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Biomechanical analysis of the sliding hip screw, cannulated screws and Targon® FN in intracapsular hip fractures in cadaver femora

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ABSTRACT

Background: Internal fixation is one of the main options for treating displaced intracapsular hip fractures. However, controversy remains over which osteosynthesis is the best choice. Using a simulated displaced intracapsular hip fracture model, we compared the mechanical stability of three types of osteosynthesis: the sliding hip screw (SHS), three cannulated screws and the Targon® FN. We also assessed whether bone mineral density (BMD) influenced the stability of the fixation.

Methods: Unstable/displaced intracapsular hip fractures were induced in a total of 12 pairs of fresh-frozen cadaver femora. Each fracture was fixed at random on the left or right side with an SHS or three cannulated screws (six bone pairs; study 1), or with an SHS or the Targon® FN implant (six bone pairs; study 2). All femoral heads were exposed to cyclic combined axial and torque loads until failure. The failure mechanism, the maximal load-to-failure and the dual-energy X-ray absorptiometry (DEXA) values of the femoral heads were determined and their relationships were analysed.

Results: There was no significant difference in the maximal load-to-failure between the SHS and the three cannulated screws. The load-to-failure was significantly higher for the Targon® FN than for the SHS. There was a high correlation between the bone mineral densities (BMDs) of the femoral heads and maximal load-to-failure in the Targon® FN group only.

Interpretation: Basing the implant choice on preimplantation BMD measurements does not ensure the best biomechanical outcome. We found that the combination of a fixed-angle device and multiple sliding neck screws (Targon® FN) enhances the mechanical strength of reconstructions in unstable/displaced intracapsular hip fractures.

Sliding hip screw (SHS) and cannulated screws are two types of osteosynthesis most often used to treat displaced intracapsular hip fracture. However, success rates are not optimal, and treatment must be improved. Approximately 30% of surgically treated displaced intracapsular hip fractures require revision surgery. These revisions are associated with a large burden of morbidity and mortality. The disability adjusted life years (DALYs) lost as a result of hip fractures ranks in the top 10 of all causes of disability scores globally.[5]

A recent Cochrane review by Parker et al. concludes that there is no clear data from randomised clinical trials upon which the optimal choice of implant for fixation of intracapsular hip fractures can be based.[15] Complications arise in 20–40% of surgically treated hip fractures due to early fracture displacement with loss of position of the fixation device. This leads to nonunion or failure to heal, probably as a result of mechanical instability of the reconstruction.[9,13] Mechanical instability may be related to bone quality, for example, as measured by dual-energy X-ray absorptiometry (DEXA), and two studies have suggested that cannulated screw fixation in osteoporotic bone can lead to early failure. These studies suggest that cannulated screw fixation should not be used in severely compromised bone to avoid early failure and subsequent hospitalisation for revision surgery.[18,19] Hence, it may be important to quantify bone quality in order to choose the optimal fixation method for a particular patient.

In the longer term, there is a 16% incidence of avascular necrosis of the femoral head for displaced intracapsular hip fractures. The SHS has a complication rate in the range of 12–32%.[3,7,8,10,12,16] For the treatment of displaced intracapsular hip fractures, SHS is associated with the same complications in terms of fracture

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healing as the multiple parallel screw technique or similar implant types.

There are no published reports of implants that are superior to the SHS and the multiple parallel screw technique.[14] The features of these two fixation methods might be combined in a new implant in order to improve the stability of the fracture. The SHS is a plate with a sliding rather than a stable fixed-angle neck screw. Consequently, the stability around the femoral neck is somewhat limited, as one screw allows rotation around its axis. This rotational stability could be markedly improved using multiple sliding, angular stable neck screws within a single design. Hence, by combining the SHS with multiple parallel screws, a new fixation device can be created that may have superior biomechanical properties.

In this study, we assessed whether this new fixation device would lead to improved reconstructive stability. To test this, we used a previously developed experimental protocol in which fresh cadaver femurs are used to create unstable/displaced intracapsular hip fractures that can be 'treated' with osteosynthesis and subsequently loaded to failure.[2] We hypothesised that the new design (i.e., the combination of multiple sliding angular stable neck screws) would have a higher mean maximal load-to-failure compared with the SHS or with three cannulated screws, and that better bone quality would lead to higher failure loads.

