Biomechanical Study. The Role of Osteoporotic or Osteoarthritic Bone in Determining the Fixation Achieved Within the Femoral Head by the Lag Screw Elements of the Dynamic Hip Screw (DHS) and DHS Blade

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Citation

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Abstract

Objective This study was conducted to investigate the fixation that the lag screw elements of two different implants used in the treatment of intertrochanteric fractures achieve within osteoporotic and osteoarthritic femoral heads, as a practical means of comparing the mechanical properties of osteoporotic bone against those of osteoarthritic bone. Methods The lag screw elements of the Dynamic Hip Screw (DHS) and DHS Blade were the two lag screws that were chosen to conduct this study with. "Pushout" tests were performed as the means to investigate the fixation that each lag screw achieved within the femoral heads, as the most common mode of failure with these devices is 'cut-out' Results The results demonstrate that the difference in mechanical properties between osteoporotic and osteoarthritic bone in cadaveric femoral heads mean that the devices used in the fixation of intertrochanteric fractures achieve a much greater fixation within osteoarthritic bone. The results also demonstrate that the overall failure patterns were similar for each device within both the osteoporotic and osteoarthritic bone apart from the large difference in forces achieved.

Conclusion The results demonstrate, that as expected when the density of the bone increases, in general the implants achieve better fixation within it. However this study also demonstrates that it is the implant that dictates the pattern of failure and not the bone.

INTRODUCTION

Previous studies by Li, B., Aspden et al [1] and Shih-Sheng Sun et al [2] have been conducted to compare the actual values for the mechanical properties of bone from osteoporotic femoral heads against those of bone from osteoarthritic femoral heads, however our study was performed with a difference perspective, to investigate what this recognised difference in the mechanical properties between osteoarthritic and osteoporotic bone has in practical terms, in relation to implant fixation. Femoral heads were again chosen as the medium to conduct this study in, as they are available post total hip replacement or hemiarthroplasty. Two implants used in the treatment of Intertrochanteric fractures were chosen as the means of testing fixation because even though the majority of intertrochanteric fractures occur with osteoporotic bone, some also have been reported with osteoarthritic bone.[3] Another factor worth noting is that there is no one clearly defined value for osteoporosis. Osteoporosis is a metabolic disease characterised by low bone mass and micro-architectural changes of bone that predispose it to fragility fractures [4]. In essence osteoporosis is a multifactorial chronic disease that may progress silently for decades until characteristic fractures occur late in life.[5] Patients with a bone mineral density of 2.5 standard deviations less than the average value for young adults are said to be opteoporotic.[6] Therefore osteoporosis can exist within a spectrum of values below a certain defined value in the literature.[6] In conducting this experiment with both osteoporotic and osteoarthritic femoral heads, it may help to demonstrate the role that bone density has on the mechanical properties of bone and ultimately on the fixation achieved within it.

'Cut out' is the most common mode of failure with the implants chosen for this study. [7] Pushout studies, as previously documentated in the literature,[8,9,10] were chosen as the method of testing to represent ‘Cut out.’ Therefore the purpose of this study was to determine the difference in the mechanical properties between osteoporotic and osteoarthritic femoral heads in practical terms, in relation to the fixation achieved within them by the lag screw elements of two different implants used in the treatment of intertrochanteric fractures.

METHODS

The implants chosen to conduct the study with were the lag screw elements of the Dynamic Hip Screw (DHS) and DHS Blade, as they are both are placed within the femoral head during the treatment of an intertrochanteric fracture but employ different methods of fixation within it. Therefore they should provide a good representation of how two implants with different fixation methods behave within osteoporotic and osteoarthritic bone.

“Pushout” tests were performed as the means to investigate the fixation that was achieved within the femoral heads, as the most common mode of failure with these devices is ‘cut-out’[7]. This occurs when, after repeated loading, the lag screw element advances through the surrounding bone substrate and ‘cuts-out’ through the femoral head. In performing the pushout tests, the different force displacement curves produced by each implant and the amount of energy required to advance the lag screw element of each implant forward through the test materials were determined. The higher the amount of energy required to advance through the test material, the greater resistance to ‘cut-out’. In clinical practice, the teaching is to place implants within the femoral head with an ideal Tip Apex Distance of less than 24mm. [7] This results in these implants having to advance through roughly 10mm of bone before they ‘cut out’ through the femoral head.

