-lactic acid (PLLA) screws and titanium screws fixation. Orthod Waves 2008;67:1-8.
6. Erkmen E, Şimşek B, Yücel E, Kurt A. Three-dimensional finite element analysis used to compare methods of fixation after sagittal split ramus osteotomy: setback surgery-posterior loading.

Br J Oral Maxillofac Surg 2005;43:97−104.
7. Joss CU, Vassalli IM. Stability after bilateral sagittal split osteotomy advancement surgery with rigid internal fixation: A systematic review. J Oral Maxillofac Surg 2009;67:301−13.
8. Bohluli B, Motamedi MH, Bohluli P, Sarkarat F, Moharamnejad N, Tabrizi MH. Biomechanical stress distribution on fixation screws used in bilateral sagittal split ramus osteotomy: Assessment of 9 methods via finite element method. J Oral Maxillofac Surg 2010;68:2765−69.
9. Joss CU, Vassalli IM. Stability after bilateral sagittal split osteotomy setback surgery with rigid internal fixation: A systematic review. J Oral Maxillofac Surg 2008;66:1634−43.
10. Brasileiro BF, Grotta−Grempel R, Ambrosano GMB, Passeri LA. An *in vitro* evaluation of rigid internal fixation techniques for sagittal split ramus osteotomies: Setback surgery. J Oral Maxillofac Surg 2012;70:941−51.
11. Murphy MT, Haug RH, Barber JE. An *in vitro* comparison of the mechanical characteristics of three sagittal ramus osteotomy fixation techniques. J Oral Maxillofac Surg 1997;55:489−94.
12. Ellis Iii E, Esmail N. Malocclusions resulting from loss of fixation after sagittal split ramus osteotomies. J Oral Maxillofac Surg 2009;67:2528−33.
13. Kim YI, Park SB, Jung YH, Hwang DS, Lee JY. Evaluation of intersegmental displacement according to osteosynthesis method

for mandibular setback sagittal split ramus osteotomy using Cone-beam computed tomographic superimposition. J Oral Maxillofac Surg 2012 Jun 21.
14. Alpha C, O' Ryan F, Silva A, Poor D. The Incidence of postoperative wound healing problems following sagittal ramus osteotomies stabilized with miniplates and monocortical screws. J Oral Maxillofac Surg 2006;64:659-68.
15. Sato FRL, Asprino L, Consani S, Noritomi PY, de Moraes M. A comparative evaluation of the hybrid technique for fixation of the sagittal split ramus osteotomy in mandibular advancement by mechanical, photoelastic, and finite element analysis. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2012 Feb 28 [Epub ahead of print].
16. Spiessl B. Osteosynthesis in sagittal osteotomy using the Obwegeser-Dal Pont method. Fortschr Kiefer Gesichtschir 1974;18:145-8.
17. Erkmen E, Simşek B, Yűcel E, Kurt A. Comparison of different fixation methods following sagittal split ramus osteotomies using three-dimensional finite elements analysis: Part 1: advancement surgery-posterior loading. Int J Oral Maxillofac Surg 2005;34:551-58.
18. Matsushita K, Inoue N, Totsuka Y. *In vitro* biomechanical evaluation of the effect of an additional L-shaped plate on straight or box plate fixation in sagittal split ramus osteotomy

using a bioabsorbable plate system. J Oral Maxillofac Surg 2011;15:139-46.
19. Yamashita Y, Mizuashi K, Shigematsu M, Goto M. Masticatory function and neurosensory disturbance after mandibular correction by bilateral sagittal split ramus osteotomy: a comparison between miniplate and bicortical screw rigid internal fixation. Int J Oral Maxillofac Surg 2007;36:118-22.
20. Rubens BC, Stoelinga PJW, Blijdorp PA, Schoenaers JHA, Politis C. Skeletal stability following sagittal split osteotomy using monocortical miniplate internal fixation. Int J Oral Maxillofac Surg 1988;17:371-76.
21. Stoelinga PJ, Borstlap WA. The fixation of sagittal split osteotomies with miniplates: the versatility of a technique. J Oral Maxillofac Surg 2003;61:1471-6.
22. Aymach Z, Nei H, Kawamura H, Bell W. Biomechanical evaluation of a T-shaped miniplate fixation of a modified sagittal split ramus osteotomy with buccal step, a new technique for mandibular orthognathic surgery. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2011;111:58-63.
23. Ribeiro-Junior PD, Magro-Filho O, Shastri KA, Papageorge MB. *In vitro* biomechanical evaluation of the use of conventional and locking miniplate/screw systems for sagittal split ramus osteotomy. J Oral Maxillofac Surg 2010;68:724-30.
24. Choi BH, Zhu SJ, Han SG, Huh JY, Kim BY, Jung JH. The need

for intermaxillary fixation in sagittal split osteotomy setbacks with bicortical screw fixation. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2005;100:292-95.

