

The dynamic locking blade plate, a new implant for intracapsular hip fractures: Biomechanical comparison with the sliding hip screw and Twin Hook

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ABSTRACT

Internal fixation of intracapsular hip fractures results in a high failure rate with non-union and avascular necrosis being the two most important complications. In order to prevent these possible complications treatment should consist of an anatomical reduction and stable fixation by insertion of a low volume, dynamic implant, providing angular and rotational stability to the femoral head. According to these principles a new implant, the dynamic locking blade plate (DLBP) was designed for the fixation of intracapsular hip fractures. We performed a biomechanical analysis in synthetic bone to compare the rotational stability and cut out resistance of the DLBP with a conventional sliding hip screw (SHS) and the more recently developed Twin Hook. The rotational stability of the DLBP proved to be three times higher than the rotational stability of a SHS and two times higher than the Twin Hook. There was no major difference in cut out resistance between the different implants. The design of the DLBP and possible advantages with regard to the healing of an intracapsular hip fracture are discussed.

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Introduction

The treatment of an intracapsular hip fracture is still under debate. There is consensus regarding the biologically young and elderly patient.² Young patients are treated with internal fixation in order to preserve the femoral head and regain full function of the hip. Elderly patients are treated with an arthroplasty in order to limit the period of immobilisation and to prevent revision surgery. The treatment of the intracapsular hip fracture in patients aged 60–80 years remains controversial and is therefore referred to as “the unsolved fracture”.^{14,25,30}

The results of internal fixation, especially in the elderly, are disappointing. A revision rate with decreased function and increased morbidity of 35% and up to 48% are reported in two large meta-analysis performed by respectively Lu-Yao and Bhandari.^{1,11}

As an illustration of the poor clinical results there are many implants available for the use of internal fixation of an

intracapsular hip fracture.^{19,29} Parker concluded from his meta-analysis of randomised trials that there is little difference in failure rate between these different implants.²⁰ However, the meta-analysis performed by Bhandari et al. demonstrated better results for screw and side-plate constructs than multiple screws.¹ The sliding hip screw (SHS) is one of the most commonly used screw and side-plate constructs with reported failure rates of 12–41%.^{3,4,7–9,12,18} The Twin Hook (Stryker, Geneva, Switzerland) has recently been developed as an alternative to the conventional side-plate with lag screw constructs.^{16,17} It consists of a side-plate with a sliding nail from which two oppositely directed apical hooks are deployed. To our knowledge there are no clinical studies available on the use of the Twin Hook in intracapsular hip fractures.

Non-union is a major cause of failure of internal fixation of an intracapsular hip fracture.²⁸ It is therefore important to realise that healing of an intracapsular femoral neck fracture is potentially compromised because of several reasons. First, the intracapsular part of the neck of the femur has no periosteal layer to participate in the bone healing process. Therefore, bone healing in the femoral neck is dependent on endosteal union alone without the formation of peripheral callus.²³ Second, primary bone healing requires, according to the interfragmentary

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strain theory, absolute stability and anatomical alignment.²¹ In order to prevent non-union of a femoral neck fracture a device for internal fixation should therefore preserve the endosteal layer of the femoral neck and provide the required stability.

Another major cause of failure of internal fixation is avascular necrosis.²⁸ The viability of the femoral head after a femoral neck fracture is dependent on the preservation of the remaining vascular supply and on the occurrence of revascularisation. Again, stable fixation and anatomical alignment are a prerequisite for this process to take place. Persistent motion at the fracture site can tear the tender, so-called, revascularisation buds during vascular ingrowth and cause avascular necrosis. Also increasing the volume of the implant within the femoral head may be deleterious to femoral head viability.^{10,27}

To prevent these possible complications of internal fixation, in our opinion, properties of a new improved implant should include: good angular and rotational stability, good femoral head fixation, a small frontal area and low implant volume and the possibility of applying dynamic compression over the fracture. Therefore, in an attempt to solve the “unsolved fracture” we designed the dynamic locking blade plate (DLBP) (BAAT Medical Engineering, Hengelo, The Netherlands), a new implant which claims the above named characteristics.

