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Biomechanical comparison of a novel engine-driven ridge spreader and conventional ridge splitting techniques

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Abstract

Objectives: Ridge splitting techniques are used for horizontal ridge augmentation in implant dentistry. Recently, a novel engine-driven ridge splitting technique was introduced. This study compared the mechanical forces produced by conventional and engine-driven ridge splitting techniques in porcine mandibles.

Material and methods: In 33 pigs, mandibular premolar areas were selected for the ridge splitting procedures, designed as a randomized split-mouth study. The conventional group underwent a chisel-and-mallet procedure (control group, $n = 20$), and percussive impulse (Newton second, Ns) was measured using a sensor attached to the mallet. In the engine-driven ridge spreader group (test group, $n = 23$), a load cell was used to measure torque values (Newton centimeter, Ncm). Horizontal acceleration generated during procedures (control group, $n = 10$ and test group, $n = 10$) was compared between the groups.

Results: After ridge splitting, the alveolar crest width was significantly increased both in the control (1.23 ± 0.45 mm) and test (0.98 ± 0.41 mm) groups with no significant differences between the groups. The average impulse of the control group was 4.74 ± 1.05 Ns. Torque generated by rotation in the test group was 9.07 ± 2.15 Ncm. Horizontal acceleration was significantly less in the test group (0.82 ± 1.05 *g*) than the control group (64.07 ± 42.62 *g*) ($P < 0.001$).

Conclusions: Narrow edentulous ridges can be expanded by novel engine-driven ridge spreaders. Within the limits of this study, the results suggested that an engine-driven ridge splitting technique may be less traumatic and less invasive than a conventional ridge splitting technique.

Dental implants are used for oral rehabilitation of edentulous patients. An implant must have sufficient alveolar bone around the implant to sustain functional loads. A narrow alveolar crest makes preparation of the implant bed difficult and is a risk factor for development of fenestration or dehiscence of the outer cortical bone.

When the residual alveolar ridge is severely compromised, defects can be corrected by block grafting with autogenous bone, xenografts, or bone substitutes, with guided bone regeneration (GBR) to allow implant placement (Kheur et al. 2014). Major drawbacks associated with onlay block autografts are an unpredictable resorption, risk of donor site morbidity, increased time and cost, and patient discomfort (Nystrom et al. 1996). In addition, GBR is often complicated by delayed healing and infection after membrane exposure. This delays placing implants as the integration of grafting materials typically requires 3–6 months (Buser et al. 1996; Machtei 2001; Silva et al. 2006).

The ridge splitting procedure, also known as split crest, edentulous ridge expansion, or split osteotomy includes sagittal osteotomy of the alveolar crest followed by lateralization of the outer labial/buccal cortical plate from the lingual bone (Simion et al. 1992; Scipioni et al. 1994) and expansion with the Summers osteotome to create space for implant placement (Summers 1994). This technique, first introduced by Tatum in the 1980s (Tatum 1986), has been improved in the past decade (Simion et al. 1992; Scipioni et al. 1994) and is now widely incorporated into implant dentistry (Beolchini et al. 2014; Tang et al. 2015).

Splitting the alveolar ridge is a technique-sensitive procedure that is performed with

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surgical tools including bone chisels, osteotomes, rotating or oscillating saws, piezoelectric devices, and surgical mallets. This procedure is particularly efficient in the maxilla, where the elastic cancellous bone allows lateral compression and expansion of the adjacent buccal/lateral cortical bone. Moreover, this technique reduces bone fenestration or dehiscence and allows for correct implant placement within the bony housing. Other advantages of this technique over GBR and block-onlay bone grafting include simultaneous implant placement, shorter treatment time, better pain management, no need for donor sites, and restoration of the buccal arch dimensions (Scipioni et al. 1994; Sethi & Kaus 2000).

Despite its benefits, the conventional ridge splitting technique has several problems. A common side effect is intense shock from the bone chisels and mallet used during surgery (Anitua et al. 2013). Generally, in the mandible, the risk of partial or complete fracture of the buccal bone plate is increased because of the rigidity of the mandibular bone. The cortical bone of the mandible is thicker and less flexible than the maxilla. The ridge splitting technique uses the lingual cortical bone as a stanchion for the chisel to force the buccal cortical plate facially to expand the edentulous ridge. If the ridge lacks an elastic bone component (cancellous bone) or has a significant undercut, risk of fracture during expansion increases.

To overcome these limitations, an engine-driven ridge spreader has been suggested as an alternative to the chisels and mallet. Unlike the hand chisels and osteotomes, engine-driven ridge spreaders do not require a mallet to fracture the alveolar crest and are considered an advantageous alternative to conventional ridge splitting techniques (Beolchini et al. 2014; Ella et al. 2014; Tang et al. 2015). Successful outcomes have been reported using ridge spreaders in surgeries that require ridge splitting, including implant installations (Beolchini et al. 2014, 2015). However, studies that evaluate the mechanical force or frictional torque required to expand the alveolar ridge are rare. Most of these studies measure elevation forces generated by osteotomes or hydraulic devices during maxillary sinus floor elevation (Crespi et al. 2014; Stelzle & Rohde 2014).

