Comparisons of Miniscrew Implant Primary Stability between Two Different Synthetic Bone Densities during Placement with Either Self-Drilling or Self-Tapping Technique: An *in vitro* Study

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Abstract

The purpose of this study was to investigate the influence of cancellous bone densities on miniscrew implant primary stability during placement with either self-drilling or self-tapping technique. Forty titanium alloy miniscrew implants were divided into two groups, according to their placement techniques, self-drilling and self-tapping, and placed into synthetic bone of different cancellous bone densities: either 0.64 g/cm3 or 0.32 g/cm3. Maximal insertion torque and vertical pull-out strength were recorded in Ncm and N, respectively. Two-way ANOVA was used to detect interaction between miniscrew implant placement technique and cancellous bone density factors. The result showed that there was a significant interaction between miniscrew implant placement techniques and different cancellous bone densities ($p<0.001$) on the miniscrew implant primary stability parameters. The insertion torque and pull-out strength values were significantly greater for the miniscrew implant placed in the high-density cancellous bone than in the low-density one ($p<0.001$). Miniscrew implant placement into the same cancellous bone density with self-drilling technique showed significantly greater insertion torque ($p<0.001$) and pull-out strength ($p<0.05$) than those with self-tapping technique. However, no statistically significant difference in maximal insertion torque was found between self-tapping miniscrew implants placed in high-density, and self-drilling miniscrew implants placed in low-density. In conclusion, cancellous bone density influences miniscrew implant primary stability for both self-tapping and self-drilling placement systems. Pre-drilling is recommended for miniscrew implant placement into high-density cancellous bone to avoid high insertion torque and maintain adequate pull-out strength.

Keywords: *Bone density/ Cancellous bone/ Self-drilling placement/ Self-tapping placement/ Primary stability*

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Introduction

Miniscrew implants have been routinely used as a reliable temporary anchorage device to achieve orthodontic treatment success.[1,2] The achievement for using miniscrew implant as an absolute anchorage is related to its stability in the bone which requires adequate primary stability followed by biological stabilization. Hence, miniscrew implant primary stability is considered as an important factor and varied according to miniscrew implant designs,[3-7] placement techniques,[8] root proximity, and soft tissue inflammation.[9]

The most important patient-related factor appears to be cortical bone quantity and quality.[10,11] A positive correlation between the thickness of cortical bone and insertion torque has been established by a systematic review and meta-analysis.[12] Significant increase in pull-out strength and insertion torque has also been reported with increased bone density in homogeneous synthetic bone.[13] However, the role of cancellous bone density on miniscrew implant primary stability is unclear. The miniscrew implant placement sites with at least 1.0-mm cortical bone thickness has been reported with great success rate, regardless of cancellous bone density.[11] On the other hand, the cortical bone thickness was reported as the only main factor, affecting miniscrew implant primary stability when placing in low-density cancellous bone.[14]

Both self-drilling and self-tapping techniques are effective for miniscrew implant placemen.[8] Self-drilling placement is a procedure that miniscrew implants are driven directly into bone. This technique produced higher bone-

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implant contact percentage than did self-tapping miniscrew implant.[15] However, the self-tapping placement was suggested in highly dense cortical bone to prevent miniscrew implant fracture and occurrence of necrotic tissues from excessive force.[16-18] To date, knowledge on cancellous bone density, influencing miniscrew implant primary stability with different miniscrew implant placement techniques is still limited. This study aimed to evaluate and compare the primary stability of miniscrew implants, placed into synthetic bone blocks with different cancellous bone densities during miniscrew implant placement with either self-drilling or self-tapping techniques.

Materials and Methods

Forty miniscrew implants (titanium alloy, Osstem Implant Co., Seoul, Korea: length, 6.0 mm: diameter, 1.8 mm) were randomly assigned to two groups according to placement systems: self-drilling and self-tapping. Synthetic composite bone blocks (Sawbones® Pacific Research Laboratories, Inc., Vashon, WA, USA) were used in this study. A 2.0-mm-thick block of synthetic cortical bone (bone density of 0.64 g/cm^3, 40 pcf) was attached to a 12.0-mm-thick cancellous bone block. Two cancellous bone densities were chosen (0.64 g/cm^3 or 40 pcf, and 0.32 g/cm^3 or 20 pcf) corresponding to the mean bone density in the anterior (0.55 g/cm^3) and posterior (0.31 g/cm^3) regions of the hard palate.[19] Ten miniscrew implants were placed into synthetic composite bone blocks according to each placement system for each cancellous bone density.