The objective of this study was to determine the biomechanical characteristics of the DLBP and compare them with the characteristics of the SHS and Twin Hook. For this purpose the rotational stability of the DLBP, SHS and Twin Hook were determined in synthetic bone. Furthermore, a cut out test procedure with dynamic axial load testing was performed.²⁶

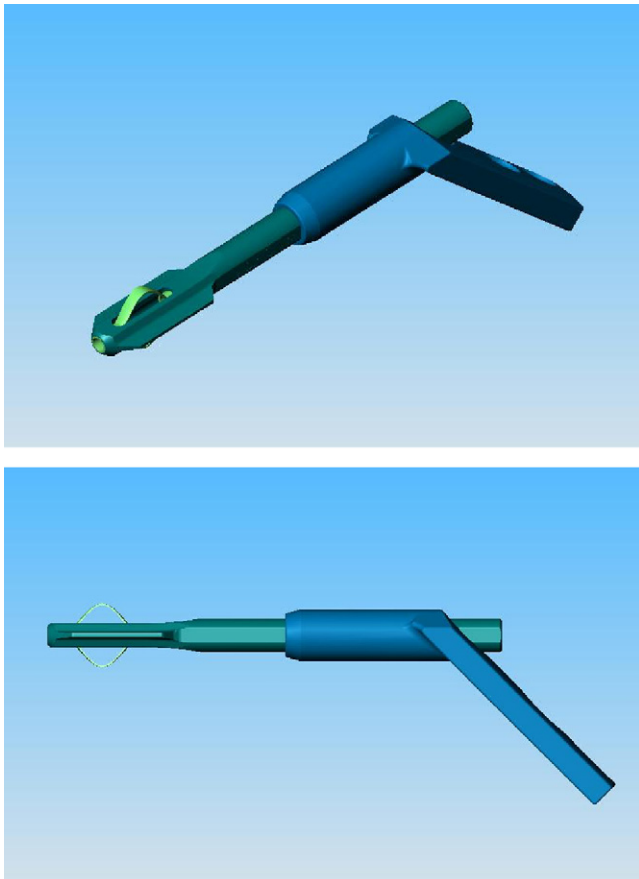


Fig. 1. Illustration of the dynamic locking blade plate (DLBP).

Table 1
Proportions of the DLBP, Twin Hook and lag screw.

| Implant | Volume (mm ³) | Frontal area (mm ²) |
|-----------|---------------------------|---------------------------------|
| DLBP | 920 | 31 |
| Twin Hook | 1500 | 50 |
| Lag screw | 1975 | 133 |

Materials and methods

The DLBP consists of a barrelled side-plate combined with a cannulated locking blade. A guide pin is inserted and the femoral head and neck are reamed with an adjustable reamer. The blade and plate are assembled together with the introducer as one device. The cannulated blade with the attached plate is then pushed over the guide pin into the femoral head. Note that this does not require a rotational force. The plate is fixed to the lateral cortex with two self-tapping screws. The blade is locked subchondrally in the femoral head by deploying the impaction anchors (Fig. 1).

The SHS is a side-plate combined with a conventional lag screw and the Twin Hook is a side-plate combined with a nail from which apical hooks are deployed.

The implants were inserted into pre-drilled bone substitute material to a defined depth following the surgical technique. Beforehand the proportions of the different implants were determined (Table 1).

A solid rigid polyurethane foam with a density of 15 pcf and 20 pcf (Sawbones, Malmö, Sweden) was used as a bone substitute material to simulate the cancellous bone in the femoral head. Both foams comply with ASTM F1839.²⁶ We chose polyurethane foam as test medium in order to obtain comparable results instead of absolute clinically relevant data.⁶ The 15 pcf foam has material properties similar to osteoporotic cancellous bone and the 20 pcf foam simulates healthy bone. Both foams provide a distinctly lower variability in their mechanical properties compared to human bone specimens.

Torsion test

Fig. 2 illustrates the test setup of the torsion test. The implants are rotated with a constant angular velocity while the torque is being measured. The implant is only loaded with a torque around the axis of the blade. The implant is rotated over 45° with an angular speed of 1°/s. Failure is defined as 20° of implant rotation. Rotational resistance is the torque at 20° of rotation.

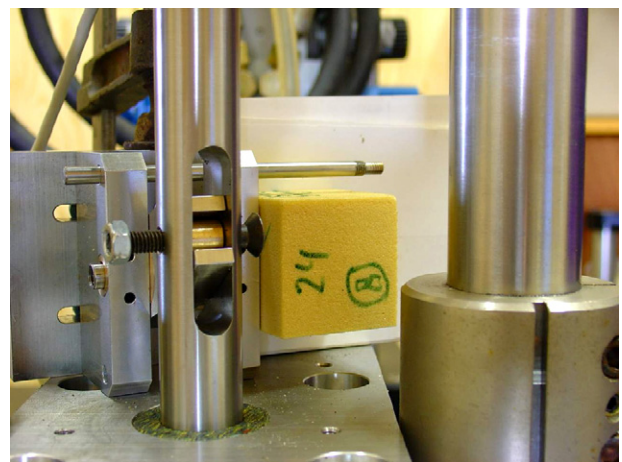


Fig. 2. Setup for the torsion test of the DLBP.