The purpose of this study was to determine the force and torque and to compare the horizontal acceleration of conventional and engine-driven ridge spreader ridge splitting techniques in pig mandibles.

Material and methods

Animal model

Ex vivo heads of 33 male domestic pigs (Bucheon, Bucheon National Agricultural Cooperative Federation, Korea), 4–5 months (90–100 kg) old, were used. The pigs had been raised according to the guidelines of Korea veterinary authorities (ministry of Agriculture, Food and Rural Affairs and Animals and Plant Quarantine agency). This study was approved by Institutional Animal Care and Use Committee of Hanyang University (2015-0243).

After slaughter, porcine skulls were dissected and the skin, lips, and underlying soft tissues were carefully removed. Then, porcine skulls were kept frozen (−20°C) wrapped with sterilized saline soaked gauze. For standardization, preoperative ridge splitting sites were determined based on cone-beam computed tomography (CBCT). Anatomical site selection for ridge splitting procedures considered as follows: (i) suitable edentulous span ≥10 mm, (ii) distance from mental foramen and mandibular canal ≥2 mm, and (iii) no impaction of tooth germ. Preoperatively, CBCT was performed on all samples to assess the three-dimensional morphology of the alveolar ridge, quality and quantity of cancellous and cortical bone, and existence of bony undercuts. The space between the first and second premolars in the pig mandible was selected for the ridge splitting procedure after radiographic confirmation.

Mechanical comparison of different instruments is limited by the use of different measurement units. The conventional ridge splitting technique is measured in impulse, and the engine-driven method is measured as torque. Therefore, we used acceleration value as another unit to compare the ridge splitting procedures. Acceleration was defined by the time rate of the velocity change, which is commonly measured in terms of *g*, Earth gravity. Several studies have reported that external acceleration injury results in headache and dizziness (Radanov et al. 2001; Endo et al. 2006).

This study was designed as a split-mouth design, and the sides were randomized to either the conventional ridge splitting group or the engine-driven ridge spreader group. A chisel and mallet were used on the control group, and impulse ($n = 20$) and horizontal acceleration value ($n = 10$) were measured. An engine-driven ridge spreader was used on the test group, and torque ($n = 23$) and

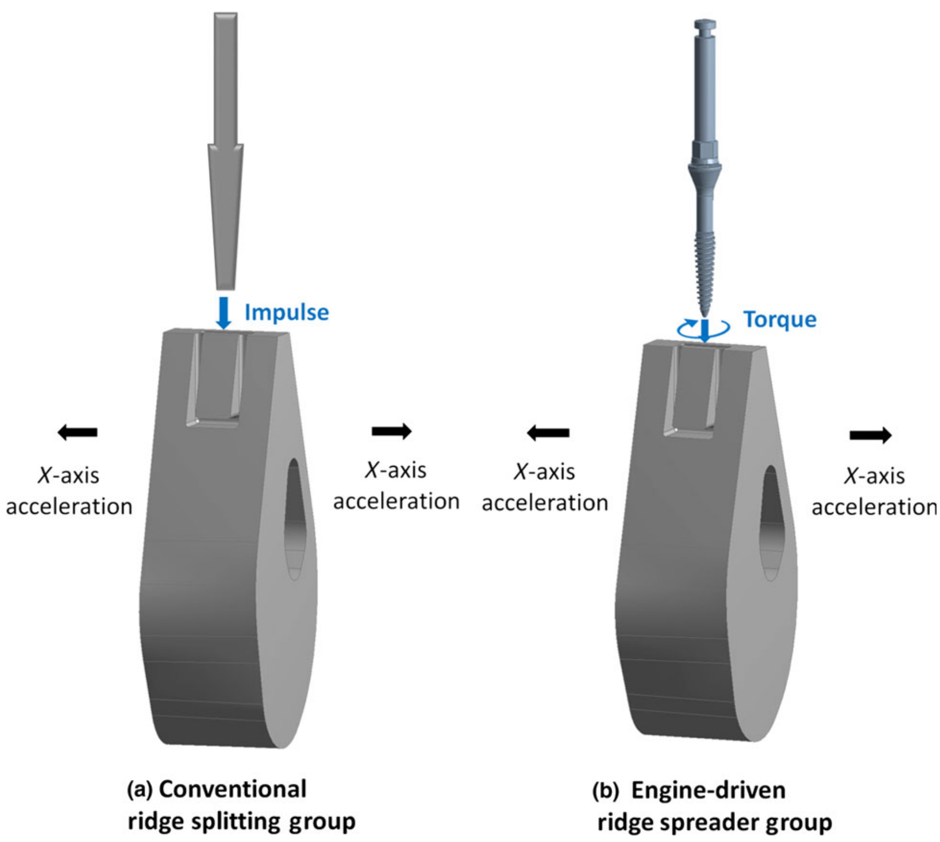

Fig. 1. Schematic drawings of experimental design. (a) Impulse and *x*-axis acceleration for the conventional ridge splitting (control) group. (b) Torque and *x*-axis acceleration for the engine-driven ridge spreader (test) group.