Materials and methods

We compared the mechanical behaviour of three types of osteosynthesis devices. We used fresh-frozen cadaveric bones and performed two studies to allow for a paired comparison of the devices. Accordingly, study 1 compared the SHS to reconstruction with three cannulated screws, and study 2 compared the sliding hip screw with a novel implant, Targon® FN, that features multiple neck screws at fixed angles in a plate. We used six pairs of fresh cadaver femora in each study (i.e., 12 pairs in total).

Prior to testing, the bones were scanned to determine their DEXA values, which indicate the bone mineral density (BMD) of the femoral heads, to check whether there is a relationship between failure load and bone quality.

Subsequent to the scanning, a subcapital intracapsular hip fracture was induced in each femoral bone using a drill-mould. The femoral neck was perforated with numerous drill holes and then mechanically fractured. In addition, a 5-mm thick slice of cortical bone material was removed from the postero-medial wall to simulate comminution as proposed by Deneka et al.[6] In this way, a Garden type 3 or 4 fracture or an AO 31-B3 fracture was created.

In study 1, the cadaveric bones were from four male and two female donors aged 65–88 years. The fractures were fixed with either the SHS ($n = 6$; DHS; Synthes®, Bettlach, Switzerland) or three cannulated screws ($n = 6$; Biomet® Large Cannulated Screw System; 6.5-mm diameter titanium self-drilling and self-tapping; Biomet Orthopedics, Inc., Warsaw, IN, USA). The cannulated screws were positioned in a triangular configuration as described by Selvan et al.[17] and Stafford et al.,[20] and supported by reports from Booth et al.[1] and Maurer et al.[11] The devices were placed according to surgical guidelines with the screw tips within 5–10 mm of the subchondral bone.

With the internal fixation in place, the femora were radiographed in the anterior–posterior and lateral planes to determine the correct reduction of the fracture and placement of the implant devices.

In study 2, the cadaveric bones were from three male and three female donors aged 84–98 years. The procedures were identical to those in study 1, except that the right and left cadaveric femurs were randomised for fixation with either the Targon® FN ($n = 6$; Aesculap®, Tuttlingen, Germany) or the SHS ($n = 6$ for each device) instrument.

Fig. 1. The Targon® FN with three TeleScrews (neck screws).Photograph taken from brochure supplied by Aesculap®, Tuttlingen, Germany.

The Targon® FN is a new device that was proposed as a head-preserving solution for medial and lateral femoral neck fractures. It was designed to withstand rotational forces and to prevent backing out of screws (Fig. 1). This device features a short anatomically fitted femoral locking plate that has the potential for up to four angle-stable screws (TeleScrews). In this study, we employed four TeleScrews (Aesculap®, Tuttlingen, Germany) using standard surgical techniques according to surgical guidelines.

The experimental protocol was described previously.[2] Briefly, the distal end of each cadaveric bone was resected 20 cm below the tip of the greater trochanter. Each bone was oriented in a neutral position (without any adduction or abduction and without any flexion or extension) and potted. The femoral heads were exposed to a cyclic combined axial, bending and torque load to simulate clinically relevant failure. This load was created using a cyclic axial force (servohydraulic MTS machine) that was applied to a region 5-cm posterior to the centre of the femoral head. Fig. 2 shows the loading condition.

The cyclic combined axial and torque load was applied in a dynamic way with a 0.5-Hz frequency and stepwise increases of 25-N increments. A total of 75 loading cycles were applied for each load, and loading was increased until the reconstruction failed.

The failure mode was recorded in detail, and the load magnitude was used as an indicator of the strength of the reconstruction.

Statistical analyses of the strength values of the SHS versus three cannulated screws and SHS versus Targon® FN reconstructions were performed with a paired t-test using SPSS 12.0.1. A p value <0.05 was considered significant.

