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.

Kazuhiro Matsushita[1], Nobuo Inoue[2], and Yasunori Totsuka[1]

[1]Department of Oral and Maxillofacial Surgery, Division of Oral Pathobiological Science, and

[2]Department of Gerodontology, Division of Oral Health Science, Graduate School of Dental Medicine, Hokkaido University

N13W7, Kita-ku, Sapporo, Hokkaido, Japan. 060-8586.

Corresponding author: Kazuhiro Matsushita

Tel: +81-11-706-4283; Fax: +81-11-706-4283

E-mail: matsushi@den.hokudai.ac.jp

Abstract

Purpose: Relapse caused by clockwise (opening) rotation of the distal segment (dentate segment) in the sagittal plane is one of the postoperative complications sometimes seen after sagittal split ramus osteotomy. The force involved in this movement is primarily exerted by the masticatory and suprahyoid muscles. For postoperative stability, we have used two plates on each side: a straight plate placed over the vertical osteotomy line at the buccal surface of the first molar; and an L-shaped plate placed at the distal or lateral part of the last molar over the osteotomy line, just crossing over the upper-lateral edge of the buccal shelf, to prevent the tail of the distal segment from moving upward. Although postoperative stability was clinically fine, experimental evaluations have not previously been performed. To clarify the effects of the L-shaped plate, we performed an experimental study using a bioabsorbable plate system.

Methods: A custom-fabricated jig was made to simulate rotational movement of the segments. Two segments made from polyoxymethylene resin were fixed with a 4-hole straight or 4-hole box poly-L-lactate (PLLA) bioabsorbable plate. An L-shaped plated was then added for rigidity and mechanical testing was performed.

Result: The yield load exerted by the 4-hole straight plate alone was 152.4±11.0 N. This increased significantly to 273.8±43.7 N with addition of an L-shaped plate ($p<0.05$).

Conclusion: Addition of an L-shaped plate significant improves the rigidity of 4-hole straight plate fixation in a bioabsorbable plate system.

Keywords: sagittal split ramus osteotomy (SSRO); stability; rigidity; bioabsorbable plate; relapse

Introduction

After sagittal split ramus osteotomy (SSRO), both the proximal segment (condylar segment) and the distal segment (dentate segment) are stabilized by positional screws and/or miniplates. Spiessl first described the use of rigid fixation for SSRO using transcutaneously placed bicortical compression lag screws, with two above and one below the mandibular canal [1]. Fixation using three positional screws had since become a popular method for achieving good rigidity and stability, and this method is particularly effective against rotational movement. However, passive fixation of segments with the condyles in desirable positions and with the proper gap between the proximal and distal segments without any compression or any tension is difficult. The miniplate technique was subsequently introduced by Michelet et al. [2]. This allows easy intraoral access and fixation with less risk of inferior alveolar nerve injury. Moreover, the technique is particularly advantageous in larger advancements where proximal and distal overlaps are minimal. Use of a 4-hole titanium miniplate has thus become popular and we have used this procedure to secure segments. Over time, however, we encountered some cases of relapse, particularly in the form of open bite, even in patients for whom proper occlusion had been obtained as planned and was reproducible at the surgery and up to several months after surgery. Such relapse as open bite was not directly attributable to plate or screw breakage and clockwise (opening) rotation of the distal segment was sometimes seen on cephalography. As has been reported previously, we attributed this phenomenon to clockwise rotation of the distal segment mainly through the pulling action of the medial pterygoid muscle attached to the inner-lower edge of the distal segment [3, 4], even with adoption of the Epker method [5]. The suprahyoid muscles attaching to the inner side of the mental region likewise pull the mandible downward (Fig. 1). To achieve more rigid fixation against rotational traction acting at the overlapping portion between proximal and distal segments, we have been looking for a novel fixating configuration. We finally switched from using a single miniplate to using two miniplates, with one placed on the buccal surface of the bone over the vertical osteotomy line using a straight plate as usually performed previously, and the other placed on the buccal shelf or retromolar region perpendicularly across the mesio-distal osteotomy line using an L-shaped plate, just holding the edge of the proximal segment (Figs. 2-5). This region provides the best quality, width of bone and strength for loading. L-shaped plate fixation was aimed not only to achieve rigidity, but also to resist rotational movement of the distal segment, and we regard this latter point as more important. The site or direction of placement for the L-shaped plate varies slightly, depending on the local situation such as the amount of bone remaining on the buccal side, the presence of wisdom teeth or the location of the anterior edge of the ramus. We have performed this technique on over 200 cases and have recognized numerous advantages in this fixating configuration in combination with the Epker method. Postoperative long-term stability was achieved, resulting in secondary benefits of early rehabilitation of mouth opening and early starting of postoperative orthognathic treatment. Patient satisfaction has also been increasing. However, no objective experimental evidence supporting the stability and rigidity has previously been described.

The purpose of this study was to biomechanically evaluate the effects of using an additional L-shaped plate on the rigidity conventionally produced by a straight or box miniplate after SSRO. To simulate the rotational movement of the distal segment generated by the masticatory and suprahyoid muscles, we devised a shearing model based on the 3-point biomechanical test and examined a bioabsorbable plate system.

Methods

To simplify the events occurring at the osteotomy and fixation site in the clinical situation, two polyoxymethylene resin plates (Duracon; Polyplastic Co., Ltd, Tokyo, Japan) were used to simulate distal and proximal segments, instead of cadaveric mandibles of human and other bony parts from animal sources. This synthetic substrate material eliminates the individual variability of bone in terms of thickness, elasticity and shape. In addition, the smooth surface of these blocks avoids any bias brought about by the rougher, more irregular surface of bone. Strength of the plate could thus be evaluated without being significantly influenced by the materials on which the plates were mounted.

Clinically, after improving an open bite, the distal segment will rotate downward to the original position due to the effects of the two stretched muscle groups (the suprahyoid muscle group and the masticatory muscle group). To simulate this phenomenon, we fabricated a special jig. The osteotomy site was simulated by overlapping Duracon plates. The plates were mounted in a custom-fabricated jig and allowed to overlap by 28 mm. A 6-mm sagittal gap was left between segments, equivalent to the vertical osteotomy line in a sagittal direction. This also enabled rotational movement of the segments without interfering with each other. The distance from the center of the rotation frame of the jig to the center of the gap was 80 mm, referencing a mean distance in humans. Due to technical issues, the distal segment was fixed and the proximal segment could be rotated, representing a reverse of the situation with actual motions in the body. However, this difference was not considered to have any significant effect on the results.