A custom-made instrument-holding system was designed and created to position the digital torque gauge (IMADA Inc., Northbrook, IL, USA) and the synthetic bone blocks (Figure 1). To obtain miniscrew implant stability, the pre-drilled pilot-hole diameter was suggested to be ranged between 69 and 77 per cent of the miniscrew diameter.[20] A 1.3-mm pre-drilled pilot-hole (72.2 percent) was chosen to be constructed in the self-tapping placement groups using a drill-bit, which was housed in the chuck of the digital torque gauge. To control the pilot-hole depth, a color-coded stop was placed at a distance of 5.0 mm from the drill-bit tip. (Figure 2).

For the maximal insertion torque evaluation, synthetic bone blocks of self-drilling group were rigidly fixed in the instrument-holding system. A miniscrew implant was gripped by the digital torque gauge. A red line was drawn on the torque-gauge holder of the instrument-holding system 5.0 mm from its edge as an indication mark. To prevent excessive torque from causing miniscrew implant neck to bone compression, the miniscrew implant was driven only 5.0 mm (not the entire thread length) into the bone block until the edge of the torque-gauge holder reached the red line, with a constant speed of twelve rotations per minute. The maximal insertion torque was then recorded. The same protocol was run with the previously drilled synthetic bone blocks for self-tapping group.

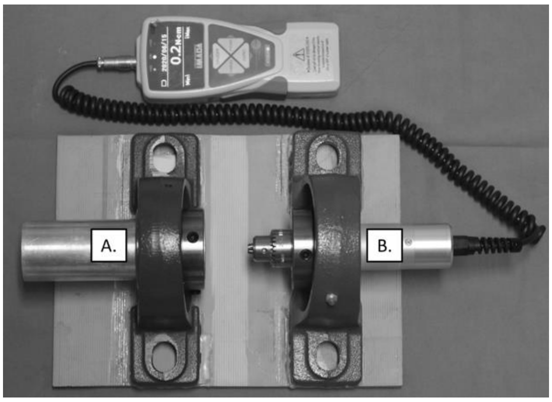

Figure 1 The instrument holding system consisted of A) a synthetic bone block holder held in a wheel bearing, and B) a digital torque gauge held in an opposite wheel bearing.

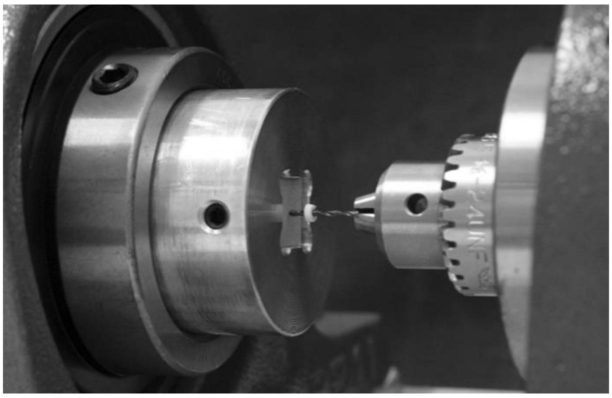

Figure 2 The pre-drilled pilot-hole was construction using the drill bit with a color-coded stop.

After the maximal insertion torque measurements, the synthetic bone blocks were transferred and fixed in the inferior clamp of a Universal Testing Machine (UTM) (Instron Corp., Canton, MA, USA). The base was customized to fit the UTM. The pull-out strength test was conducted by tightening the implant head to the pulling apparatus, which was attached to the superior clamp of the UTM. (Figure 3). A vertical force of 10 mm/min was applied parallel to the long axis of the miniscrew implant until it was removed from the synthetic bone. Peak load, in newtons (N), at the moment of implant separation, was recorded as the maximal pull-out strength.

Data were analyzed using SPSS 17.0 software (SPSS Inc., Chicago, IL, USA). All data were tested for normality using the Shapiro-Wilk test. Interaction between pilot-hole drilling and bone density was tested by two-way analyses of variance (ANOVA). Means and standard deviations of maximal insertion torque and pull-out strength were measured and compared using one-way ANOVA and the post hoc test. Results were considered statistically significant at $p<0.05$.

