European Review for Medical and Pharmacological Sciences 2016; 20: 208-213

A combined partially threaded cancellous lag screw for achieving maximum compressive force without compromising pullout strength

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Abstract. – OBJECTIVE: The partially threaded cancellous lag screw (PTLS) could not provide maximum compressive force (C_{MAX}) for compression due to compromised pullout strength (POS). The combined partially threaded cancellous lag screw (CPTLS) could provide higher C_{MAX} than PTLS. However, the change of POS at the point of C_{MAX} when using CPTLS for compression has never been explored. The aim of this study was to determine whether POS decreased at the point of C_{MAX} during CPTLS compression for different bone mineral densities (BMDs).

MATERIALS AND METHODS: Three synthetic cancellous bone blocks were used for this study, and the BMDs were 0.12 g/cm^3, 0.16 g/cm^3, and 0.20 g/cm^3, respectively. 20 pilot holes with 3.2 mm diameters were prepared equably in each block. A CPTLS was inserted through the custom-designed measuring device into a pilot hole manually until failure for measuring C_{MAX}, and the pullout test was done with the identical CPTLS for measuring POS.

RESULTS: The C_{MAX} and POS of the CPTLS were not significantly different in the three specimens, and the ratios of the mean C_{MAX} to the mean POS were very similar in the three specimens (0.98 in the 0.12 g/cc specimen, 1.01 in the 0.16 g/cc specimen and 0.98 in the 0.20 g/cc specimen).

CONCLUSIONS: C_{MAX} is achieved without a decrease in POS during CPTLS compression independent of the BMD.

Key Words:
Combined partially threaded cancellous lag screw, Maximum compressive force, Pullout strength, Bone mineral density.

Abbreviations

BMD = bone mineral density; C_{MAX} = maximum compressive force; CPTLS = combined partially threaded cancellous lag screw; POS = pullout strength; PTLS = partially threaded cancellous lag screw.

Introduction

The lag screw technique is the standard treatment for displaced intra-articular fractures, where compression provided by the lag screws is crucial for the mechanical stability of the screw-bone construct[1-3]. The partially threaded cancellous lag screw (PTLS) is the most widely used lag screw. However, PTLS is not sufficient to provide enough compressive force to maintain anatomical reduction of the joint surface in fragile fractures[4].

During PTLS compression, PTLS is rotated along the axis of PLTS, and the cancellous bone that is incorporated into the threads of the PTLS was compressed. Therefore, compressive force between fragments is generated, and meanwhile the cancellous bone surrounding the threads of PLTS is compressed and destroyed in some extent. Before maximum compressive force (C_{MAX}) is achieved, the cancellous bone surrounding the threads of PLTS is not able to resist the same shear loads compared with that prior to compression, and therefore pullout strength (POS) decreases[5,6]. For this reason, C_{MAX} is not able to be adapted for rigid fixation owing to compromise of the POS when applying the PTLS for compression.

There is no final solution to treat fragility fractures effectively and uneventfully. PTLS combined with bone cement is a choice to overcome this difficulty. However, there are many controversies regarding this technique such as cement poor biocompatibility and distribution, and implant removal[7,8]. The other way is to change the structure of lag screw. The combined partially threaded cancellous lag screw (CPTLS) is a newly designed lag screw to improve compressive ability compared with PTLS. The shank design is the main difference between PTLS and CPTLS.

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The shank of CPTLS is a compound construct, which is shortened continuously during compression. CPTLS could provide higher C_{MAX} compared with PTLS when the bone incorporated the threads was identical[9]. However, there were no documents that reported whether C_{MAX} could be adapted during CPTLS compression when taking POS into consideration.

The present study tested the hypothesis that POS did not decrease at the point of C_{MAX} and C_{MAX} could be adapted when applying CPTLS for compression, independent of bone mineral density (BMD). During screw compression, C_{MAX} is determined after compressive force decreases where POS decreases[10]. Therefore, it is difficult to determine POS directly by a pullout test at the point of C_{MAX}. If C_{MAX} values are identical to POS values when using the CPTLS for compression, we can infer that (1) the bone incorporated into the threads can resist loads that are identical to POS, and (2) POS does not decrease when completing a pullout test at this time. Therefore, we can conclude that POS do not decrease at the point of C_{MAX} during CPTLS compression. The objectives of the present study were to (1) compare the C_{MAX} and POS of the CPTLS in three specimens having different densities and (2) analyze the effect of BMD on the relationship between the C_{MAX} and POS of the CPTLS.