Results

In study 1, which compared SHS with three cannulated screws, the mean maximal load-to-failure was 135.5 ± 29.4 N for the SHS group and 219.7 ± 92.8 N in the three cannulated screw group. Hence, the reconstructions using cannulated screws seemed stronger,

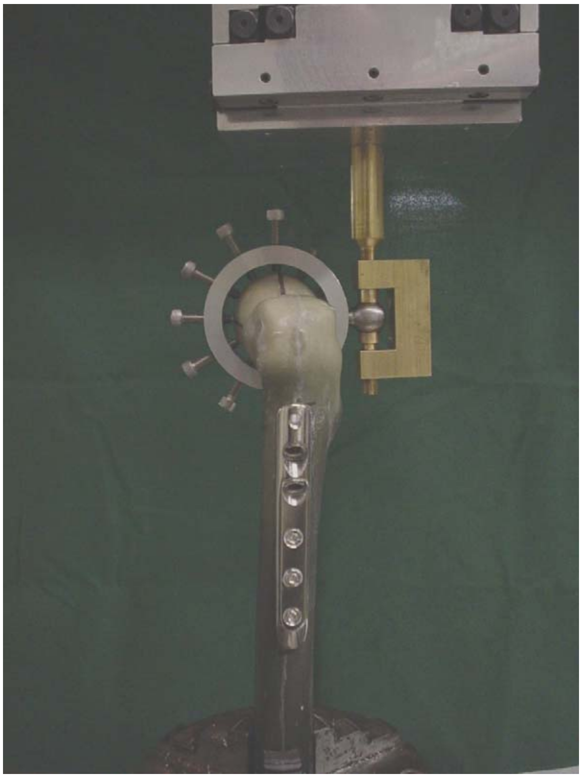

Fig. 2. Loading condition. Photograph taken during previous study.

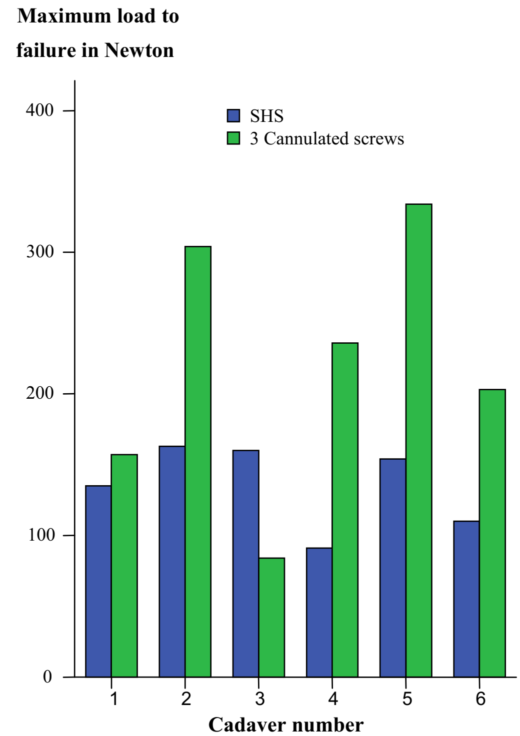

Fig. 3. Load-to-failure for hip fractures treated with SHS and 3 cannulated screws.

although the difference was not significant ($p = 0.084$) (Table 1 and Fig. 3).

The failure mode for the SHS reconstructions was a posterior rotation associated with retroversion varus deviation of the head, which is similar to failures observed in a clinical setting.

The failure mode for the three cannulated screw reconstructions was a varus posterior rotation associated with a twisting movement of the three neck screws, with perforation of the posterior neck by the posterior neck screw.

In study 2, which compared SHS with Targon® FN, the mean maximal load-to-failure was 78.0 ± 11.7 N for the SHS group and 164.0 ± 80.4 N for the Targon® FN group. This difference was statistically significant ($p = 0.035$) (Table 1 and Fig. 4).

The BMD values were not statistically different between the test groups, with $p = 0.251$ for the groups in study 1 and $p = 0.744$ for the groups in study 2. This confirms that the bones were randomised appropriately.

The correlation coefficients[4] for reconstruction strength and BMD all showed positive values, indicating stronger reconstruction with higher bone quality (Table 2). There was a high correlation ($R^2 > 0.5$) between reconstruction strength and BMD only for the Targon® FN, whereas a moderate correlation was found for the cannulated screws and the SHS (Fig. 5).

