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The new shank construct of lag screw improves the maximum compression force for internal fixations: preliminary results

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Abstract. – OBJECTIVE: The treatment of osteoporotic intra-articular fractures with AO lag screws remained challenging due to insufficient compression. Several strategies to improve the compressive ability of lag screws have been evaluated. However, the effect of the shank construct on the compressive ability of lag screw has never been explored. The aim of this study was to determine the effect of a shank construction the compressive ability of lag screw for different bone mineral densities (BMDs).

MATERIALS AND METHODS: Three synthetic cancellous bone blocks were used for this study, including 0.12 g/cc, 0.16 g/cc, and 0.20 g/cc. 24 pilot holes with 3.2 mm diameters were drilled equably in each block. An AO lag screw and a combined lag screw with the newly designed compound shank construct were inserted through the custom-designed measuring device into a pilot hole by hand until failure, and the maximum compressive force (C_{MAX}) was determined.

RESULTS: Among three densities specimens C_{MAX} of the combined lag screw was significantly higher than that of the AO lag screw ($p < 0.001$), and the mean C_{MAX} difference value of the two screws in a specimen increased as the BMD increased. The C_{MAX} of two screws increased as the BMD increased ($p < 0.001$), and the amplification of the C_{MAX} generated by the combined lag screw was higher than that generated by the AO lag screw when the BMD increased.

CONCLUSIONS: The newly designed compound shank construct improves the compressive ability of lag screws independent of the BMD.

Key Words:
Internal fixation, Lag screw, Shank construct.

Introduction

The locking plate has been used widely in the internal fixation of fractures[1,2]. However, lag screw still plays an important role in situations such as intra-articular fractures that demand the anatomical reduction and rigid fixation, and the AO lag screw is the standard for compressing between fragments[3,4]. When applying lag screws to fix fractures, the compression ability is extremely important for obtaining and maintaining the stability of bone-implant constructs[5], whereas it may be difficult to obtain sufficient compression due to the altered density and properties of the cancellous bone in the metaphyseal region[2,6].

There are two main strategies to improve the compression ability of lag screws in the metaphyseal region. The first strategy is augmentation with bone cement, increasing the stiffness of the trabecular structure surrounding threads[7]. Many biomechanical studies have demonstrated the mechanical superiority of augmentation with bone cement[8-10]. The advantages of augmentation have been clinically confirmed[11,12]. However, there are many controversies about augmentation with bone cement, including poor biocompatibility, cement distribution, and implant removal[13,14]. And the other strategy is to remodel the lag screw thread[15], increasing the contact area between the screw and the bone. Several biomechanical studies showed that the thread design significantly affected the compression effect and the maximum compression force (C_{MAX}) varied, as the parameters of the thread design were changed[16-19]. However, the advantages by the remodeling of the lag screw were restricted due to anatomic factors. While these two strategies improve the compression ability of lag screws in the metaphyseal region, they also had limitations.

The present study investigated the effect of a novel innovation of remodel the lag screw thread, termed combined lag screw, which was designed

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to improve the compression ability while not changing the thread parameters or augmenting with bone cement. On the combined lag screw, the shank was attached to the screw as a compound construct, whereas the AO lag screw was a single structure. During compression, the combined lag screw can compress the bone surrounding the thread by shortening the shank length, while the AO lag screw compresses the bone surrounding the thread by rotating the thread.

The present study tested if the compressive effect of a lag screw can be affected by changing the shank construct. And in this study, the compression abilities of the AO lag screw and the combined lag screw were compared. The purpose of this study was to determine: (1) the difference of the C_{MAX} between the combined lag screw and the AO lag screw in three densities specimens; (2) the effect of the bone mineral density (BMD) on the C_{MAX} regarding the two screws.

Materials and Methods

Specimens

Synthetic cancellous bone blocks were used for the study, with the dimensions of 180×130×40 mm^3 and densities of 0.12 g/cc, 0.16 g/cc and 0.20 g/cc (Item 1522-09, 1522-10, 1522-11, Pacific Research Laboratories, Vashon, WA, USA). These blocks have been validated to simulate the cancellous bone by the American Society for Testing Materials (*www.astm.org*). The threads of lag screw were designed to generate compression in the cancellous bone. Therefore, these blocks did not contain a cortical shell.