25. Van Sickels JE, Peterson GP, Holms S, Haug RH. An *in vitro* comparison of an adjustable bone fixation system. J Oral Maxillofac Surg 2005;63:1620-5.
26. Schwartz HC, Relle RJ. Bicortical-monocortical fixation of the sagittal mandibular osteotomy. J Oral Maxillofac Surg 1996;54:234-35.
27. Brasileiro BF, Grempel RG, Ambrosano GMB, Passeri LA. An *in vitro* evaluation of rigid internal fixation techniques for sagittal split ramus osteotomies: Advancement surgery. J Oral Maxillofac Surg 2009;67:809-17.
28. Schwimmer A, Greenberg AM, Kummer F, Kaynar A. The effect of screw size and insertion technique on the stability of the mandibular sagittal split osteotomy. J Oral Maxillofac Surg 1994;52:45-8.
29. Ozden B, Alkan A, Arici S, Erdem E. *In vitro* comparison of biomechanical characteristics of sagittal split osteotomy fixation techniques. Int J Oral Maxillofac Surg 2006;35:837-41.
30. Ming-Yih L, Chun-Li L, Wen-Da T, Lun-Jou L. Biomechanical stability analysis of rigid intraoral fixation for bilateral sagittal split osteotomy. J Plast Reconstr Aesthet Surg 2010;63:451-55.
31. Shetty V, Freymiller E, McBrearty D, Caputo AA. Experimental

analysis of functional stability of sagittal split ramus osteotomies secured by miniplates and position screws. J Oral Maxillofac Surg 1996;54:1317-24; discussion 24-6.
32. Ellis E 3rd. A method to passively align the sagittal ramus osteotomy segments. J Oral Maxillofac Surg 2007;65:2125-30.
33. Chuong CJ, Borotikar B, Schwartz-Dabney C, Sinn DP. Mechanical characteristics of the mandible after bilateral sagittal split ramus osteotomy: Comparing 2 different fixation techniques. J Oral Maxillofac Surg 2005;63:68-76.
34. Anucul B, Waite PD, Lemons JE. *In vitro* strength analysis of sagittal split osteotomy fixation: noncompression monocortical plates versus bicortical position screws. J Oral Maxillofac Surg 1992;50:1295-9.
35. Pereira Filho VA, Iamashita HY, Monnazzi MS, Gabrielli MF, Vaz LG, Passeri LA. *In vitro* biomechanical evaluation of sagittal split osteotomy fixation with a specifically designed miniplate. Int J Oral Maxillofac Surg 2012 Aug 13.
36. Chung IH, Yoo CK, Lee EK, Ihm JA, Park CJ, Lim JS, Hwang KG. Postoperative stability after sagittal split ramus osteotomies for a mandibular setback with minocortical plate fixation or bicortical screw fixation. J Oral Maxillofac Surg 2008;66:446-52.
37. Fujioka M, Fujii T, Hirano A. Comparative study of mandibular stability after sagittal split osteotomies: biocortical versus monocortical osteosynthesis. Cleft Palate Craniofac J

2000;37:551-5.

38. Ueki K, Marukawa K, Shimada M, Nakagawa K, Yamamoto E. Change in condylar long axis and skeletal stability following sagittal split ramus osteotomy and intraoral vertical ramus osteotomy for mandibular prognathia. J Oral Maxillofac Surg 2005;63:1494-9.
39. Kahnberg KE, Kashani H, Owman-Moll P. Sagittal split advancement osteotomy: comparison of the tendency to relapse after two different methods of rigid fixation. Scand J Plast Reconstr Surg Hand Surg 2007;41:167-72.
40. Blomqvist JE, Isaksson S. Skeletal stability after mandibular advancement: a comparison of two rigid internal fixation techniques. J Oral Maxillofac Surg 1994;52:1133-7.
41. Hsu SSP, Huang CS, Chen PKT, Ko EWC, Chen YR. The stability of mandibular prognathism corrected by bilateral sagittal split osteotomies: a comparison of bi-cortical osteosynthesis and mono-cortical osteosynthesis. Int J Oral Maxillofac Surg 2012;41:142-49.
42. McDonald WR, Stoelinga PJ, Blijdorp PA, Schoenaers JA. Champy bone plate fixation in sagittal split osteotomies for mandibular advancement. Int J Adult Orthodon Orthognath Surg 1987;2:89-97.
43. Throckmorton GS, Ellis E 3rd. The relationship between surgical changes in dentofacial morphology and changes in maximum bite

force. J Oral Maxillofac Surg 2001;59:620–7.

44. Sarkarat F, Motamedi MH, Bohluli B, Moharamnejad N, Ansari S, Shahabi–Sirjani H. Analysis of stress distribution on fixation of bilateral sagittal split ramus osteotomy with resorbable plates and screws using the finite–element method. J Oral Maxillofac Surg 2012;70:1434–38.

45. Cilasun U, Uckan S, Dolanmaz D, Saglam H. Immediate mechanical stability of sagittal split ramus osteotomy fixed with resorbable compared with titanium bicortical screws in mandibles of sheep. Br J Oral Maxillofac Surg 2006;44:534–37.

46. Haraji A, Motamedi MH, Moharamnejad N. Causes and incidence of miniplate removal following Le Fort I osteotomy. Eplasty 2009;9:e45.

47. Stockmann P, B�hm H, Driemel O, M�hling J, Pistner H. Resorbable versus titanium osteosynthesis devices in bilateral sagittal split ramus osteotomy of the mandible - the results of a two centre randomised clinical study with an eight–year follow–up. J Craniomaxillofac Surg 2010;38:522–28.

48. Paeng JY, Hong J, Kim CS, Kim MJ. Comparative study of skeletal stability between bicortical resorbable and titanium screw fixation after sagittal split ramus osteotomy for mandibular prognathism. J Craniomaxillofac Surg 2012;40:660–4.

49. Cilasun U, Uckan S, Dolanmaz D, Saglam H. Immediate mechanical stability of sagittal split ramus osteotomy fixed with

resorbable compared with titanium bicortical screws in mandibles of sheep. Br J Oral Maxillofac Surg 2006;44:534-7.

50. Ferretti C, Reyneke JP. Mandibular, sagittal split osteotomies fixed with biodegradable or titanium screws: a prospective, comparative study of postoperative stability. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2002;93:534-7.