To perform the pushout tests, a load was applied to the implant via the crosshead of the Tinius Olsen testing machine and as the implant advanced into the test material, a force-displacement curve was recorded. With a force displacement curve, the force is plotted along the vertical axis and the position of the implant is plotted along the horizontal axis. The peak force or pushout force on a force-displacement curve is the force at which the implant starts to move relative to the surrounding test material. This is the force at which failure occurs at the bone implant interface. The amount of energy required to reach a certain point on a force displacement curve can be determined by calculating the area under the curve to this point. Pushout tests were performed on the Tinius Olsen Tensile Testing machine at a strain rate of 2mm/min.

Figure 1

Figure 1. Customised Jig for Testing Femoral Heads Mounted on Tinius Olsen Testing Machine

Custom designed jigs (Figure 1.) were used to secure both the implants and the test specimens ensuring that the only movement that would occur during testing would be at the interface between the implant and the test material.

Ethical approval was obtained and femoral heads were collected from a local orthopaedic unit. Osteoporotic femoral heads were obtained from patients who had undergone a hemiarthroplasty for a fractured neck of femur and osteoarthritic femoral heads were sourced from the bone bank. The femoral heads that were sourced from the bone bank had been collected from patients who undergone a total hip replacement.

For this study, the femoral heads were classified as osteoporotic on the basis that the patients had undergone a hemiarthroplasty for a fractured neck of femur and osteoarthritic on the basis that the patient had undergone a total hip replacement for osteoarthritis. We do note that previous work on standardized bone density measurements of the hip have classified 'normal' bone as having a bone mineral density (BMD) of greater than 0.833 g/cm^2, 'osteopenia' as having values between 0.833 and 0.648 g/cm^2 and osteoporosis as having values lower than 0.648 g/cm^2. [8] The femoral heads in our study were also DEXA (dual energy x-ray absorbitometry) scanned prior to testing to determine their bone mineral density (BMD). To scan the femoral heads, they were placed in a water bath of depth of 15cm to represent human soft tissue. This was the same depth as that used to calibrate the DEXA scanner as per manufacturers' instructions. However as the cadaveric femoral heads in this study were DEXA scanned without their natural soft tissue covering, this could have an effect on the results obtained and could be a potential source of error. Therefore we believe a direct comparison of these results with the values quoted above for osteoporosis could be inaccurate, such that these results should only be used as a general guide and to compare the individual femoral heads within this study. This leads us to conclude that our definition of osteoarthritis and osteoporosis to be more appropriate for this study. Finally all the femoral heads were stored at -80 degrees before testing and were prepared to accept the DHS and the DHS Blade as in clinical practice, with a target tip apex distance of less than 25mm.

Statistical analysis was performed using sample t- test with minitab software.

RESULTS

The results for the pushout tests with the Dynamic Hip Screw (DHS) and DHS Blade are displayed in both figure and table form.

Figure 2

Figure 2. Peak Force achieved for Pushout with the DHS in Cadaveric Femoral Heads.

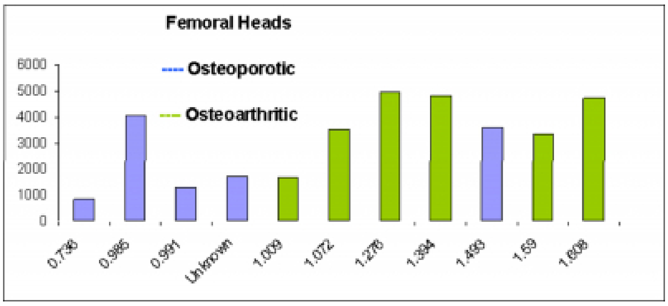

Figure 3

Figure 3. Force Displacement Curve Trendlines for both Osteoarthritic and Osteoporotic Femoral Heads with the DHS

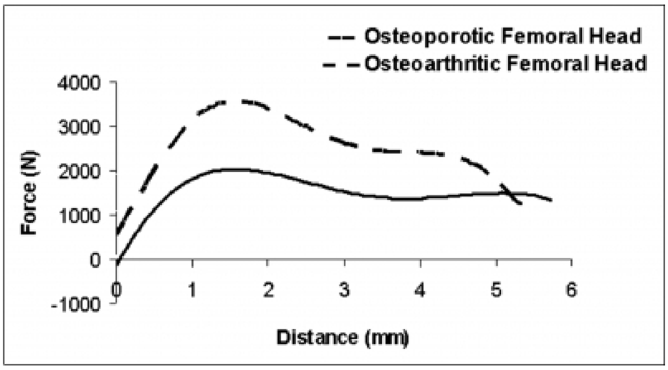

Figure 4

Table 1. Results for Peak Force achieved with the DHS in Oteoporotic Femoral Heads