Screws

The AO lag screw and the combined lag screw tested in the present study were custom manufactured by a company specializing in the production of orthopaedic implants (Weihai Wego Medical Systems, China) (Figure 1). The AO lag screw was a standard cancellous lag screw with a core diameter of 4.5 mm (Figure 1a). The combined lag screw had a compound shank, consisting of Part A and Part B (Figure 1b). Part A was contiguous to the head, which was a hollow cylinder with the outer diameter of 6.5 mm, containing fine threads (thread pitch: 0.85 mm) in the hollow (Figure 1c). Part B was contiguous to the thread, which was a cylinder with the outer diameter of 4.5 mm, containing the same fine threads on the surface (Figure 1c). Part A was connected to part B by fine threads. The custom-designed screwdriver that matched the combined lag screw consisted of the inner screwdriver and the outer screwdriver. The outer screwdriver matched Part A, and the inner screwdriver matched Part B. The inner screwdriver was locked with the outer screwdriver by bolt. When the custom-designed screwdriver was used in a locked condition, the combined lag screw was inserted as a whole and there was no relative movement between Part A and Part B.

These two screws were identical in terms of the screw length, the thread design, the shank length and the count sink (Figure 1). The screw length was 65 mm, the thread length was 32 mm with the outer diameter of 6.5 mm, and the shank length was 28.4 mm.

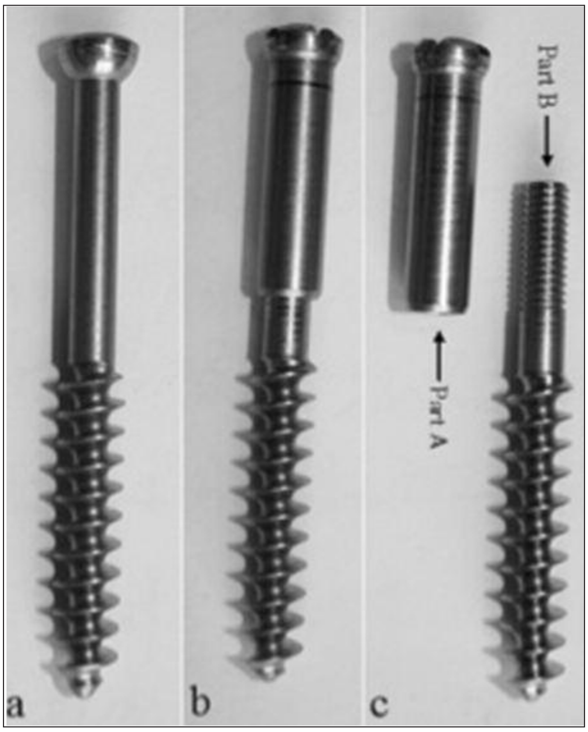

Figure 1. Photographs showing two screws used: (**A**) The AO lag screw: total length, 65 mm; thread diameter and length, 6.5 mm and 32 mm respectively; shank diameter and length, 4.5 mm and 28.4 mm respectively. (**B**) The combined lag screw: total length, 65 mm; thread diameter and length, 6.5 mm and 32 mm respectively; shank length, 28.4 mm. (**C**) The combined lag screw shank consisting of Part A and Part B. Part A was a hollow cylinder construct and contiguous to the head (the outer diameter, 6.5 mm), containing fine threads (thread pitch: 0.85 mm) in the hollow. Part B was a cylinder construct and contiguous to the thread (the outer diameter, 4.5 mm), containing the identical fine threads on the inner surface.

Failure

Failure was defined as the point at which the compression force began to decline, and the screw stripped off the material surrounding the threads at this point.

Testing

A custom-designed measuring device was used to measure the C_{MAX} generated by each screw until failure, which consisted of a 62*25*21 mm wood block, a Tekscan pressure transducer (Sensor type: 6900, with four sensor unit, Tekscan Inc., South Boston, MA, USA) calibrated to the total output force of 10 Hz, and four pieces of rigid plastic with thickness of 0.5 mm (Figure 2). The wood block was drilled with a round hole of 7 mm diameter in the middle to make the thread through. The rigid plastic was glued on each side of one sensor unit to capture all compressive load produced by screws, and two such structures were glued on either side of the a round hole in a symmetric manner. A metal washer was used to prevent the head from sinking into the round hole. The total length of the custom-designed measuring device and the metal washer was 24 mm which was shorter than the shank length, thereby, allowing the entire thread to pass through.

