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Effect of hoop stress fracture on micromotion of textured ingrowth stems for radial head replacement

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Background: Successful bone ingrowth around cementless implants requires adequate initial stability. Hoop stress fractures during stem insertion can potentially hinder prosthesis stability.
Hypothesis: We hypothesized that an oversized radial head prosthetic stem (1 mm ''too large'' and causing a hoop stress fracture during insertion) would result in an unacceptable amount of micromotion.
Materials and methods: Grit-blasted radial head prosthetic stems were implanted into cadaveric radii. Rasp and stem insertion energies were measured, along with micromotion at the stem tip. The sizes were increased until a fracture developed in the radial neck.
Results: Prosthetic radial head stems that were oversized by 1 mm caused small cracks in the radial neck. Micromotion of oversized stems (42 ± 7 μm) was within the threshold conducive for bone ingrowth (<100 μm) and not significantly different from that for the maximum sized stems (50 ± 12 μm) ($P \geq .4$).
Discussion: Contrary to our hypothesis, hoop stress fractures caused by implantation of a stem oversized by 1 mm did not result in loss of stability. Stem micromotion remained within the range for bone ingrowth and was not significantly diminished after the fracture. This suggests that if a crack occurs during the final stages of stem insertion, it may be acceptable to leave the stem in place without adding a cerclage wire.
Conclusion: A small radial neck fracture occurring during insertion of a radial head prosthetic stem oversized by 1 mm does not necessarily compromise initial stability.
Level of evidence: Basic Science Study, Biomechanical Study.

Keywords: Radial head prosthesis; fracture; hoop stress; elbow stability; micromotion

Press-fit, cementless implants are commonly used in radial head arthroplasty. Maintenance of long-term fixation and radial head stem stability depends on multiple factors, including initial stability and the presence of an environment that promotes bone ingrowth. Although no data exist specific to the proximal radius, previous micromotion analyses have shown impaired bone ingrowth and formation of an impeding fibrous tissue layer with implant micromotion over 100 to 150 μm.[12]

As with insertion of any prosthetic stem, fracturing can occur because of hoop stresses. The risk of fracturing the radial neck is higher if the original fracture extended past the level of the cut made in the radial neck. Hoop stress

The Mayo Clinic Institutional Review Board that convened on September 17, 2007, approved the project, entitled ''Stem Length and Neck Resection on Fixation Strength of Press Fit Radial Head Prosthesis'' (IRB protocol number 08-007527).

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fractures can theoretically hinder prosthesis stability. However, nothing has been published concerning how to manage these fractures around radial head prostheses. Nor can one logically conclude how to manage hoop stress fractures of the radial neck from the literature on similar fractures involving the femoral neck around hip prostheses, because the literature is controversial.[4,5,9]

Therefore, on the basis of current knowledge, no certainty exists as to what a surgeon should do if a crack develops during insertion of a radial head prosthesis. The purpose of this study was to test the hypothesis that hoop stress fractures caused by ''oversizing'' of radial head prosthetic stems by 1 mm compromise initial press-fit stability, leading to increased stem micromotion.

Materials and methods

Of the 16 fresh-frozen human radii that were tested, 10 were used for data analysis because the other 6 failed to fracture with the largest stem size. The sample size was estimated based on micromotion data obtained from the first 5 radii used in this study, in which the standard deviation of the micromotion differences between the optimally sized stems and stems that were oversized by 1 mm was calculated to be 31 μm. Assuming similar variability would be observed in the full study, then using a sample of $n = 10$ and $\alpha = 0.05$, we would have 80% power to detect a significant difference in means equal to at least 1 SD or 31 μm of micromotion between these 2 stem sizes and a difference of 18 μm of micromotion between the optimally sized stems and stems oversized by 1 mm. The mean age of the donors was 73 years (range, 47-86 years). The intact elbows were thawed overnight at room temperature before preparation. The specimens, which were supplied by our institutional cadaver bank, had no evidence of bony pathology. The elbow joint was dissected free of soft tissue before disarticulation. The proximal third of the radius was transected and securely potted in an aluminum tube with polymethyl methacrylate. We maintained exposure of each radial tuberosity as a landmark to ensure consistency in alignment. A micro-sagittal saw was used to transect the radial head at the neck.