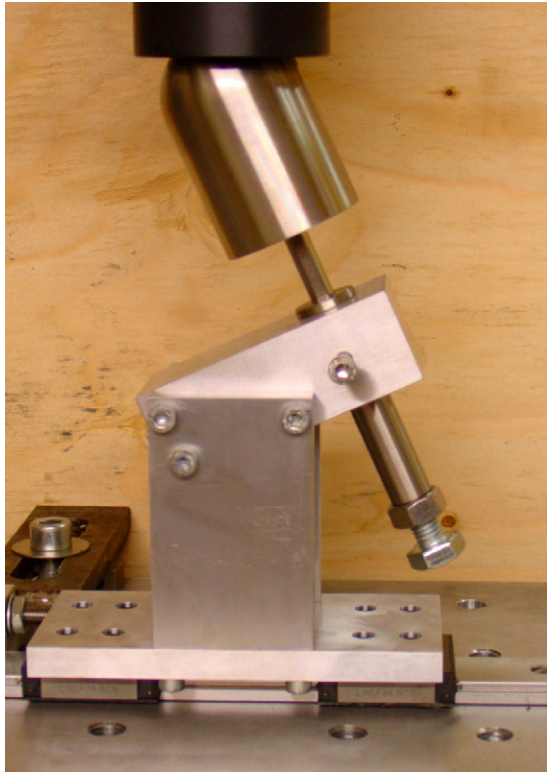


Fig. 3. Setup for the cut out test.

Four samples of the DLBP, two of the Twin Hook and three of the SHS were tested in 15 pcf and 20 pcf foam.

Cut out test

Fig. 3 illustrates the test setup for the cut out test. The test procedure is identical to the Stryker Twin Hook cut out test procedure.¹⁵

The inserted implants were placed in a steel cup and clamped to the test device. The hooks of the Twin Hook were basically orientated and the blades of the DLBP were placed in a transverse direction. As a result the impaction anchors of the DLBP are orientated in a sagittal plane. Free length of implant out of the setup is 55 mm.

The specimen is loaded with a sinusoidal multistage load according to the following description (Fig. 4):

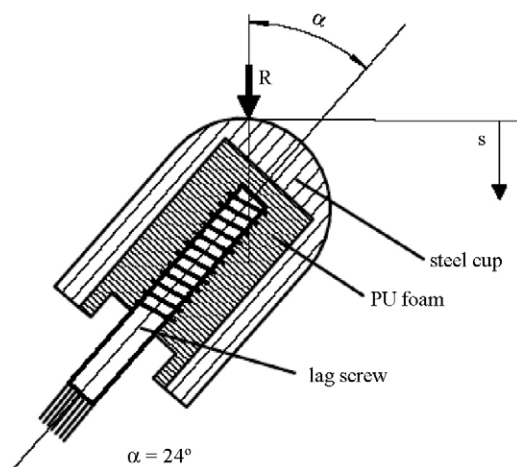


Fig. 4. Schematic drawing of the setup for the cut out test.

- The setup is preloaded with 30 N. At this load the position S_{start} is taken as reference position.
- The start load is $F_{upper} = 600$ N at a load ratio of $F_{upper}/F_{lower} = 10:1$.
- After each 700 cycles the load is increased by $\Delta F_{upper} = 50$ N.
- The force and the movement S of the screw in the foam are determined after each 100 load cycles.
- After each load stage the piston is unloaded to 30 N and the plastic deformation is determined as the difference between S_{end} and S_{start} .
- Test frequency: 2 Hz.

Cut out value was defined as the load where the total movement in the foam exceeds a value of 2 mm or more than 1 mm in one load stage. These criteria are similar to the criteria used in the cut out tests performed by Nonomiya and Bauer.¹⁵ This value was chosen since a migration of 2 mm in the femoral head can already be identified on a postoperative radiograph and might cause a change in the treatment of the patient. Three samples of the DLBP and two of the Twin Hook were tested. Cut out test values of the SHS were derived from the data published by Nonomiya and Bauer.¹⁵

Anchor expansion test

The impaction anchors of the DLBP are deployed by turning a screw inside the implant. This requires a rotational force. The required rotational force, and whether or not the impaction anchors expanded, was tested in air, 15 pcf and 20 pcf foam.

