Influence of stem geometry on the stability of polished tapered cemented femoral stems

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Polished, tapered stems are now widely used for cemented total hip replacement and many such designs have been introduced. However, a change in stem geometry may have a profound influence on stability. Stems with a wide, rectangular proximal section may be more stable than those which are narrower proximally. We examined the influence of proximal geometry on stability by comparing the two-year migration of the Exeter stem with a more recent design, the CPS-Plus, which has a wider shoulder and a more rectangular cross-section. The hypothesis was that these design features would increase rotational stability.

Both stems subsided approximately 1 mm relative to the femur during the first two years after implantation. The Exeter stem was found to rotate into valgus (mean 0.2˚, SD 0.42˚) and internally rotate (mean 1.28˚, SD 0.99˚). The CPS-Plus showed no significant valgus rotation (mean 0.2˚, SD 0.42˚) or internal rotation (mean -0.03˚, SD 0.75˚). A wider, more rectangular cross-section improves rotational stability and may have a better long-term outcome.

Polished tapered stems are now widely used for cemented fixation. This is mainly because of the good long-term results of the Exeter stem (Stryker, Newbury, UK).1 Its low failure rate has been attributed to small amounts of early subsidence which are thought to reinforce the bone-cement interface, thus stabilising the stem. While the results from the designing centre are excellent, these stems still fail, particularly when used in younger patients.1-4

As a consequence of the success of this stem, a number of new polished tapered stems have been introduced by other manufacturers. Many of these devices differ from the Exeter in terms of geometry. Computer models, however, suggest that a change in stem geometry can have a profound effect on stability.5 Wider, un cemented stems with a more rectangular cross-section have been shown to be more stable.6 Cemented polished tapered stems of this design may also be more stable.

In order to determine whether geometry does indeed influence stability, we compared the early migration of the Exeter stem with that of a relatively new device, the CPS-Plus stem (Endoplus, Swindon, UK). Migration was measured using radiostereophotogrammetric analysis (RSA). This stem is different to the Exeter model, particularly in its proximal geometry. It has an expanded lateral shoulder and a wide rectangular cross-section with sharper corners; in contrast, the Exeter has a narrow shoulder and relatively rounded corners in cross-section (Fig. 1). The manufacturers suggest that these design features will improve axial subsidence and rotational stability. The CPS-Plus also incorporates a proximal centraliser which has been shown to improve cement compression.7

Patients and Methods

We studied two groups of patients; 21 had received an Exeter stem and 21 a CPS-Plus model. All patients had primary osteoarthritis and were recruited from the routine waiting list. There was no age limit for recruitment. The local ethics committee approved the protocol and informed consent was obtained before participation. Three surgeons (DWM, PMS, PF) undertook the procedures on both groups over a two-year period from November 1999 at the same centre. All operations were performed through a modified Hardinge approach with the patient in the lateral position. All femoral components were fixed with CMW3G cement (DePuy, Leeds, UK), using third-generation cementing. The wound was drained in all cases. The patients underwent routine post-operative rehabilitation. Details of both groups are shown in Table I.
The sample size was based on a power calculation made from Altman’s nomogram. A difference of interest of 0.4 mm was chosen, based upon the work of Kobayashi et al., which suggests that a vertical migration rate of more than this is associated with a higher rate of aseptic loosening. A standard deviation of 0.3 mm was chosen, as this was the value determined during a previous RSA study which examined the migration of the Exeter stem. The power calculation indicated that a total of 20 patients were required per group ($\alpha = 0.05$, $\beta = 0.9$, $2n = 40$).

RSA measurement. Our RSA system has been previously described and has a clinical accuracy of 0.1 mm. A femoral co-ordinate system was established by implanting tantalum beads at standardised anatomical sites on the femur during surgery. All tantalum beads were placed in cortical bone. A marker ball was also placed in the cement restrictor. As previously reported, our RSA system does not require modification of the implant; geometric algorithms were used to identify the locations of the stems.

RSA radiographs were taken with the patient standing, weight-bearing equally on both legs. Measurements were made post-operatively, and then at three, six, 12 and 24 months. The initial position of each stem within the femoral canal was determined using the RSA data from the post-operative measurement. Our method for calculating anteversion of the stem has previously been described.

From the RSA data the three-dimensional migration of the stem relative to the host bone was calculated over a 24-month period. This was represented as three planar displacements of three landmarks on the stem and its internal and valgus rotation. The landmarks of interest were the head and tip.

A single sample $t$-test was used to detect significant deviations of the mean migrations from zero, zero representing the immediate post-operative measurement. Descriptive statistics were used to examine the differences in the vari-
variables of planar and rotational migration between the two groups. Specific key variables were considered as the main outcomes and analysed using a two-group independent $t$-test. The key variables were the subsidence of the tip, indicative of the overall stem subsidence, and valgus and internal rotation of the stem. All calculations were performed using SPSS 11.5 (SPSS Inc, Woking, UK). The results were regarded as significant when $p < 0.05$.