In clinical situations, selection of a titanium or bioabsorbable poly-L-lactic acid (PLLA) plate depends on the situation. The present study investigated the benefits of an additional L-shaped plate in a PLLA plate system (Neofix; Distributor, Kobayashi Medical Co., Ltd, Osaka, Japan. Manufacturer, Gunze Co., Ltd. Kyoto, Japan). PLLA straight, Box and L-shaped plates were used. All screw holes were made to the recommended dimension of 1.6 mm in diameter by 5 mm in length. Screw diameter was 2 mm, and the plate profile height was 1.0 mm. Straight and Box plates were placed over the osteotomy gap (Fig. 6). L-shaped plates were placed 20 mm posterior to the center of the gap, reflecting the mean distance from clinical situations. To eliminate changes in physical properties of the L-shaped plate by bending, the plate was used without bending, by fixation in an original configuration just as is, with three screws on the top of the Duracon (two screws in the distal segment, one screw in the proximal segment). The remaining outer side hole was left vacant. In clinical situations, we cut off the last hole, because we believe that on the proximal plate one screw is enough for exerting resistance against rotational movement and, moreover, this area will usually be located so deep that management without an angle driver or trocar is not feasible.

After mounting the complex in a mechanical testing machine (Autograph; Shimadzu Co., Ltd, Kyoto, Japan), shearing loads were applied by rotating one segment to determine the resistance stress exerted by each plate (Fig. 7). The top of the rotational segment of the jig was pulled at a rate of 5 mm/min, equivalent to 11.7 mm/min at the center of the gap at which the straight or box plate were fixated. Each test was repeated 3-5 times, depending on the number of samples. Load/displacement data were automatically gathered for each experiment. Curves for cases other than a single straight plate were poly-phasic. After the breakage of one part of a box frame, straight plate or screw, the remaining part of the plate or remaining L-shaped plate was more tolerant after the yield point and second or further curves were made. We aimed to examine the initial strength against rotational movement and evaluated the strength within the range of first yield points. The evaluated parameters were yield load, yield displacement, stiffness and load at 3.0 mm of displacement. Yield displacement is that distance at which the system begins to show permanent deformation. Yield load is that load at which the system begins to permanently deform. Stiffness is defined as the rate of change in strain as a function of stress, reflecting elastic deformation, and is expressed at Newtons per millimeter. Stiffness was calculated within the range of 50-150 N along the straight portion of the load-displacement curve. Load at 3.0 mm displacement is an arbitrary value based on clinical beliefs [6], and shearing distance >3.0 mm between the two edges of the proximal and distal segments at a osteotomy line in the sagittal plane will cause bone-healing failure.

After testing, data were acquired and means and standard deviations were derived and compared for statistical significance. Statistical analyses were performed using the Mann-Whitney U test at a significance level of $P<0.05$.

Results

The effect of the L-shaped plate was examined in both straight plate and box plate groups. With increasing loads in the straight plate group, in-line deformation was seen and plate fracture finally occurred (Fig. 8). Some slippage was also seen. However, no screw fracture was observed. Mean yield loads were 152.4±11.0 N for a single straight plate. In the group with the combination of straight and L-shaped plates, almost the same deformation was seen (Fig. 9), but yield load increased to 273.8±43.7 N. In the box plate group, both plate and screw breakage were seen with increased load, and the plate was finally teased off (Fig. 10). Yield loads were 204.5±28.6 N for a single box plate, and 274.0±46.1 N for the combination of box and L-shaped plates (Fig. 11). Significantly higher fixation was seen with the addition of an L-shaped plate in the straight plate group. However, no significant effect on yield load was found in the box plate fixation group with addition of an L-shaped plate. All load/displacement curves are shown in Figure 12. Parameters other than yield load showed no significant changes with addition of L-shaped PLLA plates in both straight and box plate groups (Table 1).

Discussion

This experiment is unique in that shearing force was applied by rotational movement of one segment, resembling physiological movement in humans. The test model used here is a modification of a 3-point biomechanical test. No similar reports appear to have been described in the literature. To a lesser or greater degree, almost all previous studies have used compression or pulling loads from various points with various materials by various ways [7-10], and have not simulated actual movements in situ.

Rigid fixation enables early oral intake and early physiotherapy. No further intermaxillary fixation (IMF) is required. Meanwhile, precise condylar positioning becomes extremely important, as stable occlusion will otherwise not be achieved and the risk of subsequent temporomandibular joint disorders is increased. This is because spontaneous adaptation of condyles or spontaneous movement to the most appropriate position in the glenoid fossa is not expected, as seen when IMF was performed in earlier days [11]. According to our clinical experience using this two-plate fixation system, we did not have to worry about postoperative plate fracture at all. Best of all, postoperative stability and predictability were fine compared with a conventional single straight plate fixation. It must be kept in mind that interfragmentary diastema produced by SSRO should be handled in quite a different way from well-reduced fracture. From the differences between these characteristic features, the efficacy of two-plate fixation in our original configuration is worth noting for SSRO.

In fact, two-plate fixation has been performed clinically and biomechanical evaluations have also been reported [12, 13], but most such evaluations have used simple parallel alignments and have not considered how to effectively suppress rotational movement. Attention had previously only been paid to the number of plates and the configuration of screws in a limited region, instead of mechanical dynamics under functional motions. Appropriate sites and configurations should be chosen on the basis of the surgical intentions and expected purposes of the supplementary plate under functional conditions, rather than merely increasing the number. Theoretically and mechanically, fixation by two plates in two different dimensions, that is, sterically, certainly produces greater stability compared with one-plate fixation in one dimension. In this regard, our configuration with a straight plate and L-shaped plate will be reasonable for exerting force against muscular pull to the original position. Resistance force against distortion, in the form of lateral movement of the jaw, might be increased by adding an L-shaped plate.

The present results demonstrated an increase in yield load by 1.8-fold by adding an L-shaped plate to single straight plate fixation. Although other parameters in the straight plate group did not show any significant increase, a strong tendency was noted. Meanwhile, in the box plate group, no significant strengthening was seen with addition of an L-shaped plate. This lack of effectiveness for the L-shaped plate with the box plate is probably attributable to the fact that the box plate is already relatively strong against shearing force, but may also be partially due to the limited number of samples.