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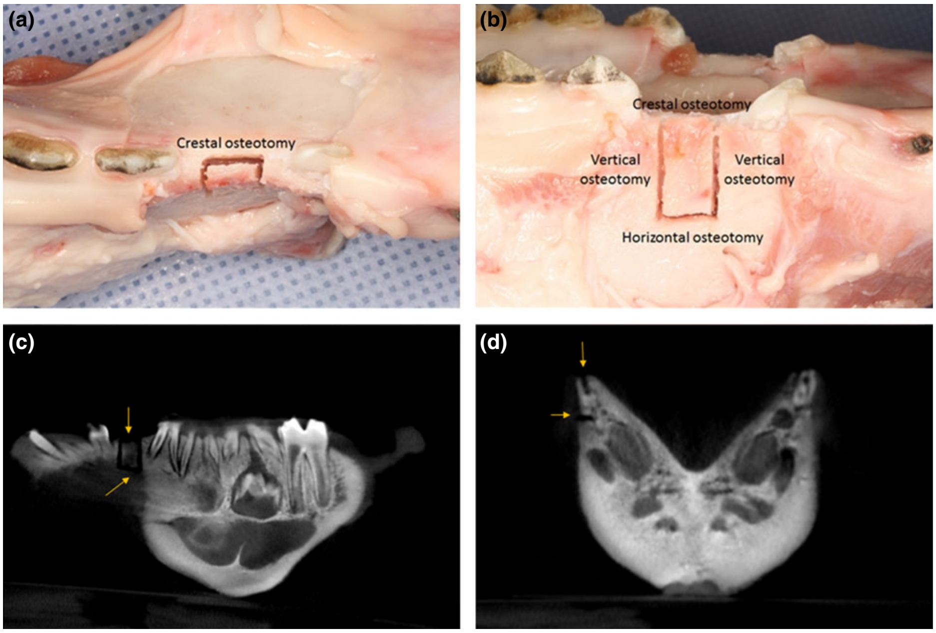

Fig. 2. (a) Crestal osteotomy was to 6 mm length. (b) Horizontal and two vertical osteotomies were performed. (c) Sagittal view of CBCT after osteotomy. Yellow arrows, vertical and horizontal osteotomy lines. (d) Coronal view of CBCT after osteotomies. Yellow arrows, crestal osteotomy in the midcrestal area and horizontal osteotomy lines in the coronal view. Horizontal osteotomy cuts and vertical osteotomies were made with to 3–4 mm depth in all the mandibles for standardization.

horizontal acceleration ($n = 10$) were measured (Fig. 1).

Surgical procedures

An incision was performed with a blade in the center of the alveolar crest encompassing the first and the second premolars. A full-thickness mucoperiosteal flap was raised to expose the labiobuccal cortical bone, lingual bone, and mental foramen. A length of 8–10 mm for the premolar and molar regions in both maxilla and mandible is generally acceptable for implant placement (Winkler et al. 2000; Pommer et al. 2011). Therefore, the osteotomy design was configured according for single-implant preparation (6 × 10 mm, Fig. 2a,b). Osteoplasty was performed in all mandibles to maintain similar specimen conditions. After osteoplasty for standardization, the mean crestal width at the experimental site was approximately 4 mm. Crestal split osteotomy was conducted to 6 mm length and 6 mm depth in the midcrest region between the first and second premolars using a microsaw and 0.8 mm carbide bur under copious irrigation with 0.9% saline (Fig. 2a,b). On the proximal and distal ends of the crestal split, two vertical osteotomies were carried out to approximately 10 mm length to release tension during expansion. Caudal ends of vertical cuts were connected with a horizontal osteotomy. All cuts were made through the buccal cortex to a depth of 3–4 mm; cortical bone was decorticated and cancellous bone was not perforated by radiographic assessment (Fig. 2c,d). After osteotomies, no expansion of buccal cortical plates was observed.

Impulse measurements for the conventional ridge splitting group

The second step of the surgical procedure was ridge splitting and lateralization of the buccal cortical plate. A chisel and mallet were used to separate cortical plates. Specially constructed sensors were attached to the mallet for impulse measurements ($n = 20$) throughout the ridge splitting procedure (Fig. 3a). Zero-point adjustments were performed for each specimen before