Materials and Methods

Specimens

Three synthetic cancellous bone blocks (Items 1522-09, 1522-10, and 1522-11; Pacific Research Laboratories, Vashon, WA, USA) were used in this study. The dimensions of the three blocks were identical (180×130×40 mm^3), while the BMDs differed (0.12 g/cm^3, 0.16 g/cm^3, and 0.20 g/cm^3, respectively) to simulate three different states (osteoporotic, osteopenic, and normal, respectively). These blocks did not include a cortical shell because lag screw threads interact with cancellous bone of the metaphyseal region to generate compression. These blocks have been validated to simulate cancellous bone samples in mechanical tests of orthopedic implants by the American Society for Testing Materials[11].

In each specimen, 20 pilot holes (diameter, 3.2 mm) were drilled at equal distance perpendicular to the surface of each block, using a drill press. Therefore, a total of 60 pilot holes were prepared in the three specimens. The length of each pilot hole was 40 mm and was longer than the thread length to ensure that the threads were engaged in the pilot hole completely.

Test Screw

The CPTLS assessed in the present study was custom-manufactured by a company specializing in the production of orthopedic implants (Weihai Wego Medical Systems Co., Ltd, Weihai, China) (Figure 1). The thread length was 32 mm with an outer diameter of 6.5 mm, which was identical to that of a 65-mm PTLS. The shank length was 28.4 mm and had a compound construct, consisting of Part A and Part B (Figure 1a), which length was identical to that of a 65-mm PTLS. Part A (outer diameter, 4.5 mm) was contiguous with the thread, which was a cylinder with fine threads (thread pitch, 0.85 mm) on the surface (Figure 1a). Part B (outer diameter, 6.5 mm) was next to the screw head which was a hollow cylinder with identical fine threads (thread pitch, 0.85 mm) on the inner surface (Figure 1a). Hence,

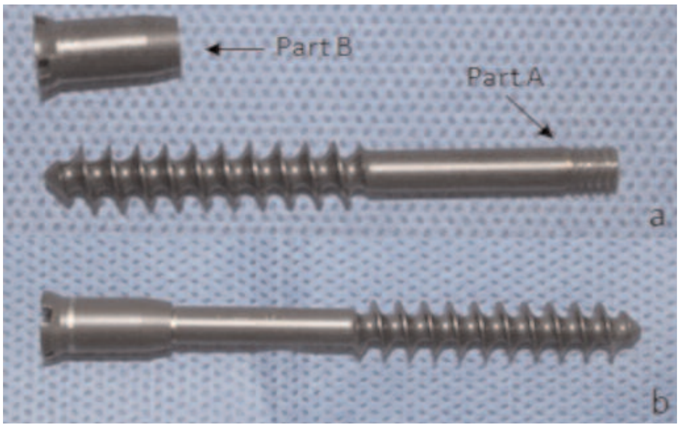

Figure 1. Images of the CPTLS. ***A,*** the CPTLS shank consists of Part A and Part B. Part A (outer diameter, 4.5 mm) is a cylinder with fine threads (thread pitch, 0.85 mm) on the surface and is contiguous with the thread. Part B (outer diameter, 6.5 mm) is a hollow cylinder with identical fine threads (thread pitch, 0.85 mm) on the inner surface and is contiguous with the head. ***B,*** the CPTLS: total length, 65 mm; thread diameter, 6.5 mm; thread length, 32 mm; shank length, 28.4 mm. CPTLS, combined partially threaded cancellous lag screw.