In clinical situations, the L-shaped plate is placed in a bent shape smoothly attached to the surface of the bone at the edge of the buccal shelf or external oblique ridge, and then each screw is installed vertical to the bone. The lateral screw inserted in the proximal segment will be almost perpendicular to the screws close to the teeth. This configuration allows strong immobilization of two segments by suppressing rotational movement of the distal segment, leading to good stability. In this experiment, however, the L-shaped plate was not placed in the same way as in clinical situations due to elimination of the bias seen with bending the plate using pliers. Hence, this study does not necessarily reflect the true effectiveness of an L-shaped plate. In particular, the box plate was already so strong that no effectiveness of an additional L-shaped plate with linear shape was obvious, and screws broke before breakage of the box plate. With straight plates, effectiveness would also have been increased if placed in the same way as in clinical situations.

Finally, although use of three bicortical screws reportedly offers the most stable situation, optimization of this method requires a proficient technique and experience with securing the segments at the desired positions. In contrast, our method is exceedingly simple and making good sense. Addition of an L-shaped plate is effective for resisting clockwise rotation of the segment in the single straight plate fixation after sagittal split ramus osteotomy. This finding confirms our clinical impression that this configuration offers very good stability. However, the effect with single box plate fixation is subtle at best. To clarify the effects of L-shaped plates in various modalities, further studies that more precisely simulate clinical conditions are required.

Acknowledgements

We wish to thank Hitoshi Ohtani of Gunze Co., Ltd (Kyoto, Japan) for providing PLLA materials, engaging in customization of a new jig and assisting with the laboratory testing.

References

1, Spiessl B (1974) Osteosynthese bei sagittaler Osteotomie nach Obwegeser/Dal pont. In Schuchardt K (ed) Fortschritte in Kiefer-und Gesichtschirurgie. Thieme, Stuttgart, pp 145-148.

2, Michelet FX, Deymes J, Dessus B (1973) Osteosynthesis with miniaturized screwed plates in maxillo-facial surgery. J Maxillofac Surg 1:79-84.

3, Reyneke JP, Ferretti C (2007) Anterior open bite correction by Le Fort I or bilateral sagittal split osteotomy. Oral Maxillofac Surg Clin North Am 19: 321-338.

4, Ellis E, Esmail N (2009) Malocclusions resulting from loss of fixation after sagittal split ramus osteotomies. J Oral Maxillofac Surg 67:2528-2533.

5, Epker BN (1977) Modifications in the sagittal osteotomy of the mandible. J Oral Surg 35: 157-159.

6, Murphy MT, Haug RH, Barber JE (1997) An in vitro comparison of the mechanical characteristics of three sagittal ramus osteotomy fixation techniques. J Oral Maxillofac Surg55: 489-494.

7, Haug RH, Barber JE, Punjabi AP (1999) An in vitro comparison of the effect of number and pattern of positional screws on load resistance. J Oral Maxillofac Surg 57: 300-308.

8, Foley WL, Beckman TW (1992) In vitro comparison of screw versus plate fixation in the sagittal split osteotomy. Int J Adult Orthodon Orthognath Surg 7: 147-151.

9, Anucul B, Waite PD, Lemons JE (1992) In vitro strength analysis of sagittal split osteotomy fixation: noncompression monocortical plates versus bicortical position screws. J Oral Maxillofac Surg 50: 1295-1299.

10, Peterson GP, Haug RH, Van Sickels J (2005) A biomechanical evaluation of bilateral sagittal ramus osteotomy fixation techniques. J Oral Maxillofac Surg 63: 1317-1324.

11, Joss CU, Vassalli IM (2008) Stability after bilateral sagittal split osteotomy setback surgery with rigid internal fixation: a systematic review. J Oral Maxillofac Surg 66:1634-1643.

12, Aymach Z, Nei H, Kawamura H, Bell W (2010) 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. doi:10.1016/j.tripleo.2010.03.028

13, Ribeiro-Junior PD, Magro-Filho O, Shastri KA, Papageorge MB (2010) In vitro biomechanical evaluation of the use of conventional and locking miniplate/screw systems for sagittal split ramus osteotomy. J Oral Maxillofac Surg 68: 724-730.

Conflict of interest

The authors declare that they have no conflict of interest.

Figure legends

Figure 1: A) Even if the mandibular ramus is split by the Epker method and the attachments of the medial pterygoid muscle are stripped from the lower border to avoid the upward muscle pull, complete eradication of the muscle action is impossible. Some remnants of the muscle, pterygomandibular sling, soft tissue envelope and reattachment of stripped muscle will eventually pull the angle of the distal segment upward. Furthermore, the suprahyoid muscle also pulls the mental region of the distal segment downward. These muscle actions rotate the distal segment clockwise (opening), finally leading to open bite as one of the most representative relapses (B).

Figure 2: To resist these forces creating rotational movement, an additional plate is placed. An L-shape plate is appropriate for the location of application and the rigidity generated, since the segments are secured just holding the edge from the upper and lateral sides. In this experiment, we paid attention to the circled area and simulated mechanical dynamics in situ.

Figure 3: Representative case for our original fixation technique. A titanium (A) or bioabsorbable (B) plate is selected, depending on the case.

Figure 4: Postoperative panoramic radiography showing a representative pattern for our original fixation. One plate is placed across the gap at the buccal side of the first molar, and the other is placed at the distal region of the last molar on each side.

Figure 5: Postoperative cephalometric radiography of the patient in Figure 4. An L-shaped plate was placed over the medio-distal osteotomy line at the upper-buccal edge of the last molar, just holding both the proximal (condylar) segment and the distal (dentate) segment.

Figure 6: Schematic representation of experimental models. Two polyoxymethylene resin plates (A and B, Duracon; Polyplastic Co., Ltd, Tokyo, Japan) were used. a, Single straight plate; b,

combination of straight and L-shaped plates; c, single box plate; and d, combination of box and L-shaped plates.

Figure 7: Mounted jig fixed on the mechanical testing machine.

Figure 8: A) Model mounted in the jig. A straight plate was fixed and rotational force could be applied by pulling the handle of the jig upward. B, C) Typical failure pattern of the plate after application of shear force. In-line deformation was seen with the breakage of inner two screw hole-frames, although all screws remained intact. This finding implies that screw heads are strong enough to resist transverse force, transmitted by the frame of the 4-hole plate, to the axis.

