Development of a half-ring diametral test to detect stress concentrations in cortical bone

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PURPOSE:

Detecting variations in strength of bones affected by defects requires a large number of samples. Testing a large number of whole bone samples is impractical. In an effort to create a more practical model for testing in diaphyseal bones, some researchers have used a diametral test loading rings of cortical bone in compression. However, the problem with a diametral compression test of a cortical bone ring is that the peak stresses in the ring occur at the load points (at 0° & 180° around the ring), and the peak tensile stress occurs at the inner diameter of the cortical ring.[1] It would be invalid to locate the cortical bone defects directly at the load points because that creates an additional stress concentration artifact from the loading apparatus. Cortical bone is weakest in tension, but the peak tensile stresses on a whole bone subjected to bending or torsion occurs on the outer surface of the cortex, which is stronger than the inner surface. The ideal location for the defect in a cortical ring would be at the 90° or 270° points around the ring, Fig. 1. But the peak stresses do not occur at that location in a diametral test, so the test is not very sensitive to defects located 90° to the applied axial load. If the cortical ring is cut in half, so the 0° and 180° load points are free ends of the half ring, then the peak tensile stress will occur at the 90° position and on the outer surface, Fig. 1. Our hypothesis is that the half ring model will produce the best sensitivity to defects at the 90° location and compared to full ring segments better simulate the sensitivity of a whole bone defect test in torsion and bending.

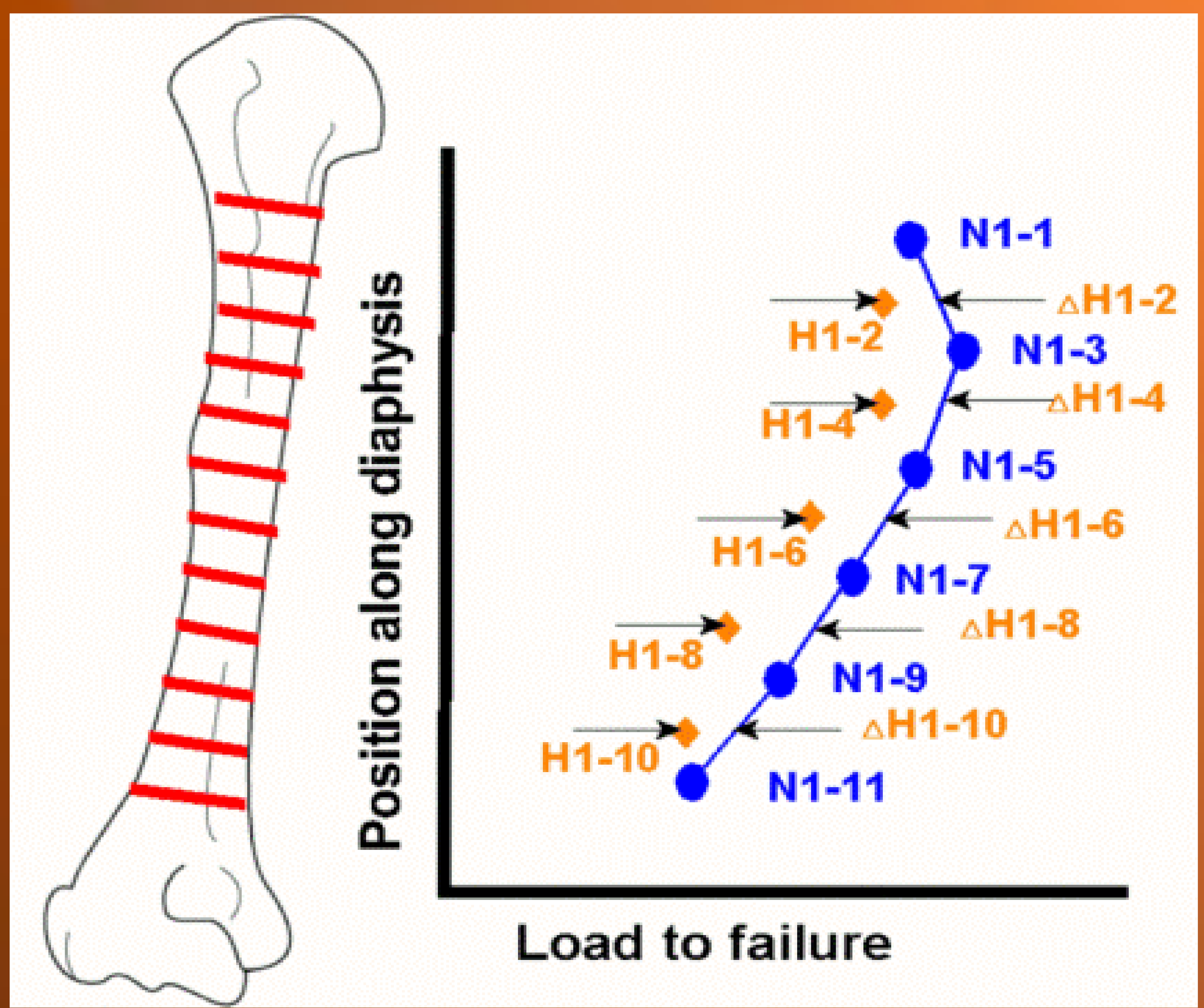

Figure 2 – The odd numbered half rings with no holes defined the profile along the diaphysis to which the holed segments were compared.