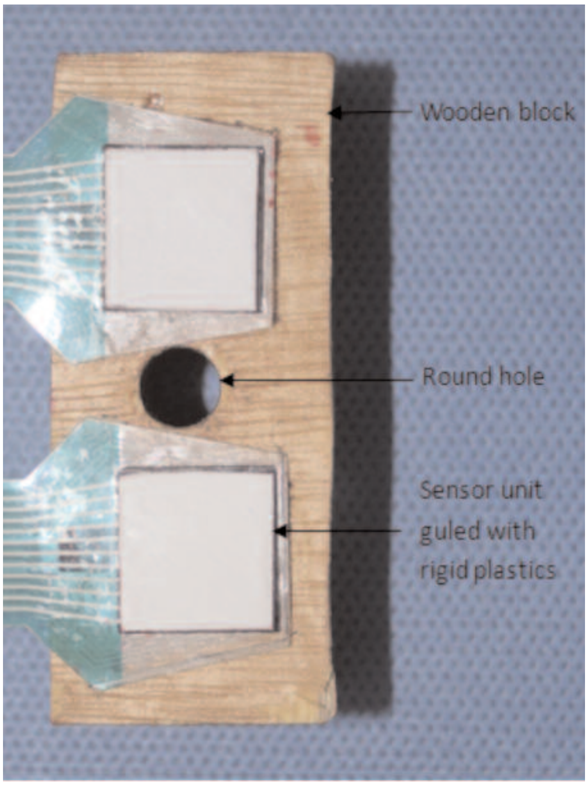

Figure 2. The custom-designed device, consisting of a wooden block with a 7-mm round hole in the middle and two sensors glued with rigid plastic, for measuring C_{MAX}. C_{MAX}, maximum compressive force.

Part A was connected to Part B with fine threads (Figure 1b). A custom-designed screwdriver was produced, and it was a compound construct, consisting of an inner screwdriver and an outer screwdriver matching Part A and Part B, respectively. The inner screwdriver was locked to the outer screwdriver with a bolt. The custom-designed screwdriver had the following two conditions: the locked condition for screw insertion and the unlocked condition for screw compression.

Mechanical Testing

Mechanical testing included compression test and pullout test which were done in sequence.

Compression Test

A custom-designed measuring device was used to measure C_{MAX} (Figure 2). This device consisted of a Tekscan pressure transducer (Sensor type: 6900, with four sensor units; Tekscan Inc., Boston, MA, USA) and a 62 × 25 × 21 mm wooden block with a spherical hole (diameter, 7 mm) in the middle for the screw. Two sensors of the Tekscan pressure transducer were glued with rigid plastic on each surface to capture compressive load completely, and were then glued to the two sides of the spherical hole in a symmetric manner. The two sensors were sandwiched between the wooden block and the specimen. On the opposite side of the two sensors, a metal washer was used to prevent the screw head from sinking into the spherical hole. The total length of the custom-designed measuring device and the metal washer was 24 mm and was shorter than the shank length, thereby, excluding the possibility of the screw thread being present in the spherical hole.

The CPTLS was inserted manually through the metal washer and the spherical hole in the wooden block, and then into the pilot hole (Figure 3). During insertion before the screw head

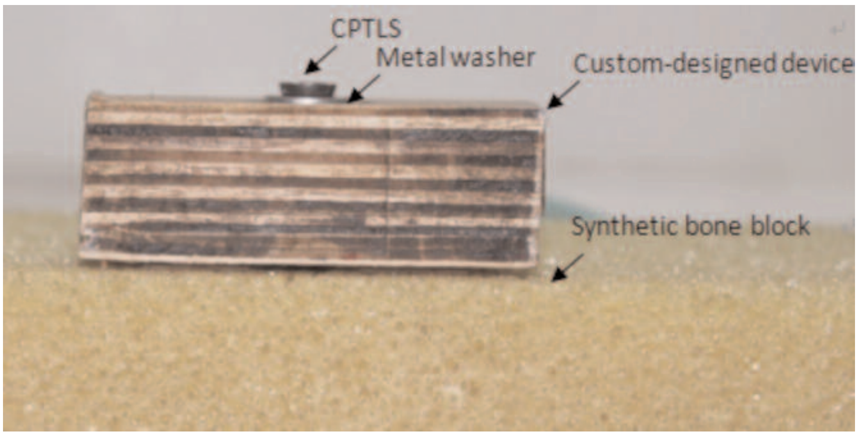

Figure 3. The system for measuring C_{MAX} consists of the CPTLS, a metal washer, the custom-designed device, and the synthetic bone block. C_{MAX}, maximum compressive force; CPTLS, combined partially threaded cancellous lag screw.

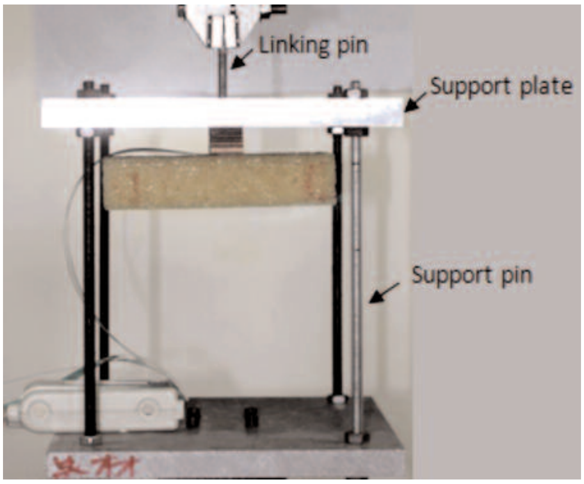

Figure 4. The system for measuring POS consists of a linking pin, a screw extraction grip, two aluminum support plate and four support pins. After the screw had been inserted without producing any compression, it was pulled out using this system and BOSE3510-AT testing machine. POS, pullout strength.