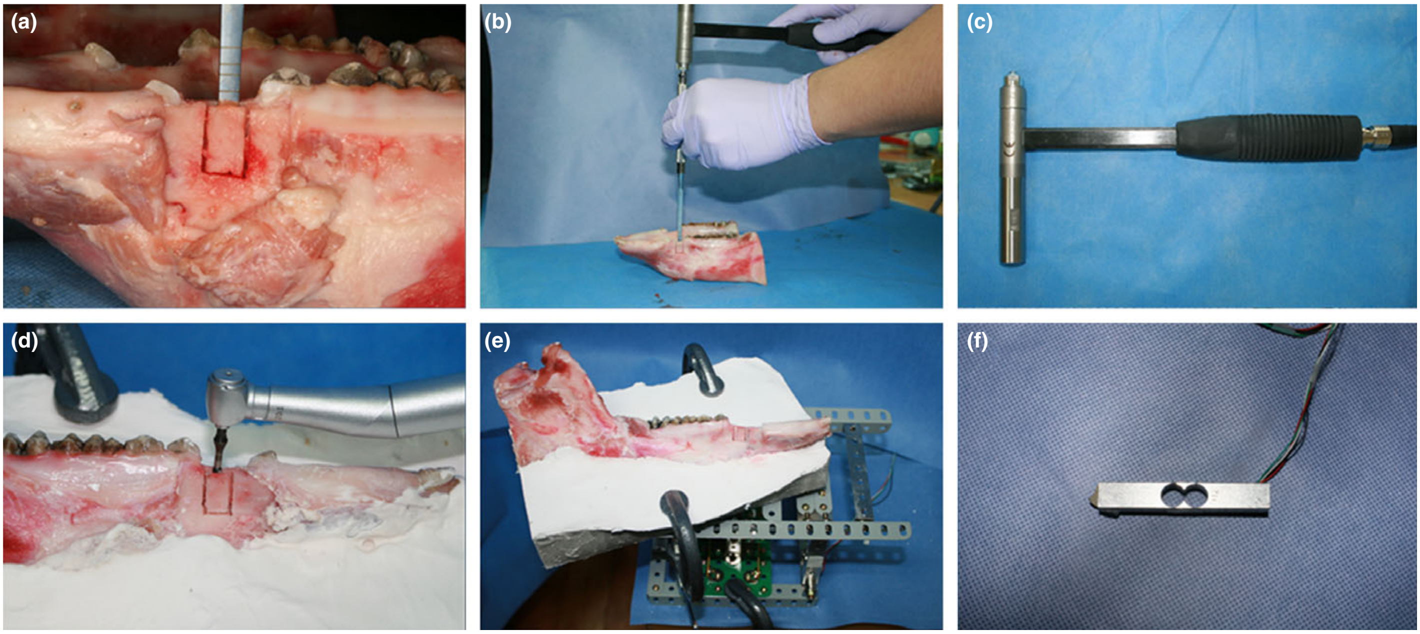

Fig. 3. (a) In the conventional ridge splitting group, impulse was measured during ridge splitting. Impulse calibration was performed to chisel depth of 10 mm. (b) A chisel and mallet with a sensor were used to evaluate impulse. (c) A sensor attached to the mallet. (d) In the engine-driven ridge spreader group, the ridge spreader drill was placed into the crestal cut and (e) a device with a load cell calibrated frictional torque to 10 mm calibration on the ridge spreader. (f) Torque value in N·cm using the load cell.

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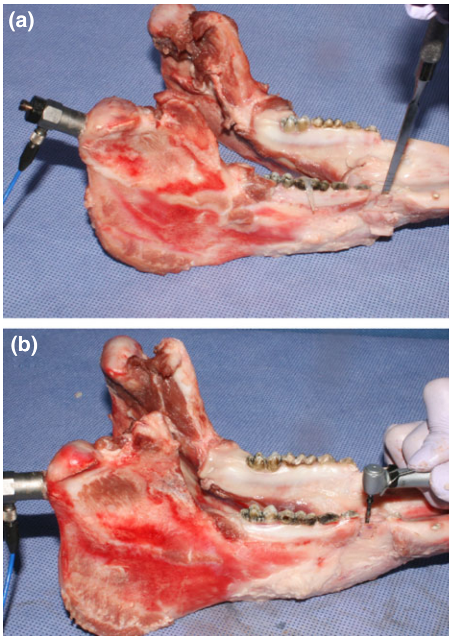

Fig. 4. Horizontal acceleration values were measured in (a) the conventional ridge splitting and (b) the engine-driven ridge spreader groups.

measurement. A straight chisel (OSS6518S; Hu-Friedy®, Rotterdam, Holland) was placed into the initial cut (Fig. 3a). The thickness of the chisel was 1.0 mm. Mobilization and gradual lateralization of the buccal segment were performed by striking the chisel with the hand mallet to 4 mm apical advancement and 10 mm calibration on the chisel (Fig. 3a). Physical interpretation and digitization of impulse values into Ns was performed with Labview and Matlab software (R2008b, The MathWorks, Natick, MA, USA) software. Impulse calibration was based on the timing of the force application and the magnitude of the force on the mallet tip. Impulse measurements continued until 10 mm advancement from the alveolar crest, when the chisel was removed.

Torque measurements in the engine-driven ridge spreader group

The ridge splitting procedure was performed using a thread-forming ridge spreader device (RS kit®, Dentium, Seoul, Korea) with site preparation as above. The ridge splitting procedure was conducted using engine-driven ridge expanders (Fig. 3d). The diameter of the ridge spreader drill was 1.2 mm. Frictional torque generated as the spreader slipped into the mandible was verified by the load cell, analyzed, and plotted using Labview and Matlab (Fig. 3e). The loading point of the load cell was directly connected to the torque measurement. Each torque-down and strain measurement was repeated in 23 specimens and performed by a single periodontist to a spreader depth of 10 mm. Passive torque values measured with the load cell were in Ncm (Fig. 3f). The splitting procedure was performed using a surgical motor with torque set at 50 Ncm, which was the value recommended by the manufacturer for sufficient expansion during ridge splitting.

Horizontal acceleration measurements

Small horizontal acceleration sensors were attached to the posterior margin of the mandibular body, perpendicular to the chisel and ridge spreader axes (Fig. 4). Acceleration measurements were repeated in 20 specimens for the conventional (n = 10) and engine-driven ridge spreader (n = 10) techniques performed by a single clinician. Signals were recorded and visualized using Labview and imported into Matlab for analysis. Acceleration values in the mandible were measured in the horizontal x-direction and are presented as g, Earth gravity.