Results

Torsion test

The results are shown in Table 2. The Twin Hook shows a strong increase in rotation resistance in the first 2° in the 15 pcf foam after which the resistance stays at a maximum independent of the angle of rotation. In the 20 pcf foam there is a reproducible rotational resistance increase at 10° after which the torque stabilises again.

The DLBP shows a similar strong increase of rotational resistance over a rotation of approximately 10° but does not stabilise. The rotational resistance keeps slowly increasing during further rotation.

Cut out test

The cut out value of 2 mm total displacement was reached in all tests before the deformation per load stage exceeded 1 mm. Table 3 shows a summary of the results. The results of the cut out tests of the different implants are all within 10% of each other.

Table 2
Mean rotational resistance at 20° of rotation.

| Foam density (pcf) | DLBP (N m) | Twin Hook (N m) | SHS (N m) |
|--------------------|------------|-----------------|-----------|
| 15 | 9.0 | 4.5 | 3.8 |
| 20 | 15.1 | 7.2 | 4.8 |

Table 3
The mean cut out resistance.

| Foam (pcf) | DLBP (N) | Twin Hook (N) | SHS (N) ^a |
|------------|----------|---------------|----------------------|
| 15 | 1133 | 1200 | 1178 |
| 20 | 2000 | 2025 | 1802 |

^a Data derived from the Stryker cut out test by Nonomiya and Bauer.

Table 4
Maximum torque anchor expansion tests.

| Material | Maximum torque (N m) |
|----------|----------------------|
| Air | 1.5 |
| 15 pcf | 1.8 |
| 20 pcf | 2.2 |

The cut out behaviour of the DLBP was similar to that of the Twin Hook. Both implants show a continuous increasing cut out displacement during the test.

Anchor expansion test

The results of the measured maximum rotational force are shown in Table 4.

In all performed tests there were no technical failures while expanding the impaction anchors.

Discussion

The DLBP, SHS and the Twin Hook follow the principles of a sliding implant with side-plate construct: fixation within the femoral head and on the lateral cortex of the femur with the possibility of dynamic compression over the fracture. One of the main differences is the insertion technique. All three implants require a guide wire and pre-drilling. Insertion of the lag screw of the SHS requires a rotational force with the risk of rotating the femoral head and thereby damaging the already compromised vascular supply of the femoral head. An anti-rotation K-wire or second screw is needed as a precautionary measure. On the contrary, the DLBP being a blade, and the Twin Hook being a nail, are pushed into the femoral head, not requiring a rotational force.

After insertion of the DLBP the impaction anchors are expanded in order to lock the blade within the femoral head and provide additional rotational stability. Rotational stability of the DLBP is mainly based on the design of the blade and the two side wings. From the Twin Hook, apical hooks are deployed to gain fixation within the femoral head and to provide rotational stability. The anchor expansion tests demonstrated that it requires a minimum of force from the surgeon to expand the impaction anchors of the DLBP. Moreover, the impaction anchors never failed to expand in any material in any of the tests.

The presently performed tests demonstrated that when the implants are rotated 20° in 20 pcf sawbone a maximum momentum of 4.75 N m for the SHS, 7.2 N m for the Twin Hook and 15.1 N m for the DLBP is measured. This means the design of the DLBP has succeeded in providing a three times higher rotational stability compared to the SHS and two times higher

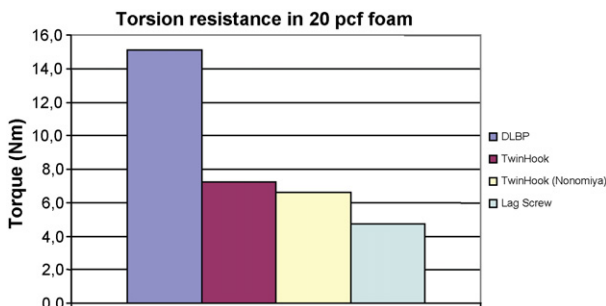


Fig. 5. Comparison of the torsional resistance results in this test and the data of Nonomiya.