Femoral Head	Density (g/cm^2)	Age	Sex	Peak Force (N)	Distance to Peak Force (mm)
22 OP	0.736	75	F	851	2.07
24 OP	0.991	75	M	1265	1.315
28 OP	Unknown	78	F	1728	1.528
20 OP	1.493	75	M	3608	1.328

Figure 5

Table 2. Results for Peak Force achieved with the DHS in Osteoarthritic Femoral Heads

Femoral Head	Density (g/cm^2)	Age	Sex	Peak Force (N)	Distance to Peak Force (mm)
5 OA	1.009	73	M	1666	1.11
18 OA	1.072	72	M	3536	1.95
37 OA	1.276	61	M	4940	1.455
7 OA	1.394	67	M	4820	2.57
9 OA	1.59	69	F	3344	2.4
17 OA	1.608	81	M	4730	2.09

The results for the DHS in the osteoporotic femoral heads (average density 1.0733+/-0.385g/cm^2 with 1 unknown) were that the mean peak force reached was 1863 +/- 1217 Newtons and that the mean distance to peak force was 1.560 +/- 0.3535 mm.(Table.1) In the osteoarthritic bone (average density 1.32483 +/-0.25351g/cm^2), the DHS reached a mean peak force of 3839.33 +/- 1267.06 Newtons and the mean distance to peak force was 1.92917 +/- 0.558 mm (Table.2), which was longer than with the osteoporotic bone

Figure 6

Figure 4. Peak Force achieved for Pushout with the DHS Blade in Cadaveric Femoral Heads

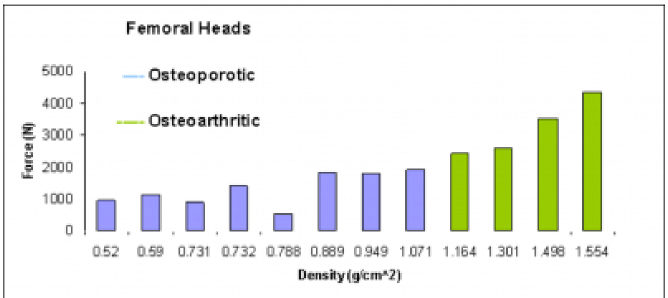

Figure 7

Figure 5. Force Displacement Curve Trendlines for both Osteoarthritic and Osteoporotic Femoral Heads with the DHS Blade

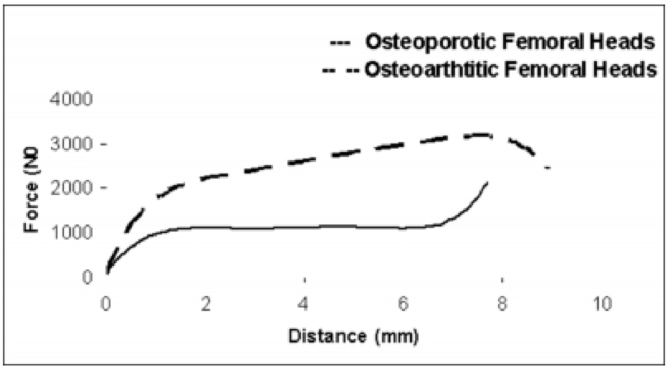

Figure 8

Table 3. Results for Peak Force achieved with the DHS Blade in Oteoporotic Femoral Heads

Femoral Head	Density (g/cm^2)	Age	Sex	Peak Force (N)	Distance to Peak Force (mm)
23 OP	0.52	77	F	947	1.268
13 OP	0.59	94	F	1140	6.698
27 OP	0.731	78	F	882	7.148
1 OP	0.732	83	F	1388	7.252
36 OP	0.788	72	M	523.5	7.298
26 OP	0.889	78	F	1830	4.5
34 OP	0.949	56	F	1778	5.498
25 OP	1.071	61	F	1930	7.46

Figure 9

Table 4. Results for Peak Force achieved with the DHS Blade in Osteoarthritic Femoral Heads

Femoral Head	Density (g/cm^2)	Age	Sex	Peak Force (N)	Distance to Peak Force (mm)
10 OA	1.164	52	M	2435	8.18
6 OA	1.301	83	M	2612	8.6
12 OA	1.498	79	F	3540	7.664
16 OA	1.554	74	M	4355	7.36