Figure 9: A) Both straight and L-shaped plates fixed in the jig. B, C) Representative outcome for cases. In-line deformation was seen with breakage almost the same as seen in fixation with a straight plate. D) Lamellar fracture was seen in some L-shaped plates.

Figure 10: A) A box plate fixed in the jig. B, C) The plate was deformed and finally teased off. The screw head was broken.

Figure 11: A) Both box and L-shaped plates fixed in the jig. B, C) The screw head fractured prior to breakage of the box plate and was lost. The remnant of the screw was placed in the jig. White turbidity was seen in the center space of the L-shaped plate.

Figure 12: Load/displacement curves for each experimental group. Curves other than for the straight plate were poly-phasic. After the breakage of one part of a box frame, straight plate or screw, the remaining part of the plate or remaining L-shaped plate were more tolerant. Evaluation of strength was thus undertaken within the range of first yield points.

Tables

Table 1: Tabulated results.

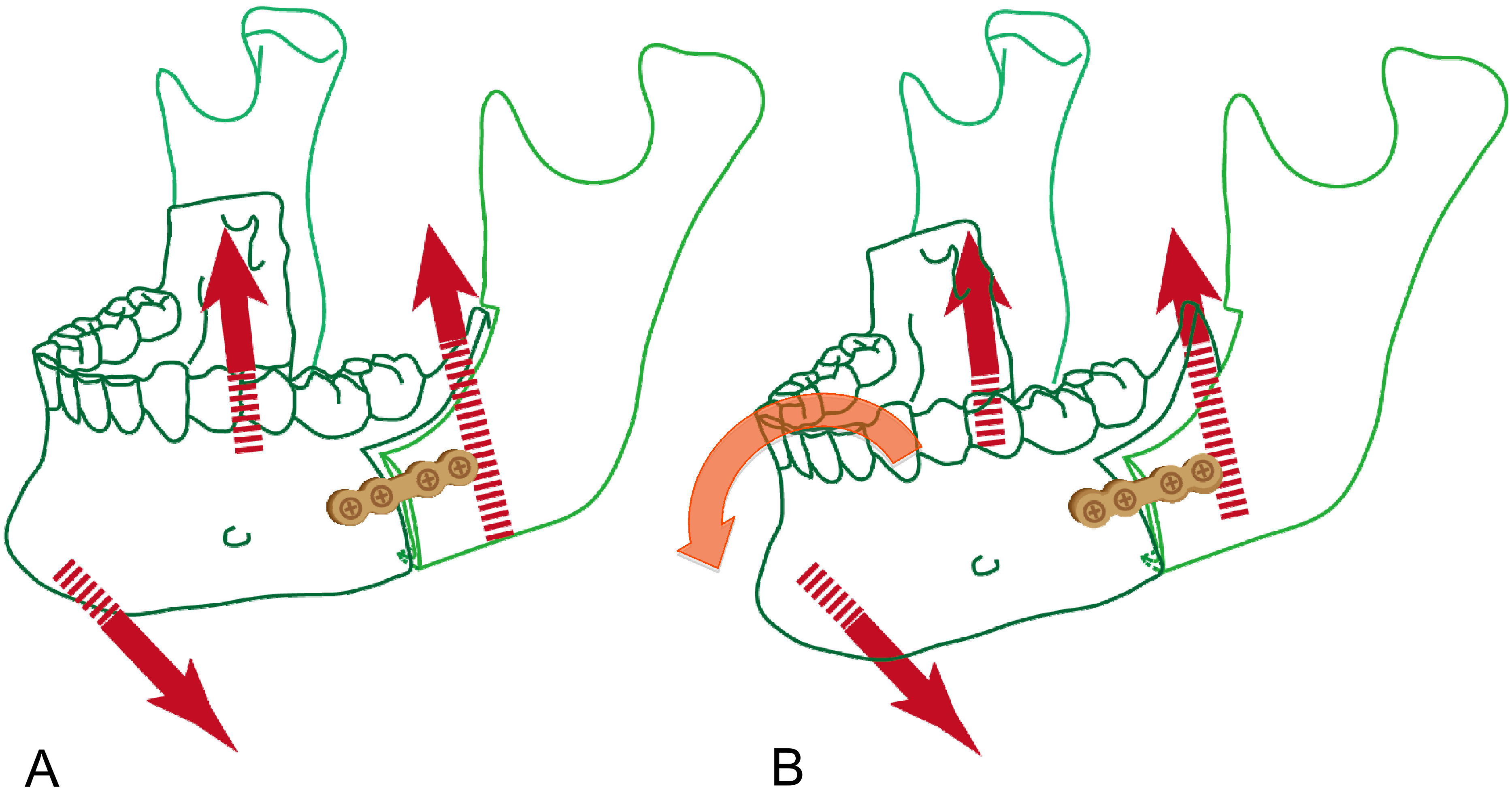


Fig. 1

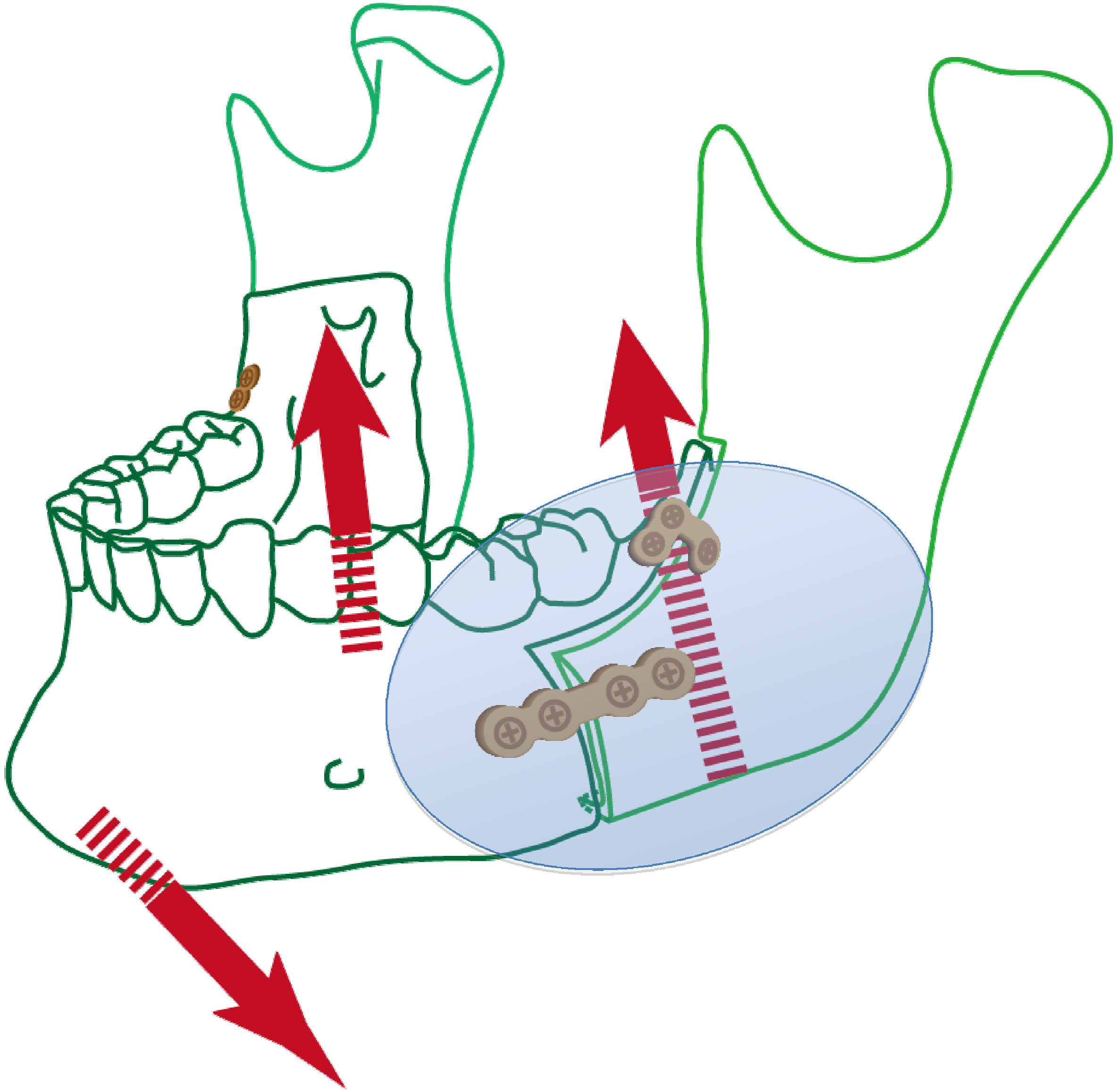


Fig. 2

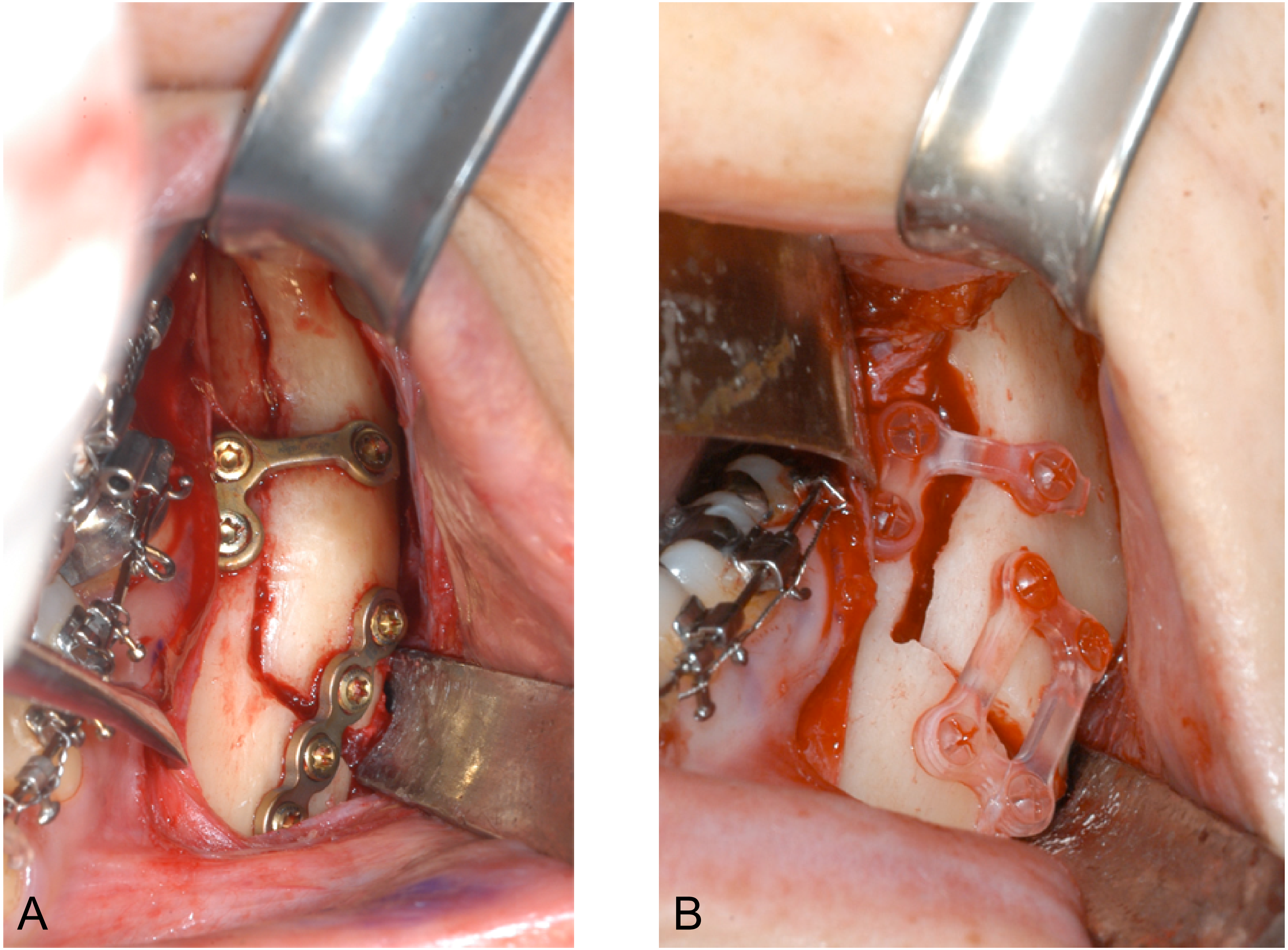


Fig. 3

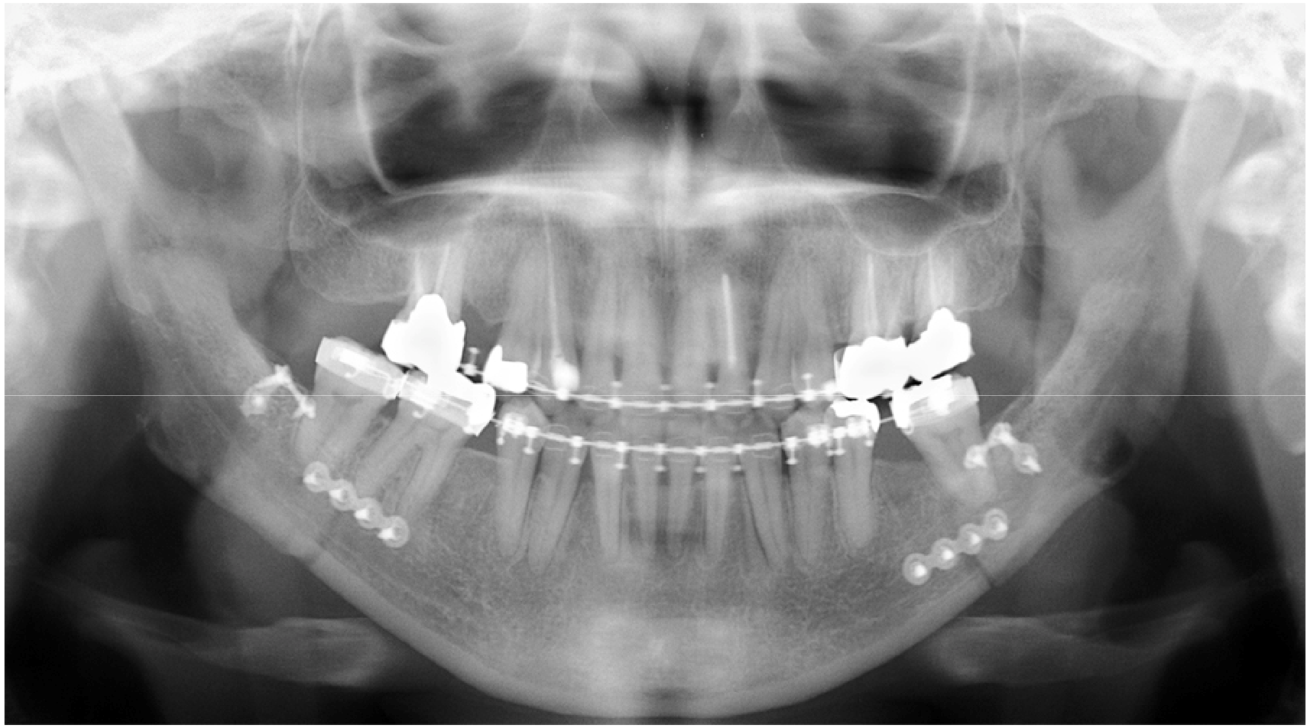
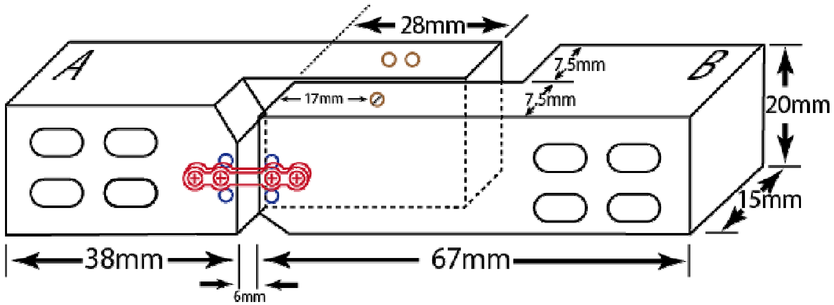
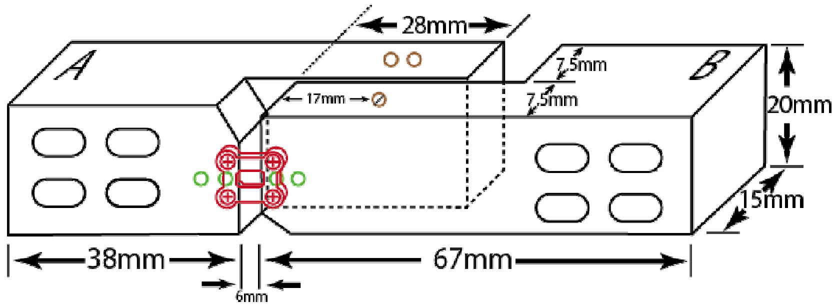