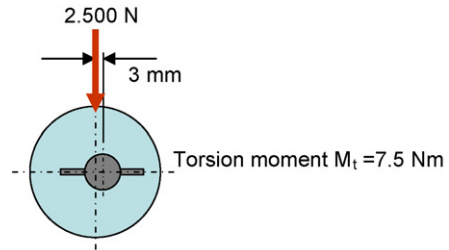


Fig. 6. Additional torsion moment due to a small misalignment.

rotational stability compared to the Twin Hook. These results are in concordance with the data published by Nonomiya and Bauer on the torsion resistance tests of the Twin Hook.¹⁵ They measured a maximum momentum of 6.59 N m at 20° of rotation in 20 pcf foam which is 9% lower than that of the current tests. This can be explained by the slight difference in test setup. Fig. 5 gives a comparison of results from Nonomiya and Bauer and the current tests. As illustrated the DLBP is far more superior in rotational stability than the Twin Hook and the SHS.

The capacity to resist high torsion loads is particularly important in intracapsular hip fractures. Hip joint contact forces are about 2.7 times body weight.⁵ This means that for a person of 95 kg forces acting on the hip will reach 2500 N. Therefore, a small misalignment of the implant in the femoral head will lead to high torsion moments. For example, with an axial force of 2500 N and a misalignment of 3 mm an additional rotation moment of 7.5 N m will be generated as shown in Fig. 6. Because of its ability to resist high rotation moments the DLBP is more forgiving with respect to proper placing of the implant in the centre of the femoral head. In contrast, placing of the conventional lag screw comes very precise. Superior or peripheral positioning is associated with an increased occurrence of cut out.^{13,22}

Overall, the cut out behaviour of the Twin Hook and the DLBP shows a high level of similarity. Because of the shape of the anchors of the DLBP it is possible to place the DLBP just beneath the surface of the femoral head, where the highest bone density exists as shown in Fig. 7. This would also be possible with the Twin Hook, but only if the hooks are partially deployed. However, this could have a negative effect on the rotational stability of the Twin Hook since the resistance against torsion loads is mainly dependent on the hooks of the Twin Hook.

Although the cut out test procedure provides us with useful and valid data it is not a true reflection of clinical practice. Normally, the surgeon would strive for an optimal reposition of the fracture which will result in bony support between the femoral head and

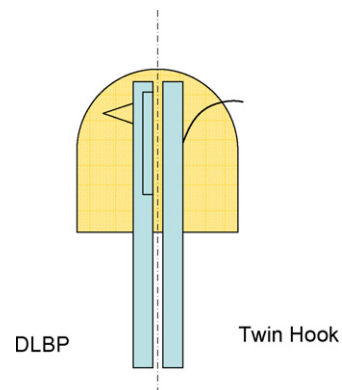


Fig. 7. Schematic comparison of a DLBP and a Twin Hook when fully deployed subchondral in a femoral head.

the trochanteric region. Therefore, a great part of the axial force acting on the hip will be diverted through the bone. Thus, in clinical practice, when care is taken with the reposition of the fracture, cut out resistance will be far higher.

Another striking difference is the proportion of the DLBP and Twin Hook when compared to the SHS. The frontal area of the DLBP is 4.3 times smaller than that of the SHS. The volume of the DLBP is 47% and the Twin Hook 76% of that of the SHS. The latter will therefore remove a greater proportion of cancellous bone. This may have adverse consequences on the stability of the fracture and the endosteal bone healing of the femoral neck, as well as on the viability of the femoral head. As mentioned in Section 1, bone healing in the femoral neck is dependent on endosteal union alone.²³ Furthermore, the rotational stability of the fracture is indispensable for the preservation of the remaining blood supply and revascularisation of the femoral head.²⁴

Conclusions

The DLBP has a far better rotational stability than the Twin Hook and SHS. Furthermore, the DLBP has a smaller volume and smaller frontal area than the SHS. There are no significant differences in cut out values between the DLBP, Twin Hook and SHS.

The superior rotational stability of the DLBP may provide the right conditions for primary bone healing of the femoral neck and revascularisation of the femoral head. Its minimal invasive characteristics may help to preserve the remaining vascular supply and respects the biology of bone healing of the femoral neck. We therefore hypothesize that the DLBP is a more biological and stable implant than the SHS and the Twin Hook leading to less avascular necrosis and a lower failure rate after internal fixation of an intracapsular hip fracture. A prospective clinical trial with the DLBP to verify this hypothesis is now being performed.

Conflict of interest

None.

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