Each specimen was implanted with a grit-blasted titanium stem (Anatomic Radial Head System; Acumed, Hillsboro, OR, USA). We tested 5 stem diameters, ranging from 6 mm to 10 mm in 1 mm increments. Our experimental protocol was designed to simulate actual intraoperative technique and followed a stepwise insertion with sequentially increasing force. A previously described custom-made slap hammer with removable weights was used.[3] The weight options were 0.5, 0.75, and 1 kg, each of which was dropped from a height of either 0.1 or 0.15 m (Fig. 1).

Kinetic energy measurements

The following formula was used to calculate the individual potential energy of each tap of the slap hammer, and all the individual values were added together to determine the final energy of insertion for each diameter of rasp and stem:

$$\text{Potential energy} = MgH$$

where M is mass (in kilograms), $g = 9.8$ m/s^2, and H is height (in meters).

Our method of determining kinetic energies for each rasp and stem depended on the maximum weight and height required to sink the implant. Each sample's testing sequence commenced with the lowest mass (0.5 kg) and the minimal height (0.1 m). If the rasp/stem did not adequately sink after 12 taps, the first parameter changed was the height. The same mass (0.5 kg) was then dropped from a height of 0.15 m until insertion occurred or 12 taps elapsed without adequate insertion. The next parameter changed was the mass (it was increased to 0.75 kg), and the height was reverted to 0.1 m again. This formulaic progression was instituted until the combination of maximum height and weight (0.15 m and 1.0 kg) was reached. Data analysis was performed on the 10 radii that fractured (fracture was not achieved in 6 specimens). The rasp or stem size that cracked the radius was categorized as oversized (maximum + 1), whereas 1 diameter increment below it was categorized as the maximum size (maximum). Each rasp/stem size within a specimen's testing sequence was assigned a label relative to the maximum. For instance, the following is an example of how we categorized a specimen that had cortical disruption at 10 mm: 6 mm (maximum − 3), 7 mm (maximum − 2), 8 mm (maximum − 1), 9 mm (maximum), 10 mm (maximum + 1).

Testing micromotion

Prosthetic tip micromotion was measured with a custom-made device previously reported by Moon et al.[11] A metal plate (6.5 mm thick and 100 mm in diameter) was fitted around the radial head stem. This plate-specimen construct was rigidly fixed in the machine. The aluminum tube in which the radius was cemented was first inserted into another, slightly larger but thicker, aluminum tube. A collar clamp was then tightly secured around the uppermost portion of this second tube (sleeve).

This sleeve/pot component was then placed in the machine, flush against a surface, which further ensured no downward motion once the axial load was applied. Lastly, a modified collar clamp was secured around the base of the sleeve to further ensure there was no motion other than the micromotion experienced by the prosthesis. A 100-N load was applied pneumatically to the center of the stem to simulate a joint compressive force and to resist motion. A radial load of 10 N was applied to a point 4.5 cm from the center of the plate by a pneumatic device consisting of a load cell and an axial load applicator. This load provided the bending moment (45 N-cm) that produced the measured micromotion (Fig. 2). A mounted laser displacement sensor recorded vertical displacement of the metal plate at a point 4.5 cm from the center of the stem, opposite from the eccentric load.

Simple geometry allowed for the conversion of plate displacement to stem micromotion, as outlined in Figure. 2. To distinguish compliance in the test apparatus from prosthetic micromotion, we measured the stiffness of the device by fixing it in a solid metal structure. After application of a 45 N-cm bending moment, there was no measurable deflection or displacement detected by the laser.

Certain implants are at risk of being subjected to characteristic abnormal loading patterns. In the elbow, posterolateral rotatory subluxation accounts for the majority of displacements that would result in eccentric loading (tilting) of a radial head prosthesis. In a previous study using this model,[11] the authors tested micromotion in 4 different directions of eccentric loading. It was found that loading direction had no significant effect on micromotion