Table 1
Mean maximum loads to failure and 95% confidence intervals of studies 1 and 2.

Test group	Mean maximum load-to-failure (N)	95% CI of difference
SHS (study 1)	135.5	104.6–166.4
3 cannulated screws (study 1)	219.7	122.3–317.1
SHS (study 2)	78.0	47.9–108.2
Targon® FN (study 2)	164.0	79.6–248.4

SHS: sliding hip screw.

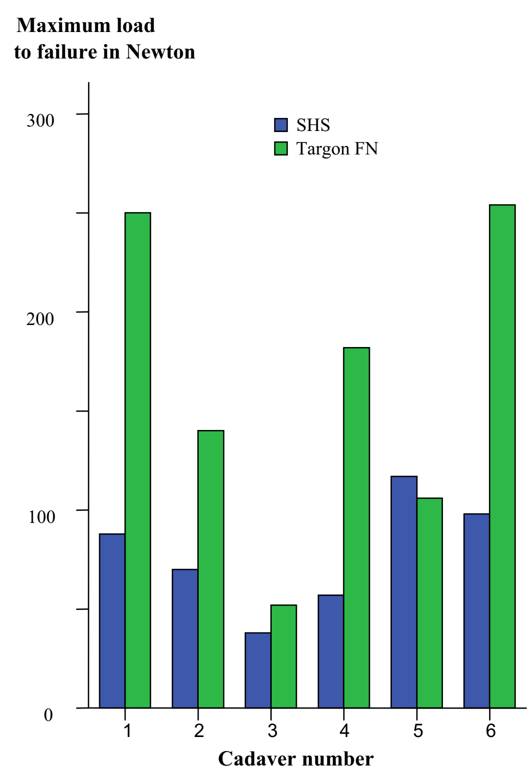

Fig. 4. Load-to-failure for hip fractures treated with SHS and Targon® FN.

Discussion

In our previous work, we compared the SHS with the PerCutaneous Compression Plate for fixation of intracapsular hip fractures. Our results highlighted the importance of superior fixation for withstanding axial and rotational loads, particularly in comminuted

Table 2
Correlation coefficients for maximum load-to-failure versus BMD.

	Mean BMD	R^2	Standard error of the estimate
Cannulated screws (6 femora)	0.733	0.153	95.462
Targon® FN (6 femora)	0.626	0.537	61.153
SHS (12 femora)	0.700	0.296	35.966

BMD: bone mineral density (g/cm^2); SHS: sliding hip screw.

fractures in which stable anatomical reposition cannot be achieved, always.[2] Furthering our search for the most stable implant for successful treatment of unstable intracapsular hip fractures, we performed a biomechanical analysis of the SHS, cannulated screws and Targon® FN (present study).

The three cannulated screws were positioned in a triangular configuration according to Booth et al.,[1] Maurer et al.,[11] Selvan et al.[17] and Stafford et al.[20] These studies showed that the most stable construct was achieved using the triangular configuration with the top up. Compared with other configurations of cannulated screws, this configuration conferred a higher load-to-failure, less displacement and more energy absorption before failure and increased stability.

