Mechanism for Rotational Stability in Cemented Femoral Implants

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Introduction
Despite the long history and clinical evidence demonstrating cemented femoral implants are performing excellently [1] it is still important to understand and quantify the mechanisms for their function to allow for future development. Modifying the design of femoral implants requires the characterisation of existing clinically successful implants. Previously stem geometry has been shown to significantly affect rotational stability. This study identifies the mechanical characteristics required for rotational stability in cemented implants through changing the effective stem length. The stem investigated was an Exeter 44-1 manufactured by Stryker.

Methods
Ten cement mantles were produced which were tested at 9 different lengths. Changes to implant length were simulated by removing length from the distal portion of the cement mantle, leaving the distal implant in the air providing no mechanical stiffness. A precision saw was used to cut the cement mantle, taking approximately 15mm long segments from the distal end of the cement mantle, and then the testing regime was repeated. The 44-1 geometry was simulated for stem lengths of between 40 to 150mm. At each simulated implant length the system was disassembled and reassembled five times and a test performed. A single test is comprised of a pre-cycling phase in which the implant is loaded with stair climbing forces for 100 cycles, then the three testing protocols are performed five times each. Each loading protocol is performed ten times and the torque and angular displacement recorded for calculation of rotational stiffness. After each loading protocol the implant is extracted and the extraction force recorded for a total of 15 values per test. Mechanical testing was carried out on the implant-cement construct with three different loading profiles, single leg standing, rising from a chair and stair climbing. The single leg condition was simulated with a 0.4-2KN (~200kg) compressive force. The chair rising was simulated with a torque of 2-19Nm and compressive force of 0.4KN. Stair climbing was simulated with a combination of torque and compressive force from the previous two loading conditions. Rotational stiffness was measured during the chair rising and stair climbing loadings.

Results
Shortening the stem increased the rotational stiffness, which leads to a design philosophy that the shorter the implant, whilst maintaining proximal geometry, the greater the capability to resist torsional forces such as those in stair climbing.

Rotational stiffness was significantly larger (p<0.05) in combined loading when comparing similar implants lengths. Under both loading conditions the implant increased in rotational stiffness as the implant became shorter except at 115mm.

Under pure rotational loading there is very little difference in stiffness between 150mm and 85mm, except at an implant length of 115 mm where there was a significant drop in rotational stiffness (p<0.05). At 115mm the implant has distinct flats in the anterior-posterior plane, distally from there the implant is approximately round. From 100mm progressing proximally the rotational stiffness increases significantly (p<0.05) at a 100mm length implant is equivalent to a full length stem. Under the combination loading protocol, again at an implant length of 115mm, there was a significant drop in rotational stiffness (p<0.05) which recovered slightly at 100mm but was less than the original stiffness at 150mm. From 115mm progressing proximally the rotational stiffness increases significantly (p<0.05). Between 100mm and 85mm lengths stability is equivalent to the full length stem.

Discussion
Modifying the design of femoral implants, in an effort to solve further clinical indications, requires characterisation of existing (clinically successful) implants. The experimental work carried out here has quantified the rotational characteristics of a clinically successful implant. Shortening of the femoral component (Exeter 44 No.1) did little to affect the rotational stability of the implant. The testing protocol is this study completely isolates the proximal stem and shows that rotational stability results from the proximal stem. There is clinical comment on proximal stability and the requirement for it [2, 3], but no studies on the mechanism behind proximal stability in cemented implants.

The mechanism for the implant becoming more rotationally stable is that the same force is distributed over an area of cement which is more capable of resisting torque. In the case of femoral implants each implant has a specified geometry which will result in a common torsional rigidity if the anterior-posterior plane profile is maintained. However if the implants are shortened distally then the overall average distance, for the calculation of the resistive moment (equivalent rotational stiffness), will increase. Practically, implant manufacturers change implant cross section when changing implant length, therefore as part of the pre-clinical testing of these implants it is vital to ensure a minimum rotational stiffness is achieved.

This paper presents a mechanism for clinically observed rotational stability and explains the mechanical characteristics required for rotational stability in cemented implants. Therefore for development of future implants to address further indications designers need to consider the primary finding of this work that shortening a femoral implant, whilst maintaining proximal geometry, does not reduce the performance under torsional loading conditions.

References