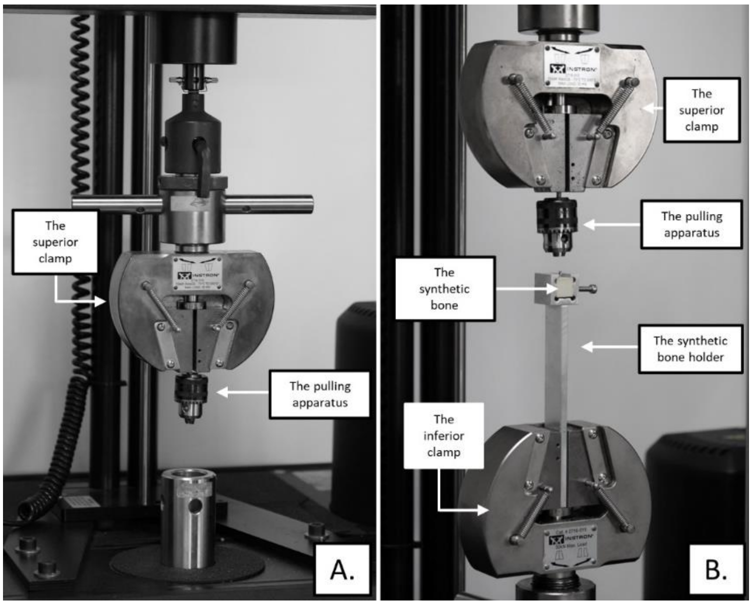

Figure 3 A. The pulling apparatus was held in the superior clamp of the UTM, B. The whole picture of pull-out strength test: the synthetic bone blocks fixed in the holder held in the inferior clamp of UTM.

Results

Pertaining to the miniscrew implant primary stability parameters, a two-way ANOVA revealed that there was a significant interaction between different miniscrew implant placement systems and cancellous bone densities ($p<0.001$).

Insertion torque Mean maximal insertion torque is presented in Figure 4. ANOVA revealed significant differences in mean maximal insertion torque ($p<0.05$) among the four groups. Tukey HSD post-hoc comparison tests showed that significantly greater maximal insertion torque was observed in 40-pcf cancellous bone for each placement system (self-drilling and self-tapping: 22.98±1.16 Ncm and 12.16±0.54 Ncm, respectively) than in 20-pcf cancellous bone for each placement system (self-drilling and self-tapping: 11.58±0.38 Ncm and 7.55±0.32 Ncm, respectively) ($p<0.001$). In addition, significantly greater maximal insertion torque was also shown in self-drilling miniscrew implants ($p<0.001$) than in self-tapping miniscrew implants. However, no statistically significant difference was found between self-drilling miniscrew implants placed in 20-pcf cancellous bone density (11.58±0.38 Ncm) and self-tapping miniscrew implants placed in 40-pcf cancellous bone density (12.16±0.54 Ncm) ($p<0.05$). (Figure 4)

Pull-out strength Mean pull-out strength showed a trend similar to that of the maximal insertion torque. Tukey HSD post-hoc comparison tests showed that mean pull-out strength was significantly different among the four groups (p<0.05), as shown in Figure 5. Mean pull-out strength was significantly greater for miniscrew implants, placed in 40-pcf cancellous bone than those, placed in 20-pcf. Self-drilling miniscrew implants, placed in 40-pcf cancellous bone showed the greatest mean pull-out strength at 348.26±22.81 N, whereas self-tapping miniscrew implants, placed in 20-pcf cancellous bone revealed the least (177.35±12.09 N). Moreover, self-drilling miniscrew implants in 40-pcf and 20-pcf cancellous bone (348.26±22.81 N and 201.69±9.42 N, respectively) revealed significantly greater pull-out strength than did self-tapping miniscrew implants in 40-pcf and 20-pcf cancellous bone (259.55±23.0 N and 177.35±12.09 N, respectively). (Figure 5)