Fig. 4

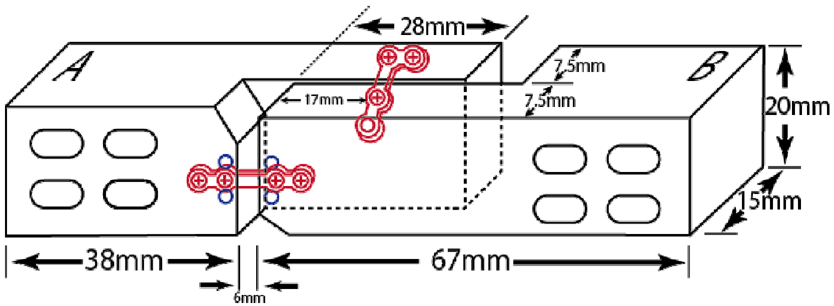
Fig. 5



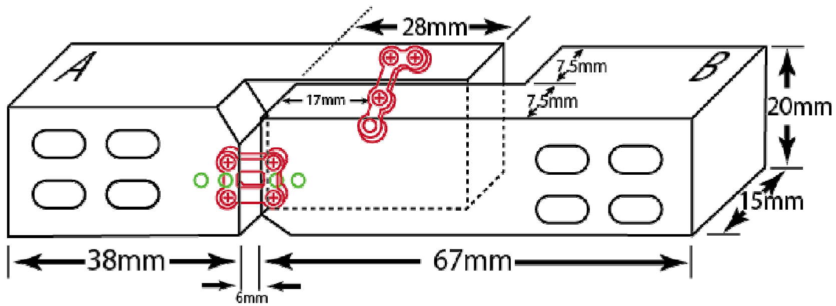
a: Single bioabsorbable straight plate



c: Single bioabsorbable box plate



b: Combination of bioabsorbable straight and L-shaped plate



d: Combination of bioabsorbable box and L-shaped plate

Fig. 6

Fig. 7

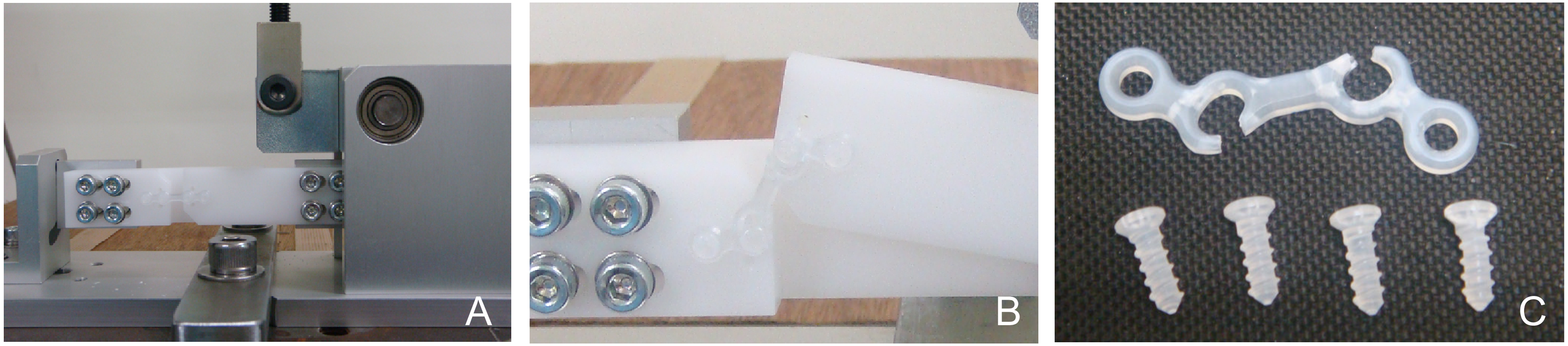


Fig. 8

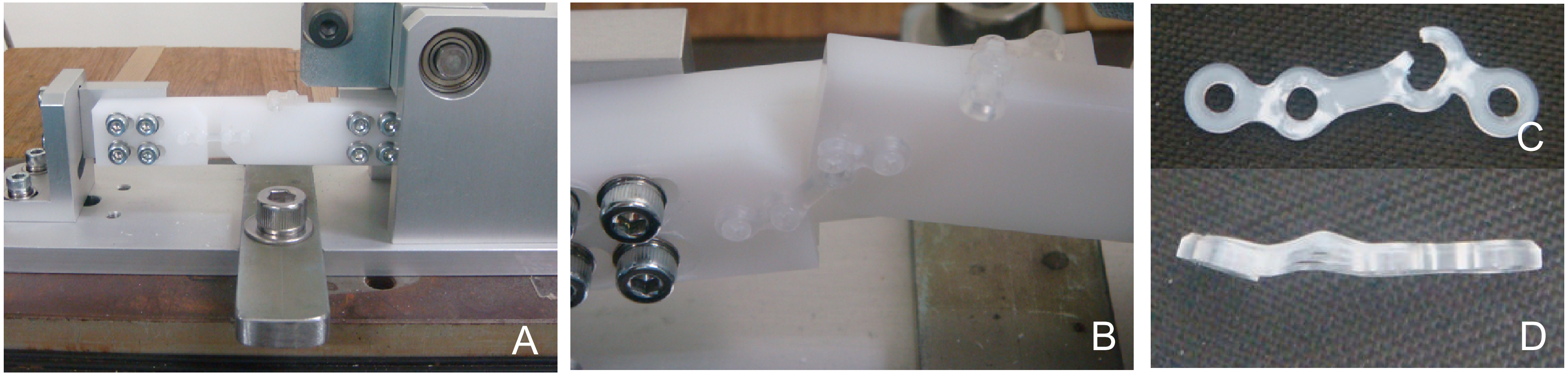


Fig. 9

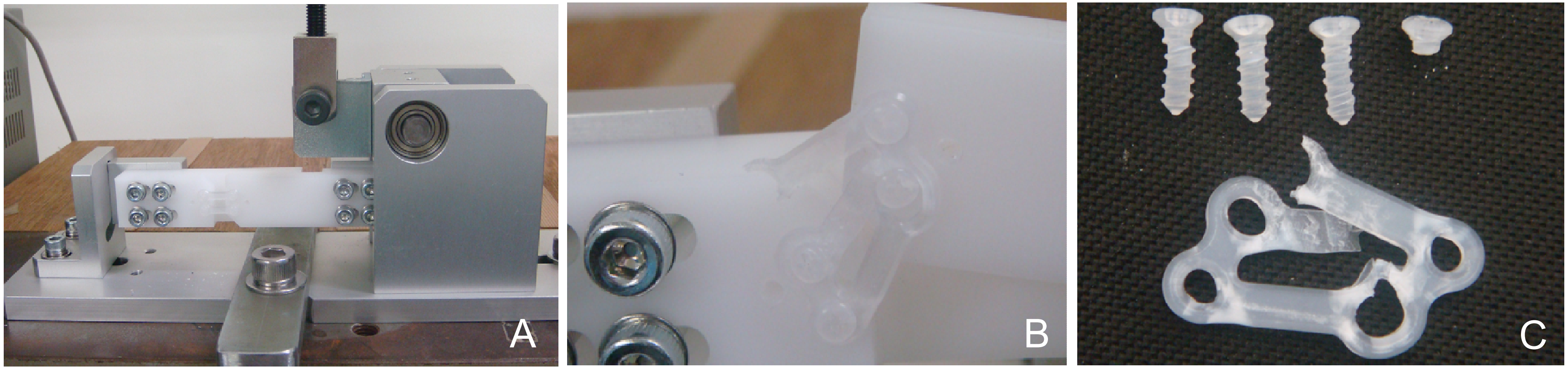


Fig. 10

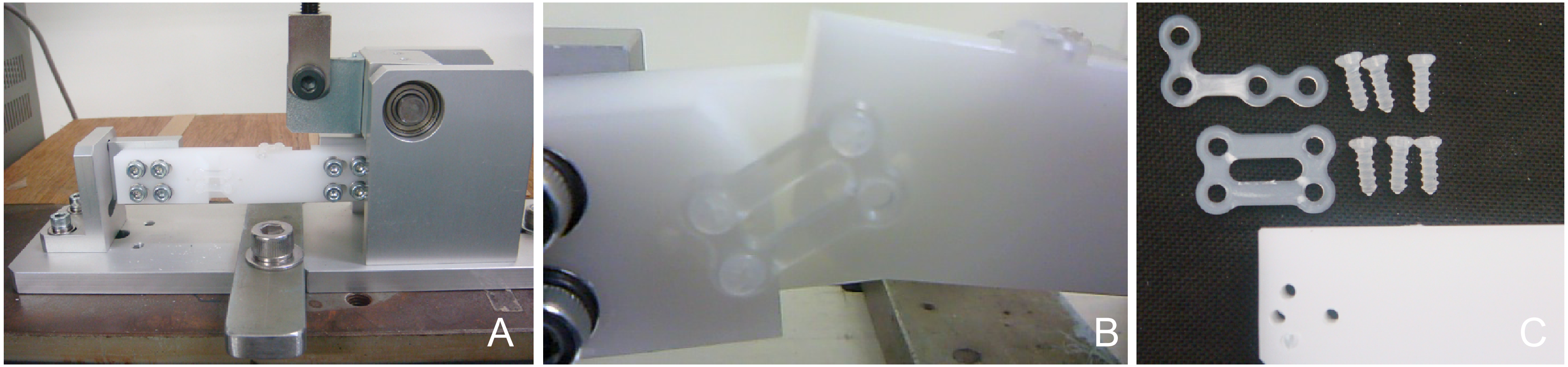


Fig. 11

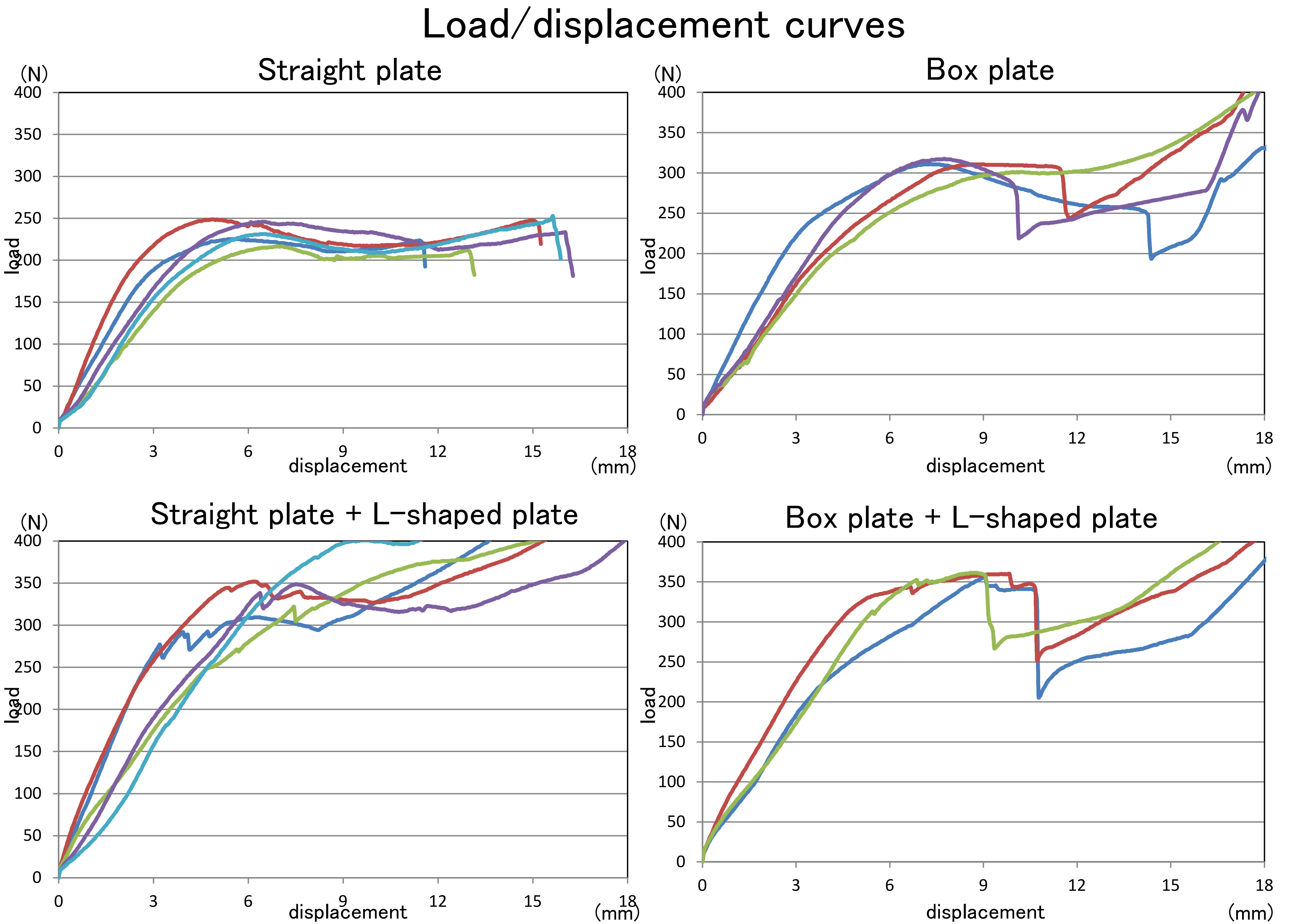

Load/displacement curves
Straight plate
Box plate
Straight plate + L-shaped plate
Box plate + L-shaped plate
(N)
load
displacement
(mm)
0
50
100
150
200
250
300
350
400
0
3
6
9
12
15
18

Fig. 12

Tabulated results

	Yield load (N)	Yield Displacement (mm)	Load at 3.0 mm Displacement (N)	Stiffness (N/mm)
Straight	152.4±11.0*	2.66±0.58	171.9±30.7	63.9±15.5
Straight + L-shaped	273.8±43.7*	4.12±1.34	208.2±52.2	72.0±18.8
Box	204.5±28.6	2.83±1.69	170.5±34.6	58.5±12.3
Box + L-shaped	274.0±46.1	2.69±2.54	192.7±29.1	59.0± 9.6

*Significant difference (P<0.01), by Mann-Whitney U test