METHODS:

In order to define the sensitivity of the full vs. half ring tests and to compare those models to full specimen bend and torsion tests, a standard tube of uniform materials was chosen. 20 polycarbonate tubes of 19 mm diameter (3/4") with a 3 mm wall (1/8") were prepared in 25 cm lengths for 4 point bend and axial torque testing. 12 tubes had holes with 10-24 threads applied at mid shaft. 6 tubes were tested in bending with no screw holes, 6 with screw holes; 5 were tested in torsion with no screw holes, 5 with screw holes. Next 21 rings of 1 cm length were prepared from the polycarbonate tubes. 14 had 10-24 threaded holes and 14 had no holes. 7 full rings with holes and 7 without holes were tested in diametral compression. The remainder of the rings were cut in half and tested as half rings, 7 with no holes and 7 with holes.
The % reduction in load to failure was calculated from the means of the holed vs. no-holed tubes and rings from each test. The standard deviation was estimated by calculating the deviation of each holed specimen from the mean of the non-holed specimens. Strength reduction % of whole tube tests to the diametral tests of whole and half rings were compared. Next human cadaveric humeri had lines drawn along the anterior surface of the diaphysis. The diaphyses was then cut into rings 1 cm long. The line on each ring served to maintain orientation. Each ring was then cut along the sagittal plane. The medial and lateral half rings were labeled and numbered.

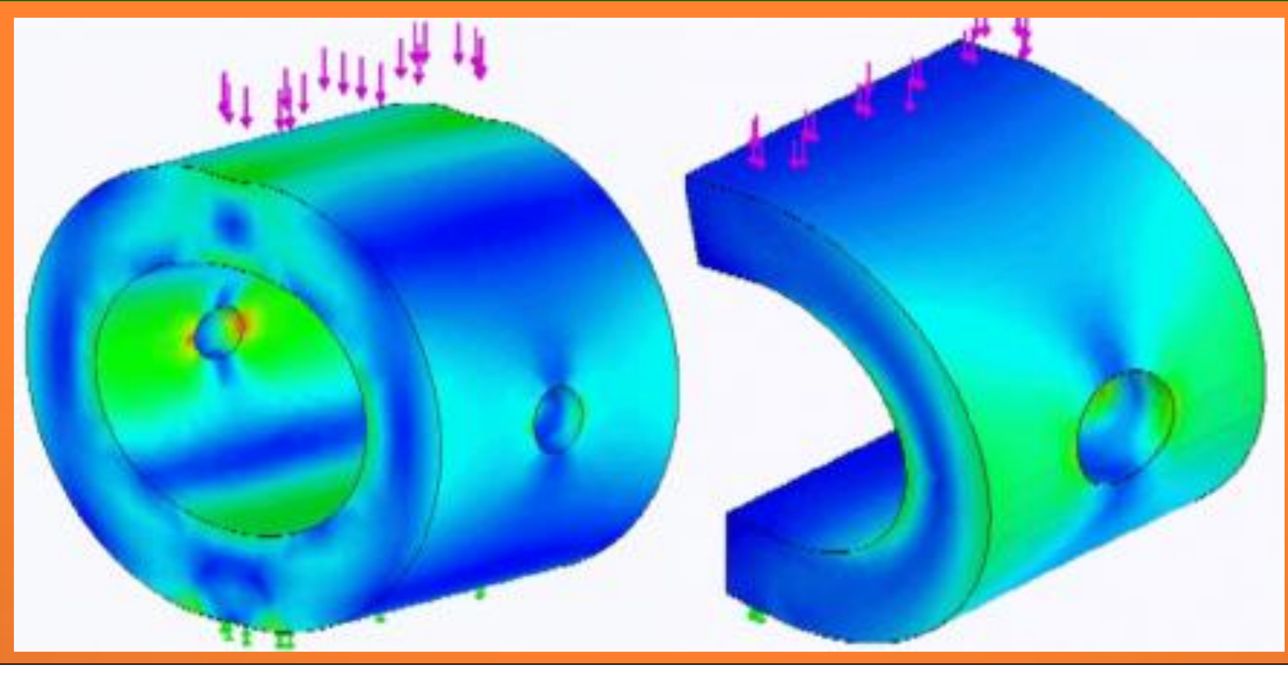

Figure 1 – Finite element model shows stress distributions in full and half rings in diametral compression

The odd numbered specimens were left intact, the even numbered specimens were drilled and tapped for 3.5 mm bone screws. 6 bones produced 246 half rings, 126 with no holes, 120 with holes. A theoretical value for the strength of each even numbered segment was extrapolated based on the values of the adjacent odd numbered segments. The difference between this value and the measured value for the even numbered segment with a hole were compared to express a % change which could be attributed to the screw hole, Fig. 2.