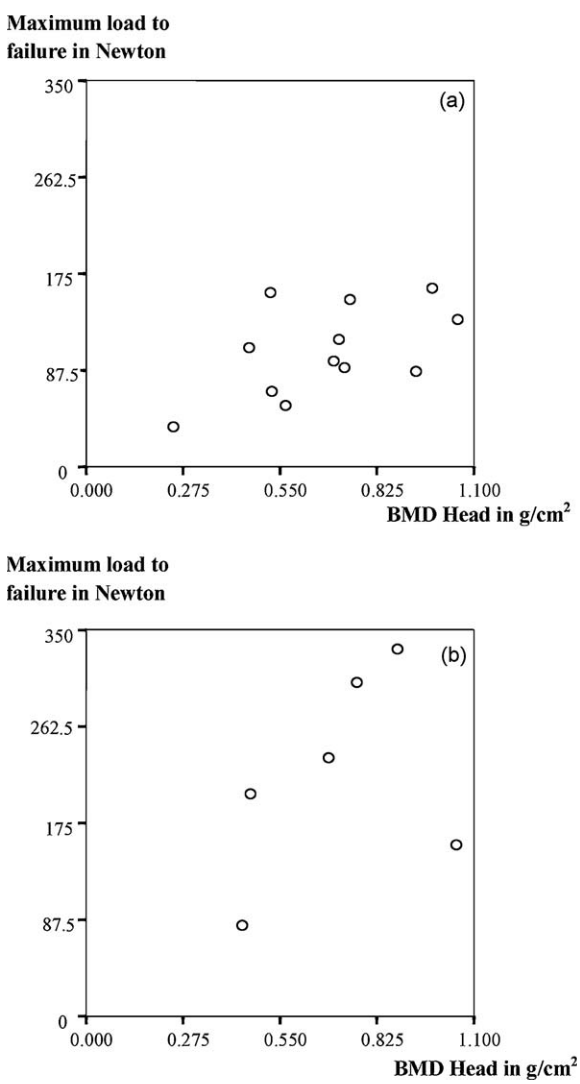

Fig. 5. Correlation coefficients for reconstruction strength and BMD for (a) femora treated with SHS (includes femora in studies 1 and 2); (b) femora treated with 3 cannulated screws (study 1); (c) femora treated with Targon® FN group (study 2). Mean correlation coefficients are shown.

Study 1 compared fixation with an SHS versus three triangular configuration cannulated screws. There was no difference in the reconstructive strength obtained with these two devices. However, there was a clear trend for greater reconstructive strength with the triangular configuration cannulated screws compared with the SHS. Sjöstedt et al.[18] and Spangler et al.[19] reported that cannulated screw-fixation failure is due to early failure in the osteoporotic bone; by contrast, we found a weak trend towards lower strength with lower bone quality alone.

The earlier studies suggested that to prevent early failure and subsequent hospitalisation for revision surgery, cannulated screw fixation should not be used in severely compromised bones. Our biomechanical results do not support this conclusion. The discrepancy between our results and earlier findings may be due to the limited number of specimens tested relative to the many ways in which reconstructions can fail. On the one hand, a larger sample size (i.e., more bones) is desirable for determining the relationship of bone quality and reconstructive strength with greater certainty. On the other hand, the need for a larger sample size highlights the fact that reconstructive failure is not very dependent on bone quality. Determination of bone quality may be of little value for an individual patient because other factors (such as fit, local variations in bone quality and geometry, activity level, and loading angles) may be more important than bone quality *per se*. A multifactorial analysis is needed to assess the combination of parameters that predict low or high reconstructive strength for a given patient.

In our opinion, the bones used in studies 1 and 2 were comparable: There was no significant difference between the two study groups in terms of BMD ($p = 0.967$). Thus, it seems as though the Targon® FN device has a significantly higher load-to-failure compared with the SHS.

The correlation coefficient between failure load and BMD was low in study 1 (SHS vs. three cannulated screws). This could be explained by a single femoral reconstruction with a relatively low failure load but a rather high BMD. Hence, although the bone was strong, the reconstruction was not. Careful evaluation of the X-ray did not show incorrect placement of the implant, and, therefore, the reason behind this relatively weak reconstructive strength remains unknown.

We found a high correlation between BMD and the strength of the reconstruction only with the Targon® FN implant. The SHS and three cannulated screws showed only moderate correlations, even in the standardised setting in which our biomechanical testing took place. In our opinion, this indicates that preimplantation BMD measurements do not help guide device choice in a way that results in a better patient outcome. That is, BMD itself is not a predictor of success or failure.

Prospective clinical studies are needed to confirm these experimental findings *in vivo*.

In conclusion, our study supports the hypothesis that the combination of a fixed-angle device and multiple sliding neck screws enhances the mechanical strength of reconstructions in unstable/displaced intracapsular hip fractures.

Contributors

E. Brandt designed the study and performed the biomechanical tests and wrote the manuscript. N. Verdonschot designed the study and supervised the biomechanical tests and reviewed the manuscript. A. van Vugt reviewed the manuscript and the study design. A. van Kampen reviewed the manuscript and the study design.

Conflict of interest statement

There are no conflicts of interest.

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