Statistical analysis

Experimental data were identified and plotted in Labview and Matlab and analyzed using SPSS 21.0 (IBM corp., Armonk, NY, USA). Mean values and standard deviations as well as first, second (median), and third interquartiles were calculated in both groups. The Wilcoxon signed-rank test was used for finding significant differences in preoperative to postoperative crestal width, and the Mann–Whitney U-test was used for evaluating differences between the test and control groups. Based on a previous *in vitro* study, a

***Table 1.* Comparison of ridge width between conventional and engine-driven ridge spreader groups**

	Conventional group (n = 20)			Engine-driven ridge spreader group (n = 20)		
No.	Ridge width at baseline (mm)	Ridge width after ridge splitting (mm)	Ridge width gain (mm)	Ridge width at baseline (mm)	Ridge width after ridge splitting (mm)	Ridge width gain (mm)
1	3.36	4.76	1.4	3.57	5.4	1.83
2	3.82	5.16	1.34	4.12	5.09	0.97
3	4.34	5.29	0.95	4.25	5.24	0.99
4	4.58	6.15	1.57	4.55	5.2	0.65
5	3.93	5.85	1.92	4.56	5.85	1.29
6	3.75	Buccal fracture	NA	4.01	4.78	0.77
7	3.99	4.71	0.72	4.04	4.99	0.95
8	3.95	4.68	0.73	4.54	5.85	1.31
9	3.61	5.19	1.58	3.78	3.92	0.14
10	3.75	4.48	0.73	4.8	5.02	0.22
11	3.51	5.21	1.7	4.59	6.02	1.43
12	4.1	6.12	2.02	4.22	4.89	0.67
13	3.83	4.27	0.44	4.37	5.4	1.03
14	3.61	5.11	1.5	3.87	4.88	1.01
15	4.46	5.5	1.04	3.8	4.75	0.95
16	4.08	5.21	1.13	3.93	4.89	0.96
17	4.11	5.46	1.35	3.92	4.65	0.73
18	4.35	5.59	1.24	4.87	6.07	1.2
19	4.46	5.06	0.6	3.81	4.75	0.94
20	4.58	6.04	1.46	3.74	5.32	1.58
Mean ± SD	4.01 ± 0.36	5.25 ± 0.54	1.23 ± 0.45	4.17 ± 0.38	5.15 ± 0.52	0.98 ± 0.41
Median (Q1–Q3)	3.97 (3.48–4.46)*	5.16 (4.28–6.04)*	1.34 (0.50–2.18)	4.25 (3.61–4.89)†	5.20 (4.58–5.82)†	0.97 (−0.72–2.66)

NA, not applicable; SD, standard deviation; Q1, first interquartile; Q3, third interquartile.
No significant difference was found between two groups for ridge width gain (P = 0.089, the Mann–Whitney U-test).
*,†Indicate statistically significant difference between preoperative and postoperative ridge width (P < 0.001, the Wilcoxon signed-rank test).

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Table 2. **Mechanical force measurements in conventional and engine-driven ridge spreader groups**

Sample no.	Conventional group (n = 20) Impulse (Ns)	Engine-driven ridge spreader group (n = 20) Torque (Ncm)
1	4.94	8.5
2	4.25	7.61
3	3.8	14.84
4	5.47	6.71
5	6.68	5.38
6	6.49	12.02
7	5.21	8.42
8	4.49	8.92
9	3.34	12.35
10	3.15	10.18
11	3.64	7.92
12	3.01	6.83
13	4.78	9.42
14	5.42	8.49
15	4.92	10.21
16	5.24	7.83
17	3.86	9.92
18	4.86	8.42
19	5.24	9.29
20	6.01	8.04
Mean ± SD	4.74 ± 1.05	9.07 ± 2.15
Median (Q1–Q3)	4.49 (2.72–6.26)	8.50 (4.39–12.1)

Ns, Newton × second; Ncm, Newton × cm; SD, standard deviation; Q1, first interquartile; Q3, third interquartile.

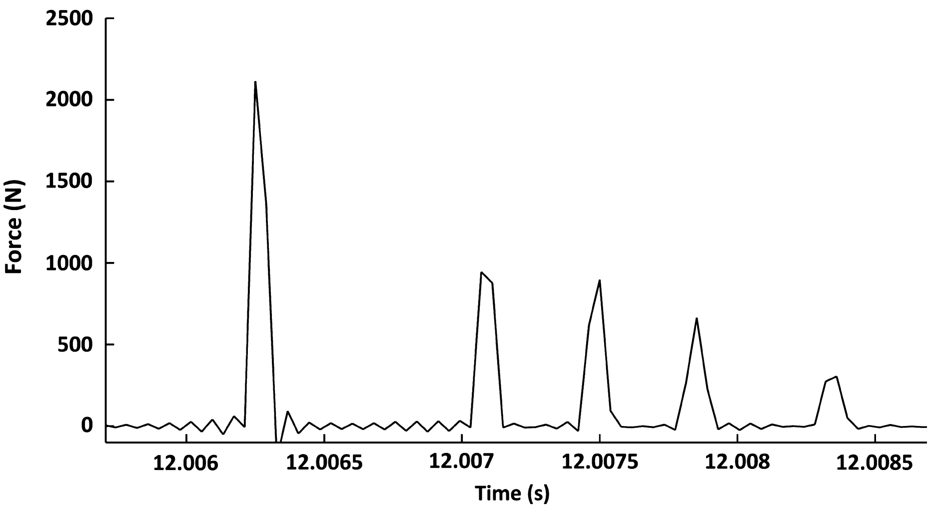

Fig. 5. Magnification of the impulse graph. Total impulse was calculated by multiplying force (Newton) and time (second) for area underneath the force-versus-time graph.