**Results**

There were no significant differences between the Exeter and CPS-Plus stems in their initial placement in the femoral canal. The positions of the tips of the stems relative to the central axis of the femur were similar ($p = 0.54$, Fig. 2) between the two groups, as were those of the shoulder ($p = 0.36$). There was also no significant difference in anteversion between the two groups ($p = 0.87$). The stems in the Exeter group were anteverted by a mean of 5.8˚ (SD 2˚) those in the CPS-Plus group were anteverted by a mean of 9.0˚ (SD 3˚).

For both groups no significant migration of the restrictor was detected in any plane (Fig. 3, Table II). The Exeter stem subsided, rotated into valgus and internally rotated during the two years (Figs 3 and 4, Table II). The CPS-Plus stem subsided without any significant rotation (Figs 3 and 4, Table II).

Both stems subsided a similar amount over the two-year period of study (Figs 3 and 4, Table III), with no significant difference between the two groups ($p = 0.23$). The tip of the Exeter stem subsided by a mean of 0.86 mm (SD 0.50), whereas that of the CPS-Plus stem subsided by a mean of 0.67 mm (SD 0.56). Although the Exeter stem rotated into valgus by a mean of 0.20˚, the CPS-Plus stem demonstrated no significant valgus rotation (mean -0.07, SD 0.29). There was a significant difference in valgus rotation between the two groups at two years ($p = 0.034$, Table II).

The Exeter stem showed a mean internal rotation of 1.28˚ (SD 1.00) during the two years (Table III) and the CPS-Plus stem displayed no significant internal rotation (-0.03, SD 0.75). These differences in internal rotation were highly significant ($p < 0.001$, Table III).

**Discussion**

This study demonstrates that proximal stem geometry influences rotational stability for cemented, polished
The three planar migrations of the tips of the stems compared with those of the cement restrictor for the Exeter and CPS-Plus stems a) anterior migration, b) medial migration and c) superior migration (means and SDs are shown). Positive migrations correspond to the directions given for each y-axis.
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The CPS-Plus stem is more rotationally stable than the Exeter stem, exhibiting negligible internal rotation during the first two years after implantation. It also undergoes less valgus rotation.

For both stems all migrations occurred within the cement mantle, as the marker beads placed in the cement restrictors showed no significant change. All stems in both groups were initially placed in similar positions in the femoral canal. Stems of both designs subsided a similar amount, but the Exeter stem moved into valgus as it subsided, while the CPS-Plus stem subsided axially within the femoral canal.

Internal rotation results from the action of the joint reaction force, which is directed mainly posteriorly and inferiorly.\textsuperscript{13,14} This applies a large, internally rotating
torque to the stem, which is maximal when standing up from a sitting position and while climbing stairs. All polished tapered stems will also experience a laterally directed force as they subside. This occurs as the stem subsides onto the calcar, cement compression medially forcing the shoulder of the stem to migrate laterally and rotating it into valgus.

The enhanced rotational stability of the CPS-Plus stem can be explained by its proximal geometry. This is wider in cross-section with sharper corners than the Exeter. As a result, it is better able to resist the torsional load which is exerted by the joint reaction force. It is also better able to resist lateral forces. Whereas the shoulder and head of the Exeter are pushed laterally as the stem subsides onto the calcar, cement compression medially forcing the shoulder flare of the CPS-Plus stem subsides axially within the femoral canal. This is probably due to the shoulder flare of the CPS-Plus stem.

Large amounts of posterior migration of the head, and therefore internal rotation, may be detrimental in the long-term as this is a probable cause of failure in matt cylindrical stems such as the Charnley. It may also be detrimental in polished tapered stems in the long term. Internal rotation over time may cause cement deformation and allow gaps to form at the postero-medial and antero-lateral corners of the prosthesis-cement interface proximally. This, in turn, may allow fluid and polyethylene debris to pump in and out of these gaps during cyclical loading. Recent studies have suggested that fluid pumping can result in pressure-induced osteolysis, which may be an important mechanism of failure. In addition, fretting has been observed on the postero-medial and antero-lateral portions of the shoulders of retrieved Exeter stems, suggesting that internal rotation is a mechanism of failure. Valgus rotation may also be detrimental to stem survival by causing gaps to form medially. This would allow fluid pumping to occur, which may be prevented by axial subsidence of the stem.

The designers of the CPS-Plus stem aimed to improve rotational stability and promote axial subsidence. This study demonstrates that they have achieved this. However, both stems subside a similar amount, which suggests that improving cement pressurisation has only a marginal influence on stability.

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References