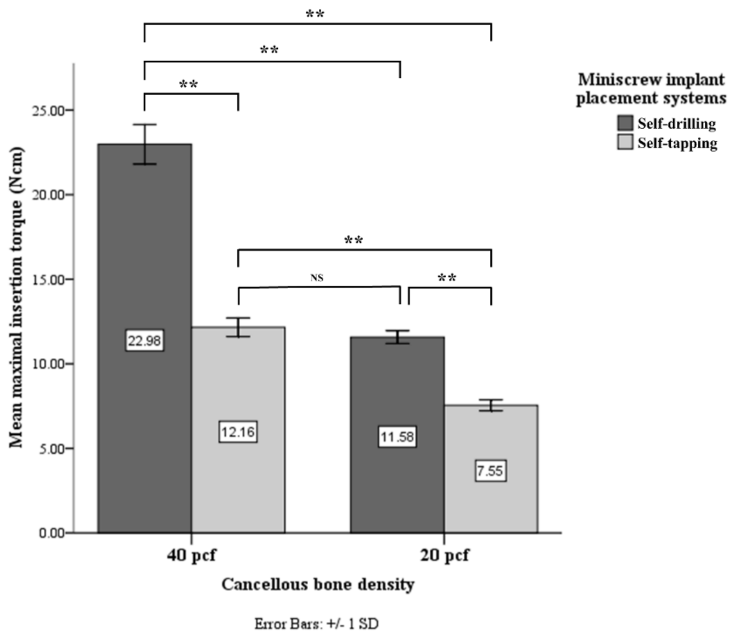

Figure 4 Means and standard deviations of maximal insertion torque values in implants placed with self-drilling and self-tapping systems in synthetic composite bone blocks with two different cancellous bone densities: 40 pcf and 20 pcf.
** indicates a statistically significant difference at p<0.001, NS indicate a non-statistically significant difference p<0.05

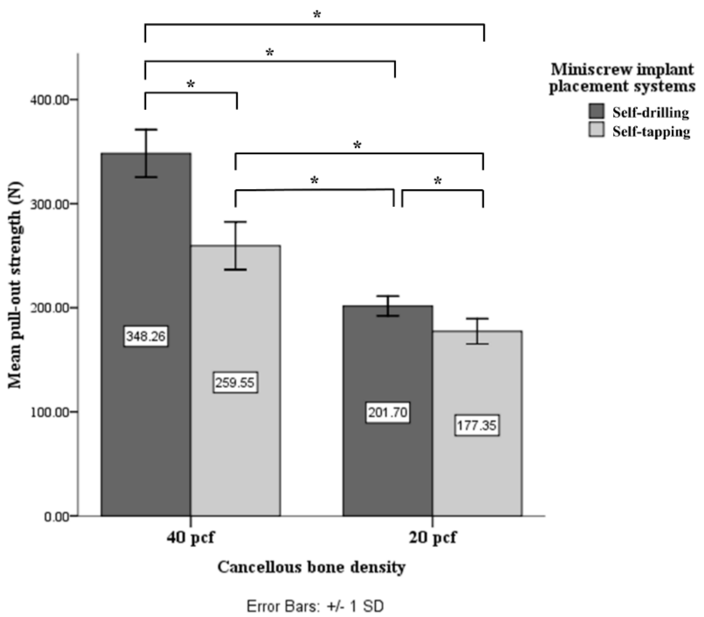

Figure 5 Means and standard deviations for pull-out strength in implants placed with self-drilling and self-tapping system in synthetic composite bone blocks with two different cancellous bone densities: 40 pcf and 20 pcf.
* indicates a statistically significant difference at p<0.05

Discussion

The cancellous bone strength is proportionate to its density and trabecular orientation, which is not homogenous within the cancellous bone and leads to a variation of physical attributes.[21] Use of synthetic polyurethane bone blocks does not exactly imitate the clinical conditions; however, it allows standardization and homogeneity of the bone density to be used as one factor testing miniscrew implant primary stability in our present study. Influences of cortical bone density on miniscrew implant stability has been established,[10-12,15,22] so synthetic cortical bone density and thickness in this study were determined to be 40 pcf and 2.0 mm, respectively, in order to compare two different cancellous bone densities (20 pcf and 40 pcf).

Role of cancellous bone density on miniscrew implant primary stability is still controversy. With a constant cortical bone thickness of 1.0 mm, miniscrew implant primary stability showed no difference with varying cancellous bone densities.[11] Marquezan et al.[23] assessed miniscrew implant primary stability in two bovine pelvic regions: iliac and pubic bone. Although iliac bone presented less cancellous bone density than did pubic bone, the miniscrew implant primary stability in both regions were similar. Later, Marquezan et al.[14] found that the cortical bone thickness was the only main factor affecting miniscrew implant primary stability in low-density cancellous bone. However, it was demonstrated that, in the absence of cortical bone, cancellous bone density was related to the miniscrew implant primary stability. Pan et al.[24] used resonance frequency analysis for assessing miniscrew implant stability in synthetic bone models and found that miniscrew implant primary stability was positively correlated to bone mineral density at the receptor site: as the cancellous bone density increased, the miniscrew implant primary stability also increased.[14,24] In the present study, the means of maximal insertion torque and pull-out strength were significantly increased for miniscrew implants, placed in high-density cancellous bone than those placed in low-density cancellous bone in both self-drilling and self-tapping techniques. Theoretically, high-density cancellous bone has higher trabeculae numbers with fewer trabeculae separation than the low-density cancellous bone does,[14] requiring higher insertion torque for miniscrew implantation[25] and higher pull-out strength for detaching the miniscrew implants.[16,26]