RESULTS:

The % reduction in strength for the whole tubes in bending and torsion are compared to the full and half ring tests in Fig. 3. The reduction in strength for the full ring test was significantly less than the reduction seen in both the 4 point bend, $P < 0.04$, and torsion, $P < 0.002$, tests of the whole tubes. The half ring test was not significantly different from the 4 point bend and was only slightly different from the torsion test, $P < 0.05$. The % loss of strength for the half ring tests in the cadaver bones using the half ring test was 42.9% ± 19.5.

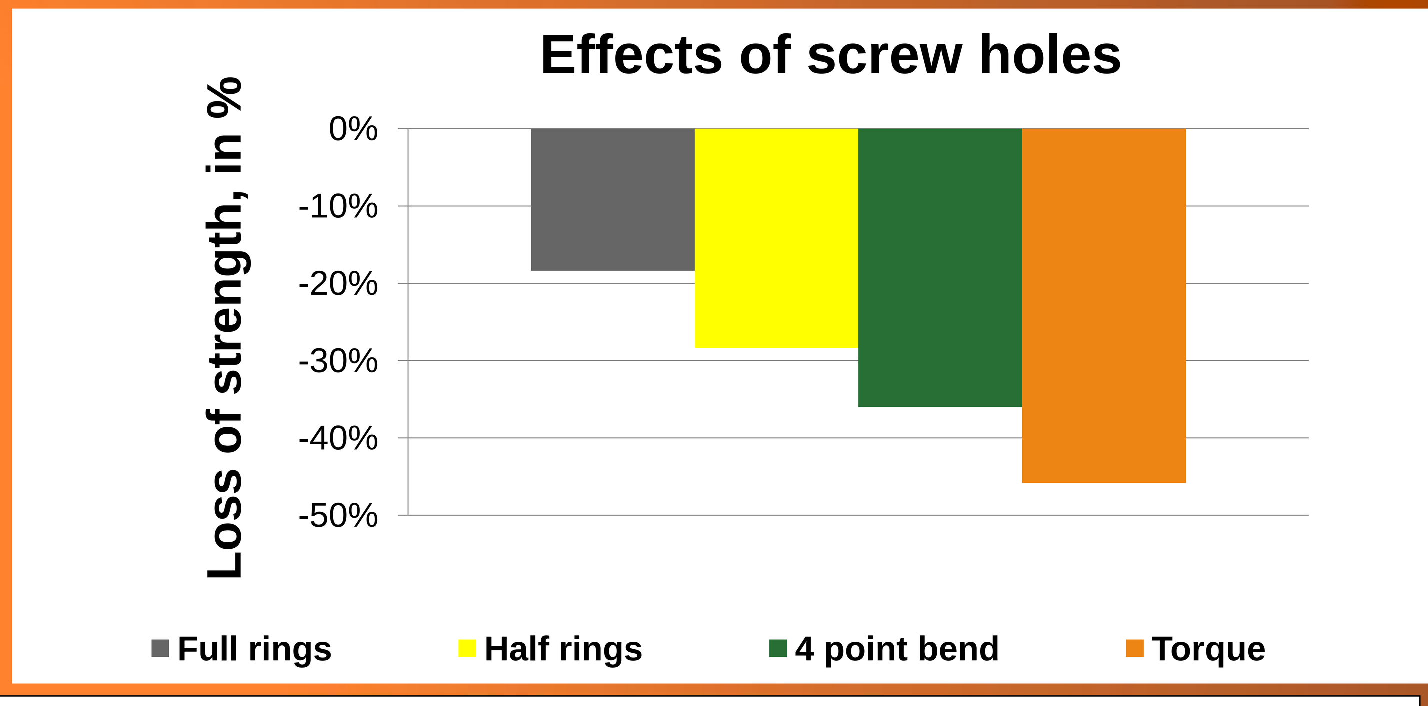

Figure 3 – The sensitivity of the polycarbonate half ring test was much closer to that of the whole tube tests than that of the full ring tests.

DISCUSSION:

The sensitivity to detect the effect of screw holes for the half ring test was significantly better than for the full ring diametral test. Using this test in the cadaver bones gave results which were close to reported values for the reduction of strength in torsion and bending for cadaver bones.

SIGNIFICANCE:

The half ring diametral compression test provides a means of testing a large number of samples from a small number of bones with adequate sensitivity to detect the effects of small localized defects in diaphyseal bone.

ACKNOWLEDGEMENTS:
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