Screw Insertion and Compression Force Measurement

Twenty-four pilot holes of 3.2 mm were drilled equably to a depth of 40 mm using a drill press, which was perpendicular to the surface of each block. The length of the pilot hole was longer than the thread length to ensure that threads could be completely inserted into the pilot hole.

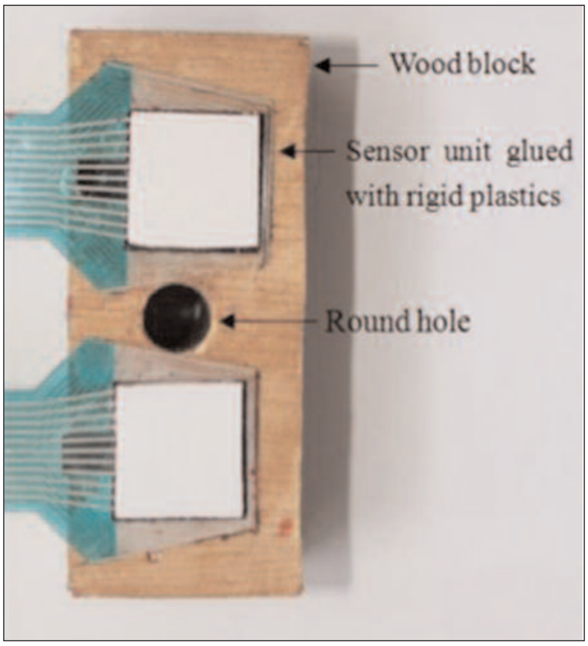

Figure 2. The custom-designed device for measuring the C_{MAX} that consisted of a wood block with a round hole and two sensors glued with rigid plastics.

The combined lag screw was inserted by the locked screwdriver (custom-designed) as a whole through the metal washer and the custom-designed measuring device into a pilot hole by hand, and stopped at the point where 2 N force was produced indicated on the monitor of the transducer, thereby, sandwiching the Tekscan pressure transducer between the wood block and the specimen (Figure 3). Then the custom-designed screwdriver was unlocked, following by rotation of the outer screwdriver to shorten the shank. During this procedure, the inner screw-

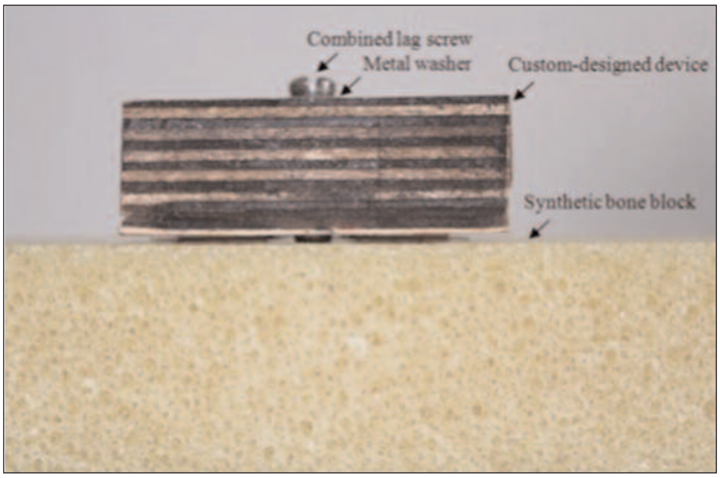

Figure 3. The construct can generate and measure the C_{MAX}. It consists of a combined lag screw, a metal washer, a custom-designed device and a synthetic bone block.

Table I. C_{MAX} of AO lag screw and combined lag screw in three densities *p*-value.

Density (g/cc)	CMAX (N) AO screw	CMAX (N) Combined screw	*p*-value
0.12	309.00 ± 22.32	411.59 ± 32.55	< 0.001
0.16	488.21 ± 25.24	618.16 ± 23.76	< 0.001
0.20	656.55 ± 36.59	917.88 ± 33.97	< 0.001
p-value	< 0.001	< 0.001	

driver did not rotate, and the relative displacement between threads and bone surrounding thread appeared in the screw axial direction, thereby, producing compression force.

The level of the compression force was recorded from the transducer until the failure happened (each density, 12 insertions; total 36 insertions).