Both the self-drilling and self-tapping miniscrew implants have been widely used as anchorage reinforcement devices in orthodontic practice. However, no earlier studies have reported on which miniscrew implant placement system justify higher success rate. Previous studies revealed that the self-drilling miniscrew implants provided greater bone contact and stability than did the self-tapping miniscrew implants.[15,27,28] In self-tapping technique, pre-drilled pilot-hole creation is intentionally performed to minimize insertion torque while maintaining primary stability during miniscrew implant placement into highly dense bone.[16,17] As shown in our present study, there was statistically significant decrease in maximal insertion torque when self-tapping technique was used. Decreases in the maximal insertion torque during self-tapping miniscrew implant placement have been formerly stated.[27,28] Miniscrew implant insertion requires torsional force to displace surrounding bone, particularly for placement into highly dense bone.[25] Using self-tapping technique, less amount of bone needs to be displaced due to pilot-hole creation. As the self-tapping miniscrew implants are inserted, less compression occurs on the neighboring bone, and insertion torque decreases.[16]

To date, optimal maximal insertion torque values for successful miniscrew implant placement have not been clearly elucidated due to different types of research study designs. Previous studies revealed that maximal insertion torques for successful self-tapping miniscrew implant placement should be in the range of 5.0 to 10.0 Ncm in the buccal alveolar bone of maxilla[29,30]and at 14 Ncm in the palatal bone.[31] In this study, miniscrew implant placement with the self-tapping system in low- and high-density cancellous bone showed maximal insertion torques at 7.55±0.32 Ncm and 12.16±0.54 Ncm, respectively, which are in the recommended ranges. In self-drilling technique, maximal insertion torques for the successful implantation were recommended in the range of 6-12 Ncm in the buccal alveolar bone of maxilla[30] and 10-20 Ncm in the palatal bone.[31,32] From our results, self-drilling miniscrew implant placement in the low-density cancellous bone showed maximal insertion torques at 11.58±0.38 Ncm, which is in the suggested range, whereas placement of self - drilling miniscrew implants in the high-density cancellous bone showed excessive maximal insertion torques at 22.98±1.16 Ncm. A clinical implication of this finding is that the self-tapping technique is suitable in insertion sites with high-density cancellous bone.[31]

Pull-out strength is determined as a standardized method of the mechanical testing of miniscrew implant holding power.[33] A correlation between cancellous bone density and pull-out strength has been tested.[34] It was reported that the pull-out strength of miniscrew implants, placed in normal bone were greater than those, placed in osteoporotic bone. In comparison with bone volume and cortical bone thickness, cancellous bone density has been described as the most sensitive variable, affecting the pull-out strength.[35] In the present study, the greatest and smallest pull-out strength are 348.26±22.81 N and 177.35±12.09 N, respectively, which are in the recommended range of 134.5 to 388.3 N to be sufficient to resist orthodontic force load.[36] Furthermore, the pull-out strength of the self-drilling miniscrew implants was statistically significantly higher, when compared to the self-tapping miniscrew implants, which is in line with the earlier studies.[37,38] Interestingly, our study showed that there was no statistically significant difference in maximal insertion torques between self-drilling miniscrew implant placement in the low-density cancellous bone and self-tapping miniscrew implant placement in the high-density cancellous bone. This could be explained that pilot-hole creation reduces bone mass of high-density cancellous bone,[25] which was comparable to the low-density cancellous bone, resulting in non-significant difference in maximal insertion torques between these two groups. Also, it should be noted that the insertion torque and pull-out strength values, derived from self-tapping technique are also influenced by pilot-hole size; as the pilot-hole size increases, insertion torque and pull-out strength decrease.[16,17] Our findings agreed with a previous study, emphasizing that during miniscrew implant placement into the high-density bone, pre-drilling did not compromise miniscrew implant primary stability.[39]

Although the findings of our present study could not be directly extrapolated to clinical orthodontic practice because of an *in vitro* methodology, it was shown that cancellous bone density played an important role in the primary stability of miniscrew implant. Considering high-density bone, self-tapping miniscrew implant placement is recommended to avoid high insertion torque and maintain adequate pull-out strength. The pull-out strength parameter used in this study showed the mechanical properties of the miniscrew implants only in the vertical direction. However, orthodontic forces are practically applied with different directions on miniscrew implants. The effects of various force directions on different cancellous bone density should be further studied. Furthermore, biological response might be another major factor affecting miniscrew implant retention as well as later stability which is inevitable to be further studied.