sample size of 20 was required to determine significance (Stelzle & Rohde 2014). As impulse and torque were measured in different units and could not be directly compared, horizontal acceleration was used for comparison between these two groups. Horizontal acceleration was compared using the Mann–Whitney U-test. The level of significance was set at $\alpha = 0.05$.

Results

This study was conducted on 33 porcine mandibles. A single clinical parameter (alveolar ridge width) and three mechanical values (impulse, torque, and horizontal acceleration) were evaluated. The units of mechanical values were impulse (Ns) or torque (Ncm) depending on the device used.

One buccal segment was fractured at the basal corticotomy line during an impulse test, and the data were excluded from the analysis. In torque measurements, three data sets were lost to programming errors.

Bone width changes after ridge splitting procedures

Table 1 shows alveolar bone width at baseline and after ridge splitting procedures. After ridge splitting procedures, alveolar ridge width was significantly increased in the control (1.23 ± 0.45 mm) and test (0.98 ± 0.41 mm) groups ($P < 0.001$) with no significant differences between these two groups.

Mechanical force measurements

In the conventional ridge splitting group, mean impulse value was 4.74 ± 1.05 Ns (Table 2). Total impulse from the chisel during ridge splitting was the area under the force-versus-time graph (Fig. 5). Mean torque of the engine-driven ridge spreader group was 9.07 ± 2.15 Ncm (Table 2, Fig. 6).

Comparison of horizontal acceleration values

In acceleration measurements, mean x-axis acceleration was 64.07 ± 42.62 g in the conventional ridge splitting group and 0.82 ± 1.05 g in the engine-driven ridge spreader group (Table 3). The conventional ridge splitting group showed significantly higher horizontal acceleration values during ridge splitting compared to the engine-driven ridge spreader group ($P < 0.001$) (Table 3, Fig. 7).

Discussion

Ridge splitting procedures have produced safe, predictable results for more than 20 years (Simion et al. 1992; Scipioni et al. 1994; Elnayef et al. 2015; Bassetti et al. 2016). Despite the high success rates, excessive force from splitting procedure sometimes may cause the fracture of buccal cortical plates or trauma to bony plates leading to crestal bone resorption.

Recently, an engine-driven ridge spreader with screw-shaped thread-forming drills has been introduced as an alternative to conventional ridge splitting with chisels and a mallet. The drills allow horizontal bone to expand and condense by gradually increasing diameters for immediate implant placement (Siddiqui & Sosovicka 2006). Previous clinical studies showed that ridge splitting with rotating instruments was time effective, less invasive, and less stressful than conventional methods (Blus & Szmukler-Moncler 2006; Beolchini et al. 2014). However, little data are available about the mechanical force or frictional torque used to expand the alveolar ridge. We evaluated the mechanical force used on conventional ridge splitting and engine-driven ridge spreader groups and compared the ridge width between two groups after ridge splitting.

After ridge splitting, the ridge width increased in both groups and the ridge width

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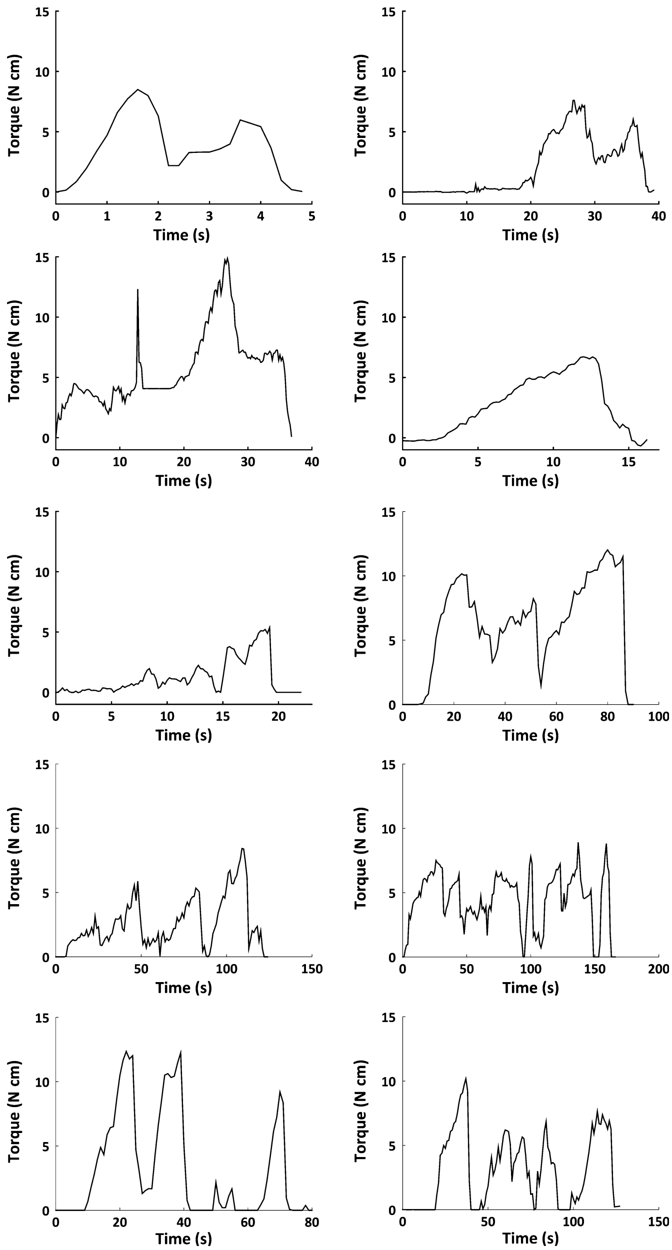