In the same construct applied in the combined lag screw, the AO lag screw was manipulated by hand. The level of the compression force was recorded from the transducer until the failure happened (each density, 12 insertions; total 36 insertions).

Statistical Analysis

After test, the C_{MAX} was determined from the time-load curve recorded by the Tekscan pressure transducer. Two-tailed, unpaired Student's *t*-tests were used for the comparing the C_{MAX} of two screws in each specimen, and one-way ANOVA with LSD post hoc tests were used for comparing the C_{MAX} of each screw in three densities specimens. The significance level was set to $p < 0.05$.

Results

The C_{MAX} of the combined lag screw was significantly higher than that of the AO lag screw in three densities specimens (Table I). And the BMD did not affect the superiority of the combined lag screw compared with the AO lag screw in generating the C_{MAX}. The difference value of the C_{MAX} in a specimen (the combined lag screw compared with the AO lag screw) increased as the BMD increased. In the 0.12 g/cc specimen, the mean C_{MAX} of the combined lag screw was 102.59N higher than that of the AO lag screw (411.59 ± 32.55 N compared with 309.00 ± 22.32 N; $p < 0.001$) (Figure 4a). In the 0.16 g/cc specimen, the mean C_{MAX} of the combined lag screw was 129.95 N higher than that of the AO lag screw (618.16 ± 23.76 N compared with 488.21 ± 25.24 N; $p < 0.001$) (Figure 4b). In the 0.20 g/cc specimen, the mean C_{MAX} of the combined lag screw was 261.33 N higher than that of the AO lag screw (917.88 ± 33.97 N compared with 656.55 ± 36.59 N; $p < 0.001$) (Figure 4c).

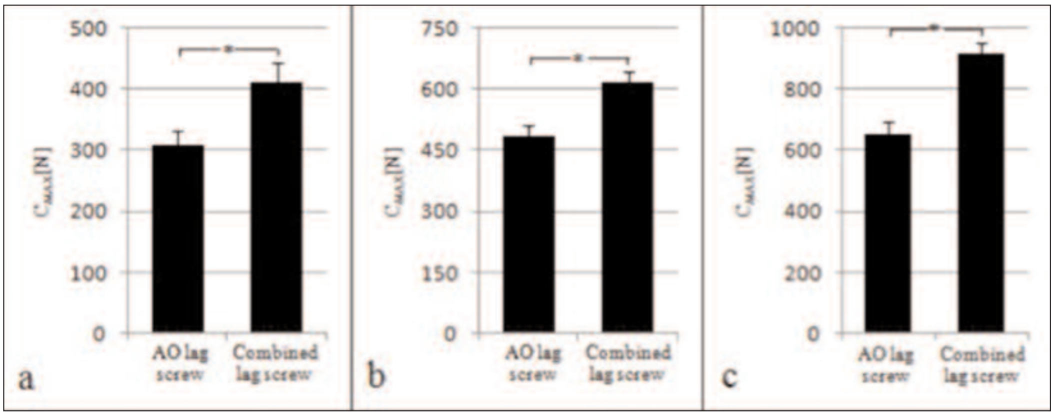

Figure 4. *A*, In the 0.12g/cc specimen, the mean C_{MAX} of the combined lag screw was 102.59N higher than that of the AO lag screw. **B**, In the 0.16 g/cc specimen, the mean C_{MAX} of the combined lag screw were 129.95 N higher than that of the AO lag screw. **C**, In the 0.20 g/cc specimen, the mean C_{MAX} of the combined lag screw were 261.33 N higher than that of the AO lag screw. *Significant ($p < 0.001$).

The C_{MAX} of two lag screws was significantly affected by the BMD (Table I). As the BMD increased, the C_{MAX} of two lag screws increased. The data from the AO lag screw showed that the mean C_{MAX} increased by 58.00% for the 0.12 g/cc in relation to 0.16 g/cc (309.00±22.32 N compared with 488.21 ± 25.24 N; $p < 0.001$), and increased by 34.48% when the BMD increased from 0.16 g/cc to 0.20 g/cc (488.21 ± 25.24 N compared with 656.55 ± 36.59 N; $p < 0.001$) (Figure 5a). The data of the combined lag screw demonstrated that that the mean C_{MAX} increased by 50.19% for the 0.12 g/cc in relation to 0.16 g/cc (411.59 ± 32.55 N compared with 618.16 ± 23.76 N; $p < 0.001$), and increased by 48.49% when the BMD increased from 0.16 g/cc to 0.20 g/cc (618.16±23.76 N compared with 917.88 ± 33.97 N; $p < 0.001$) (Figure 5b).