Conclusions

Cancellous bone density influences miniscrew implant primary stability for both self- tapping and self-drilling placement systems. Pre-drilling is recommended for miniscrew implant placement into high-density cancellous bone to avoid high insertion torque and maintain adequate pull-out strength.

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เพ็ชรไพลิน ภู่สันติสัมพันธ์ ธีระวัฒน์ โชติกเสถียร* ประจักษ์ จริยพงศ์ไพบูลย์** คณิช ตรีภูวพฤทธิ์**

บทคัดย่อ

การศึกษานี้มีวัตถุประสงค์เพื่อประเมินผลของความหนาแน่นของกระดูกโปร่งต่อเสถียรภาพปฐมภูมิของหมุดเกลียวขนาดเล็กในระหว่างการปักโดยใช้เทคนิคการปักแบบเจาะในตัวและแบบเจาะร่องนำ หมุดเกลียวขนาดเล็ก โลหะผสมไทเทเนียม 40 ตัวถูกแบ่งเป็น 2 กลุ่มตามลักษณะเทคนิคในการปัก คือการปักแบบเจาะในตัวและแบบเจาะร่องนำ หมุดเกลียวขนาดเล็กของแต่ละกลุ่มจะถูกปักลงในกระดูกสังเคราะห์ที่มีความหนาแน่นของกระดูกโปร่งที่ต่างกันที่ 0.64 กรัม/ซีซี และ 0.32 กรัม/ซีซี แรงบิดสูงสุดและแรงต้านการดึงในแนวดิ่งจะถูกบันทึกในหน่วยของนิวตันเซนติเมตรและนิวตันตามลำดับ คำนวณการแจกแจงปกติด้วยสถิติชาพิโร-วิลค์ และใช้การวิเคราะห์ความแปรปรวนสองทางเพื่อตรวจสอบปฏิสัมพันธ์ระหว่างปัจจัยเรื่องเทคนิคการปักและความหนาแน่นของกระดูกโปร่ง ผลการศึกษาพบว่าปัจจัยเทคนิคการปักและความหนาแน่นของกระดูกโปร่งมีปฏิสัมพันธ์กันอย่างมีนัยสำคัญ ($p<0.001$) ต่อเสถียรภาพปฐมภูมิของหมุดเกลียวขนาดเล็ก พบแรงบิดสูงสุดและแรงต้านการดึงในแนวดิ่งมากกว่าอย่างมีนัยสำคัญในกลุ่มหมุดเกลียวขนาดเล็กที่ถูกปักในกระดูกโปร่งที่ความหนาแน่นมากกว่า ($p<0.001$) เมื่อพิจารณาหมุดเกลียวขนาดเล็กกลุ่มที่ถูกปักในกระดูกโปรงที่มีความหนาแน่นเดียวกัน หมุดเกลียวขนาดเล็กที่ปักด้วยเทคนิคการปักแบบเจาะในตัวให้แรงบิดสูงสุด ($p<0.001$) และแรงต้านการดึงในแนวดิ่ง ($p<0.05$) มากกว่ากลุ่มที่ถูกปักด้วยเทคนิคแบบเจาะร่องนำ แต่อย่างไรก็ตามไม่พบความแตกต่างอย่างมีนัยสำคัญของแรงบิดสูงสุดระหว่างกลุ่มที่ถูกปักด้วยเทคนิคการปักแบบเจาะในตัวในกระดูกโปร่งที่มีความหนาแน่นมาก และกลุ่มที่ถูกปักด้วยเทคนิคแบบเจาะร่องนำในกระดูกโปร่งที่มีความหนาแน่นน้อยกว่า จากการศึกษาสรุปว่า ความหนาแน่นของกระดูกโปร่งมีผลต่อเสถียรภาพปฐมภูมิของหมุดเกลียวขนาดเล็กในระหว่างการปักทั้งเทคนิคการปักแบบเจาะในตัวและแบบเจาะร่องนำ การเจาะร่องนำไว้ก่อนเหมาะสำหรับการปักหมุดเกลียวขนาดเล็กลงในกระดูกโปร่งที่มีความหนาแน่นมากเพื่อหลีกเลี่ยงแรงบิดสูงสุดที่มีค่ามาก และเพื่อคงไว้ซึ่งแรงต้านการดึงในแนวดิ่งที่พอเพียง

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