Fig. 6. Torque graphs for the engine-driven ridge spreader group. Maximal torque during ridge splitting was considered meaningful.

gain did not show any significant differences between two groups. We digitized the applied force of a mallet striking chisels and transduced the frictional torque of the engine-driven ridge spreader during ridge splitting. To the best of our knowledge, this study was the first to make mechanical measurements of the ridge splitting procedure. Several studies have measured the mechanical force in maxillofacial regions, but most were performed on maxillary sinus elevation techniques. Muller et al. (1985) suggested that a force greater than 20 MPa should be avoided to protect sinus tissue from compression damage. Crespi et al. (2014) compared manual and electrical mallets for sinus surgery with a fast force of 90 daN/8μs. Another mechanical study demonstrated that perforation of the Schneiderian membrane occurred at a tension of 7.3 N/mm (Pommer et al. 2009). In our study, the force of hand malleting was measured as impulse and mean impulse during ridge splitting was 4.74 ± 1.05 Ns. An average torque of 9.07 ± 2.15 Ncm was required to expand the alveolar ridge with the ridge spreader.

A major concern during ridge splitting procedures is risk of labial/buccal bone fracture. Fracture of outer cortical plates often occurs because of a lack of cancellous bone. As the mandibular cortical plates are thicker and the overall mineralization of bone is higher compared to the maxilla (Contessi 2013), expanding the buccal cortical plate of the mandible is difficult. To avoid fracturing the buccal cortical plate, forces and torques should be controlled by mechanical devices designed to regulate applied pressure. In addition, chisels should be inserted using controlled steps and a specific sequence of instruments should be used to measure the viscoelastic properties of the bone to make sure that it can withstand gradual expansion. Another preventive step to avoid bone fractures is use of vertical osteotomies with a trapezoidal design, which releases tension during expansion (Engelke et al. 1997; Tang et al. 2015). In this study, crestal split osteotomy was to 6 mm depth in the midcrest region and two vertical (10 mm length) osteotomies were carried out to release tension during expansion. Before main experiments, preliminary studies identified the ideal osteotomy depth and configured the maximum allowable force. At less than 6 mm depth, the buccal cortical plate had increased risk of a fracture before reaching the targeted depth of 10 mm during both expansion techniques. Therefore, we used an intraosseous groove depth of 6 mm to prevent complete fractures. Nevertheless, the fracture of buccal plate occurred in one site of the conventional ridge splitting group. On the other hand, there was no fractured site in the engine-driven ridge spreader group.

Another possible complication of ridge splitting procedures is vertigo. Iatrogenic benign paroxysmal positional vertigo (BPPV) following use of an osteotome and a mallet has been reported, particularly during maxillary sinus floor elevation (Kim et al. 2010; Sammartino et al. 2011; Crespi et al. 2014). BPPV is characterized by short, recurrent episodes of vertigo after the use of osteotome techniques, initiated by displacement of otoliths in the semicircular canal after mallet hitting. The symptoms are unpleasant with a sense of spinning or whirling of the room. BPPV incidence after a sinus floor elevation using an osteotome technique is 2.4–3.0% (Di Girolamo et al. 2005; Sammartino et al. 2011). A previous study suggested that three factors trigger BPPV following dental surgical procedures: percussive forces from the osteotome and mallet, vibratory forces from the implant drill, and hyperextended head position (Sammartino et al. 2011). Infrequently, orthognathic surgery (Beshkar et al. 2013) or removal of impacted teeth (Chiarella et al. 2007) trigger BPPV onset. As BPPV incidence during ridge splitting has not been reported, we assume that BPPV can occur from the

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Table 3. **Comparison of horizontal acceleration in conventional and engine-driven ridge spreader groups**

Sample no.	Conventional group (*g*)	Engine-driven ridge spreader group (*g*)
1	47.77	0.44
2	47.13	3.42
3	18.93	0.55
4	45.79	0.3
5	66.01	0.27
6	147.19	0.56
7	23.22	0.38
8	39.84	0.07
9	76.79	1.91
10	128.07	0.28
Mean ± SD	64.07 ± 42.62	0.82 ± 1.05
Median (Q1–Q3)	47.13 (7.26–87.0)*	0.38 (−0.58–1.34)*