The shank construct influenced the effect of the BMD on the C_{MAX}, and the amplification of the C_{MAX} generated by the combined lag screw was higher than that generated by the AO lag screw as the BMD increased (Figure 5). When the BMD increased from 0.12 g/cc to 0.16 g/cc, the mean C_{MAX} amplification of the combined lag screw was 206.57 N, and the mean C_{MAX} amplification of the AO lag screw was 179.21 N. When the BMD increased from 0.16 g/cc to 0.20 g/cc, the mean C_{MAX} amplification of the combined lag screw was 299.72 N, and the mean C_{MAX} amplification of the AO lag screw was 168.34 N.

Discussion

The standard AO lag screw is demanded for treatment of the displaced intra-articular fractures[4]. However, rigid fixation may be difficult for elderly patients with osteoporosis, and consequent clinical outcomes are often poor[2,6]. The combined lag screw is able to improve compression for rigid fixation, implicating its significance in clinical application. In previous studies from other groups[17-19], the C_{MAX} was selected as the parameter assessing the compression ability of a lag screw. In our study, we compared the compression ability of the combined lag screw with the AO lag screw in three densities specimens. Three important findings emerged. First of all, the C_{MAX} of the combined lag screw was significantly higher than that of the AO lag screw in three densities specimen. Secondly, the C_{MAX} of two lag screws and the difference value of the C_{MAX} generated by two lag screws in a specimen increased as the BMD increased. Thirdly, the amplification of the C_{MAX} generated by the combined lag screw was higher than that generated by the AO lag screw as the BMD increased.

The factors that affect the C_{MAX} include the screw design and the specimen character. In our model, the uniformity of the synthetic bone and a fixed depth of the thread into the specimen excluded the influence of specimen character on the compression to the utmost extent. Previous

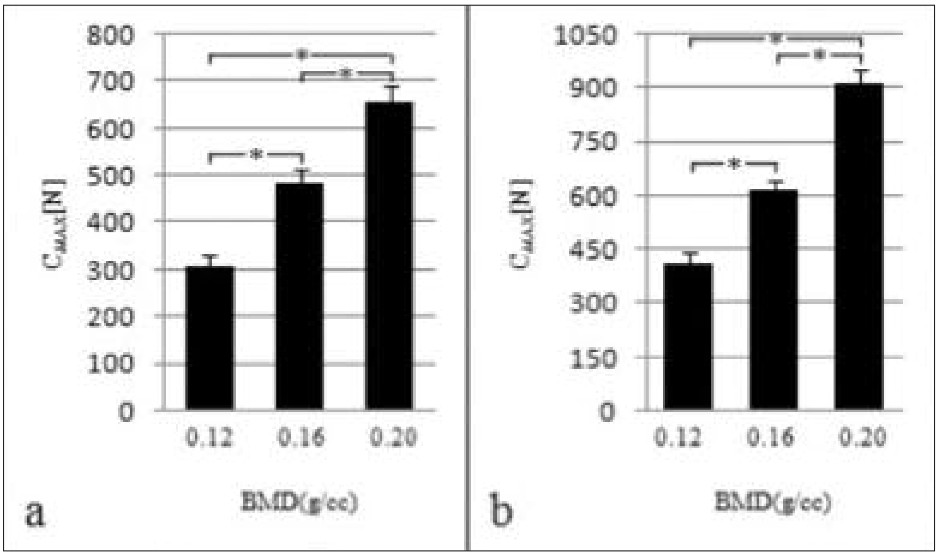

Figure 5. A, When using the AO lag screw, the mean C_{MAX} increased by 58.00% (179.21 N) for the 0.12 g/cc in relation to 0.16 g/cc and increased by 34.48% (168.34 N) in the 0.16 g/cc in relation to 0.20 g/cc. **B**, When using the combined lag screw, the mean C_{MAX} increased by 50.19% (206.57 N) for the 0.12 g/cc in relation to 0.16 g/cc and increased by 48.49% (299.72 N) in the 0.16 g/cc in relation to 0.20 g/cc. *Significant ($p < 0.001$).

studies[16-19] revealed that the thread design affected the C_{MAX} greatly. In our study, we eliminated this influence due to the identical threads of the AO lag screw and the combined lag screw; therefore, we were able to independently evaluate how the shank construct affected the C_{MAX} of a lag screw. Our results demonstrated that the C_{MAX} varied significantly when the shank construct was changed.