compressed the metal washer, we manually manipulated the locked custom-designed screwdriver to advance the CPTLS as a whole, thereby, eliminating the relative movement between Part A and Part B. When the screw head was close to (less than 1 mm) the metal washer, we stopped advancing the screw, unlocked the custom-designed screwdriver, and rotated only the outer screwdriver. Therefore, Part A did not rotate while Part B rotated around Part A owing to the fine threads, thereby shortening the shank length. This process allowed the 6.5-mm thread to compress the bone surrounding the thread along the axis of the screw in a linear manner. Compression and time data were recorded using the transducer at 10 Hz until failure. Failure was defined as the point at which compressive force began to decline and the screw stripped the material surrounding the threads (each specimen, 10 insertions; total, 30 insertions). The C_{MAX} values were determined from the compression-time curves recorded using the Tekscan pressure transducer.

Pullout Test

An aluminum test jig was designed and constructed for measuring the POS (Figure 4). The test jig consisted of a linking pin, a screw extraction grip, two aluminum support plate and four support pins. The CPTLS was inserted manually as a whole with the locked custom-designed screwdriver through the screw extraction grip, the custom-designed measuring device and then into the pilot hole where the screw thread was engaged completely without producing any compression. The CPTLS was then pulled using the BOSE3510-AT testing machine (Bose Corporation, ElectroForce Systems Group, Eden Prairie, MN, USA), and the pullout rate was maintained at 0.02 mm/s. Load and displacement data were detected at 100 Hz using 75 load cells, which were calibrated to an accuracy of 1/100 (each specimen, 10 insertions; total, 30 insertions). During the procedure, the POS values were determined from the load-displacement curves and the compression-time curves recorded using the Tekscan pressure transducer. Therefore, we could proportion relation between the numerical

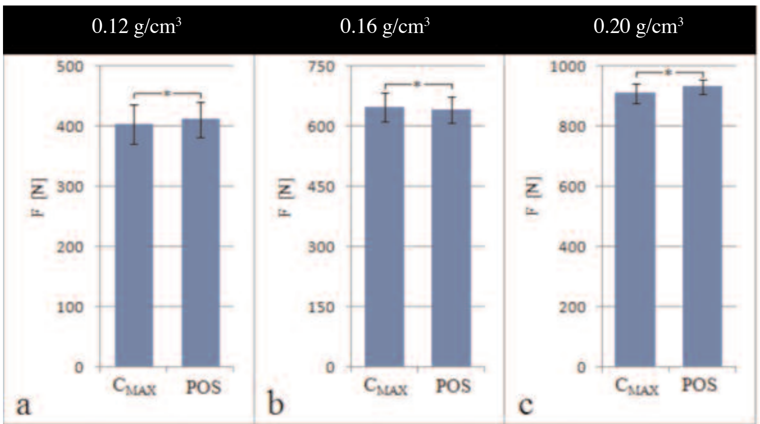

Figure 5. In the 0.12 g/cm^3 specimen, the mean C_{MAX} is 403.65 N and the mean POS is 411.51 N ***(a)***. In the 0.16 g/cm^3 specimen, the mean C_{MAX} is 648.97 N and the mean POS is 641.82 N ***(b)***. In the 0.20 g/cm^3 specimen, the mean C_{MAX} is 910.92 N and the mean POS is 932.68 N ***(c)***. *Not significantly different ($p > 0.05$). C_{MAX}, maximum compressive force; POS, pullout strength.

Table I. The C_{MAX} and POS of the CPTLS at the three densities.

Density (g/cm^3)	CMAX (N)	POS (N)	*p*-value[a]	Ratio[b]
0.12	403.65 ± 33.10	411.51 ± 29.35	0.581	0.98
0.16	648.97 ± 35.86	641.82 ± 33.33	0.650	1.01
0.20	910.92 ± 32.97	932.68 ± 23.52	0.107	0.98

[a]t-test for the difference between the C_{MAX} and POS at each density; [b]Ratio of the mean C_{MAX} to the mean POSat each density. C_{MAX}, maximum compressive force; CPTLS, combined partially threaded cancellous lag screw; POS, pullout strength.

value from the Tekscan pressure transducer and from the BOSE3510-AT testing machine.