The results for the DHS Blade in the osteoporotic femoral heads (average density 0.78375 +/-0.18263g/cm^2) produced a mean peak force of 1302.31 +/- 512.596 Newtons with an average distance to peak force of 5.89 +/- 2.138 mm.(Table.3) The results for the DHS Blade in the osteoarthritic femoral heads (average density 1.37925 +/-0.1799g/cm^2) produced a mean peak force of 3235.5 +/- 889.86 Newtons with an average distance to peak force of 7.951 +/- 0.549 mm. (Table.4)

DISCUSSION

This study was conducted to investigate the fixation that the lag screw elements of two different implants used in the treatment of intertrochanteric fractures could achieve within osteoporotic and osteoarthritic femoral heads as a practical means of comparing the mechanical properties of osteoporotic and osteoarthritic bone. We recognise that our definition of osteoporosis and osteoarthritis is arbitrary and some of the femoral heads classified as osteoporotic have a BMD above the quoted value of 0.648 g/cm^2 in the literature [8], however we believe our definition to be suitable for the purpose of this study. We do believe that our study revealed some interesting findings. The first result that we would like to note is that although there is a generalised upward progression in peak forces with both implants as the density of the femoral heads increases, the relationship is not linear with some individual variations. These individual variations may be due to a number of factors that can affect bone quality such as the age or sex of the patient from whom the bone sample was taken as it was impossible to match all these variables in this study. Another reason for the variations may be that as widely accepted, cadaveric specimens are not uniform and this can result in specimens with vastly heterogeneous bone quality and strength. [11,12,13] The next point worth noting about the results is the large and statistically significant difference in the peak forces achieved by each implant within the osteoporotic and osteoarthritic femoral heads and this was even with the small study size here. (DHS group - p value of 0.048, DHS Blade group - p value of 0.016). The fact that both implants reach significantly higher peak forces in the osteoarthritic femoral heads and that these peak forces are reached later in the curve confirms that with osteoarthritic bone, a much greater amount of energy is required to displace the implants within the bone and bring about failure. Therefore the osteoarthritic bone offers vastly superior resistance to implant displacement within it and therefore failure. Another finding was that when analysing the individual force displacement curves and then the overall trendlines for each implant as demonstrated in both figures 3 and 5, it was noted that both the DHS and the DHS Blade produced similar force displacement curves with a similar overall pattern of failure within both the osteoarthritic and osteoporotic bone except that for the fact that with the osteoarthritic bone, the peak forces reached were much higher and occurred later in the curves than with the osteoporotic bone. Therefore, although the bone density may decide the peak force at which failure occurs, it is the implant that influences the pattern of failure with the same overall pattern of failure evident with both implants in both the osteoporotic and osteoarthritic bone.

We recognise that this study had a number of limitations. We realise that the numbers of femoral heads within each group was relatively small but statistical significance was reached with our study. There were a limited number of femoral heads available and if problems were encountered during testing with a femoral head, then that femoral head was lost to the study and unfortunately not replaced. This resulted in the uneven number of femoral heads in each group. We also recognise that the definition of osteoporosis and osteoarthritis was arbitrary and that if we were true to the clearly defined values for osteoporosis within the literature [14], very few of our femoral heads would have been defined as osteoporotic but again it is worth mentioning that the femoral heads that we labelled osteoporotic were all harvested post hemiarthroplasty from patients who had sustained a femoral neck fracture secondary to osteoporosis. Another factor was that although we conducted the DEXA scans as accurately as possible, we could not eliminate completely the error that could occur as a result of the femoral heads not being covered by their normal soft tissue envelope while being scanned and therefore classifying the femoral heads by their absolute density values may have lead to some femoral heads being inaccurately classified. We also recognise that in the clinical environment, implant failure occurs with cyclical loading but that here pushout studies were deemed sufficient to demonstrate the resistance that occurs to implant displacement during ‘cut out’.

One final point is that with regard to the trendline shown in figure 5. for the DHS Blade in the osteoporotic bone, not all the force displacement curves were allowed to progress the same distance, as some were stopped earlier after their peak forces were reached and therefore only a few were allowed to progress beyond 6mm until their peak forces were reached. This may account for the sudden increase in the values at the end of the curve, as if all were allowed to proceed an equal distance then the increase would be much less pronounced

CONCLUSION

The results of this study have demonstrated, that as expected when the density of the bone increases, in general the implants achieve better fixation within it and require a higher force and a greater amount of energy to bring about failure. However this study also demonstrates that it is the implant that dictates the pattern of failure and not the bone, as the pattern of failure remains constant in both osteoporotic and osteoarthritic bone for each implant.

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