The modification of the shank construct from a simple structure to a compound structure changed the mechanical manner during compression. During the compression using the AO lag screw, the screw rotated and, therefore, the thread compressed the cancellous bone in a rotating manner. For the compression using combined lag screw compression, the thread did not rotate and the shank was shortened continuously; thus, the thread compressed the cancellous bone in a linear manner. Therefore, the different manners caused that the C_{MAX} of the combined lag screw was larger than that of the AO lag screw, which is independent of the BMD. Our results confirmed the advantages of the C_{MAX} accompanied by the shank construct change in three densities specimens. And our results also demonstrated that the mean C_{MAX} difference value of two lag screws on the same specimen increased as the BMD increased.

The compression ability of the lag screw is improved significantly by changing the shank construct. Our results demonstrated that the combined lag screw was superior to the AO lag screw in the compressive ability and this advantage was obtained by changing the shank construct from a simple structure to a compound structure. Rigid fixation of intra-fractures depends on friction between the fractures, the implant and bone, which is proportional to the C_{MAX}[5,15]. Therefore, the combined lag screw was better in maintenance of rigid fixation when compared with the AO lag screw. When encountering osteoporotic bone, there is a necessity to improve the compressive ability of the lag screw. This superiority in compression provided by the combined lag screw is able to improve the stability of bone-implant constructs and the clinical outcomes without extra side effects and difficult techniques compared with bone cement augmentation.

The BMD significantly affected the C_{MAX} of two lag screws, which increased in an ascending order when the BMD increased. The shank construct influenced the effect of the BMD on the C_{MAX}, and the amplification of the C_{MAX} generated by the combined lag screw was higher than that generated by the AO lag screw as the BMD increased. Therefore, the combined lag screw was more sensitive to the BMD change. Our study demonstrated that the C_{MAX} of two lag screws lied fairly lower (309.00 ± 22.32 N for the AO lag screw and 411.59 ± 32.55 N for the combined lag screw) when the BMD reached a severely osteoporotic level (0.12 g/cc)[13,22]. Thus, bone cement augmentation in conjunction with lag screws may be an option in treating severely osteoporotic intra-articular fractures. The combined lag screw was more superior in compression and more sensitive in the BMD change than the AO lag screw. Therefore, when using the combined lag screw, smaller dose cement may provide more compression force compared with the AO lag screw. Decreased bone cement dose in bone cement augmentation was able to decrease the side effects and technical difficulty of the procedure, which has clinical significance.

We would like underline that: firstly, we selected the synthetic cancellous bone blocks as a simulated cadaveric bone model. Although these blocks have been widely used in comparative studies of different screw types[17-19], they were not the cadaveric cancellous bone, and the concrete data from this study cannot be applied directly in clinic. Secondly, we only compared the C_{MAX} of the AO lag screw and the combined lag screw in three densities specimens. More densities should be included to demonstrate more details regarding the BMD effect on the C_{MAX} of two screws. Moreover, our study does not include the pullout strength as another parameter. The pullout strength compromises in the process of achieving the C_{MAX} when using the AO lag screw[20,21] and, thus, it can assess the compressive ability of a lag screw applying the C_{MAX} in conjunction with the pullout strength in a more comprehensive way.

Conclusions

The shank construct was an important factor that significantly affected the compression ability of a lag screw in this study of synthetic cancellous bone specimens. The combined lag screw with a compound shank structure was better than the AO lag screw that had a simple structural shank in terms of the compression ability. The BMD significantly affected the compression ability of a lag screw regardless of the shank constructs. Our study demonstrates the biomechanical advantages of the combined lag screw and provides an important experimental evidence for improving the compression ability, which is highly demanded in the clinic treatment of osteoporotic intra-fractures. Additional studies will be performed to investigate other effects accompanying with the new shank construct, and maximally optimize fixation strength of such lag screws for intra-fractures.

Conflict of Interest

All authors of this manuscript have declared that no conflict of interest exists with regard to the carrying out and reporting of this research

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