Compression test and pullout test which were done in sequence. Therefore, the C_{MAX} values unit conversion with Newton was completed according to the proportion relation.

Statistical Analysis

A two-tailed, unpaired Student's *t*-test was used to compare the C_{MAX} and POS of each specimen. The significance level for all analyses was set at $\alpha < 0.05$.

Results

The C_{MAX} and POS of the CPTLS were not significantly different in the three specimens, and the ratios of the mean C_{MAX} to the mean POS were very similar in the three specimens (Table I).

The ratios of the mean C_{MAX} to the mean POS were 0.98 in the 0.12 g/cm^3 specimen (mean C_{MAX}, 403.65 ± 33.10 N; mean POS, 411.51 ± 29.35 N; $p = 0.581$; Figure 5a), 1.01 in the 0.16 g/cm^3 specimen (mean C_{MAX}, 648.97 ± 35.86 N; mean POS, 641.82 ± 33.33 N; $p = 0.650$; Figure 5b), and 0.98 in the 0.20 g/cm^3 specimen (mean C_{MAX}, 910.92 ± 32.97 N; mean POS, 932.68 ± 23.52 N; $p = 0.107$; Figure 5c).

Discussion

The present study found that the C_{MAX} and POS of the CPTLS were not significantly different in the three specimens and that the ratios of the mean C_{MAX} to the mean POS were very similar in the three specimens. Therefore, during CPTLS compression, C_{MAX} was achieved without a decrease in the POS.

During the CPTLS compression, the compound shank shortened continuously, thereby extracting the thread along the axis of the screw. This was identical to the scenario in the pullout test where the thread was extracted along the axis of the screw[12]. Therefore, the C_{MAX} and POS could be defined as the maximum force produced when the thread was extracted and the bone surrounding the thread was compressed along the axis of the screw. Hence, for a CPTLS, the C_{MAX} and POS should be identical, independent of BMD, in theory.

Our findings confirmed this, demonstrating that the C_{MAX} and POS of the CPTLS were not significantly different in the three specimens and that the ratios of the mean C_{MAX} to the mean POS were very close to 1 in the three specimens (0.12 g/cm^3, 0.98; 0.16 g/cm^3, 1.01; 0.20 g/cm^3, 0.98). The characteristic of the specimens might have caused the minor difference between C_{MAX} and POS. Synthetic bone has been shown to be relatively uniform[11]; however, slight nonuniformity may be present, which can affect the C_{MAX} and POS[13].

POS did not decrease at the point of C_{MAX}, and therefore C_{MAX} could be adapted during CPTLS compression. This characteristic was provided by the compound shank of CPTLS, which made the bone incorporated into the threads compressed in a linear manner during compression. The parameters of the threads could affect the values of C_{MAX} and POS[13]. In our test, the CPTLS used in measuring C_{MAX} was identical with that used in measuring POS. Therefore, the parameters of the threads did not affect the relationship between C_{MAX} and POS.

There were two causes that CPTLS was superior to PTLS in compressive ability. Firstly, CPTLS could provide higher C_{MAX} compared with PTLS[9]. Secondly, during screw compression, C_{MAX} of CPTLS could be applied, while C_{MAX} of PTLS could not be applied[5,6]. This superiority in compression with the CPTLS could provide advantages in the maintenance of rigid fixation. Additionally, this might be more important when encountering osteoporotic fractures because achieving sufficient compression can be difficult[4].

The present study has some limitations. First, we only investigated whether POS decreased at the point of C_{MAX}. Studies involving more points are needed to assess the change of POS and compressive force during CPTLS compression. Second, there were no dynamitic tests to assess the superiority of CPTLS in compressive ability. Finally, we chose synthetic bone blocks to simulate cadaveric bone. Although these blocks have been used widely in studies of the C_{MAX} and POS, and the findings of this study were provided by the structure of CPTLS, future studies were demanded to confirm this finding in cadaveric bone.

Conclusions

C_{MAX} is achieved without a decrease in POS during CPTLS compression. This characteristic of the CPTLS is determined by its design and is independent of BMD. Our study confirmed this characteristic in three specimens having different densities. This characteristic provided advantages in terms of compressive ability and surgical operation. Further studies will be performed to investigate the other effects and benefits of the CPTLS and optimize the fixation strength of this lag screw for intra-fractures.

Conflict of Interest

The Authors declare that they have no conflict of interests.

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