SD, standard deviation; Q1, first interquartile; Q3, third interquartile.
*Statistically significant ($P < 0.001$, the Mann–Whitney *U*-test).

percussive action of the mallet. The results of a randomized trial by Sammartino et al. (2011) demonstrated that in sinus floor elevation, screw osteotomes are better than mallet osteotomes for preventing onset of BPPV. The study concluded that the reason for BPPV is the percussive force from the mallet osteotome. Likewise, in our findings, *x*-axis (horizontal) acceleration was significantly greater in the conventional ridge splitting group using chisels and mallet (64.07 ± 42.62 *g*) than in the engine-driven ridge spreader group (0.82 ± 1.05 *g*). These observations suggested that BPPV occurrence could be suppressed in ridge spreader-expanded patients, reducing patient distress. Physiologically, the semicircular canals are responsible for detecting angular head acceleration, while otoliths respond to linear acceleration or gravity effects (Angelaki et al. 2001). Therefore, risk of vertigo increases with head acceleration. The risk of BPPV can be reduced using engine-driven ridge spreaders that lower horizontal acceleration during ridge splitting. For these reasons, an engine-driven ridge splitting technique with ridge spreaders might be preferred to conventional ridge splitting procedures to avoid risk of BPPV.

After ridge splitting, buccal bone resorption was reported in several studies (Jensen et al. 2009; Beolchini et al. 2014; Ella et al. 2014). In animal studies, a higher horizontal and vertical resorption was observed at the expanded ridge sites compared with the pristine control sites (Beolchini et al. 2014, 2015). In their experiment, horizontal resorption at 1 mm level was prominent (Beolchini et al. 2014). They suggested that it is because of remodeling process as was shown in the previous study (Rossi et al. 2014). Additionally, trauma from splitting the crest with chisels and mallet seems to be contributing to the buccal bone resorption. Therefore, less traumatic osteotomy procedure with an engine-driven ridge spreader might be beneficial in preventing crestal bone resorption. To prevent buccal bone resorption, mucosal flap leaving the periosteum attached to the buccal bone was used in a ridge expansion procedure in miniature pigs (Stricker et al. 2015). They suggested that careful handling and preservation of the periosteum seemed to be important for the long-term success of implants placed simultaneously with ridge splitting. In our study, we did not evaluate buccal bone resorption according to two different techniques. Therefore, more clinical studies with radiographic evaluation or histomorphometric studies are needed to compare these two ridge splitting procedures for preventing bone resorption.

Although we showed several benefits to the engine-driven ridge spreader, evidence for clinical application is still insufficient. Further clinical studies are necessary to establish the effects of mechanical forces such as percussive impulse, torque, and acceleration on bone regeneration during ridge splitting procedures for dental implants.

Narrow edentulous ridges were successfully expanded by a conventional and an engine-driven ridge splitting procedure with ridge spreaders. Within the limits of this study, we concluded that engine-driven ridge spreaders caused less horizontal acceleration than a conventional ridge splitting technique. Therefore, we suggest that the engine-driven ridge splitting procedure with a ridge spreader kit is less surgically aggressive and less traumatic than a conventional ridge splitting procedure and might minimize mandibular fracture, bone resorption, and patient discomfort during ridge splitting procedures.

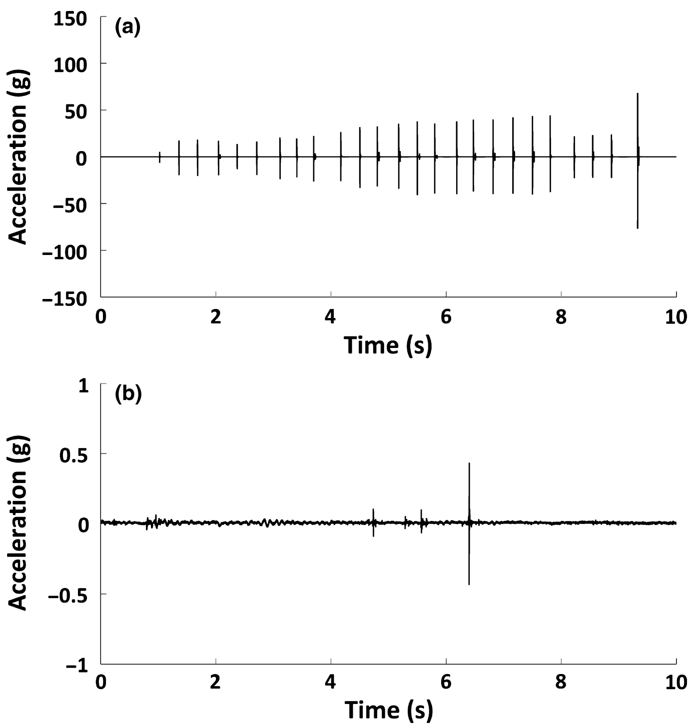

Fig. 7. Horizontal acceleration values. (a) Conventional ridge splitting group. (b) Engine-driven ridge spreader group. The conventional ridge splitting group showed significantly higher horizontal acceleration than the engine-driven ridge spreader group.

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