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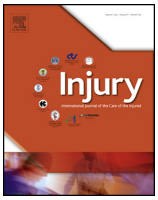

Does the relative density of periarticular bone influence the failure pattern of intra-articular fractures?

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ABSTRACT

Introduction: The architecture of joints almost certainly influences the nature of intra-articular fractures, and the concavity is much more likely to fail than the associated convexity. However, local differences in periarticular bone density potentially also plays a critical role. The purpose of this study was to investigate if there was any difference in periarticular bone density in intra-articular fractures between the two opposing joint surfaces, comparing the convexity to the concavity.

Materials and methods: We retrospectively identified a series of 1003 intra-articular fractures of the hip, knee, and ankle; 129 of these patients had previously undergone CT scanning during their routine clinical assessment. Periarticular bone density was assessed using Hounsfield Units (HU) as a measure of the composite density of the adjacent bone. Bone density was compared between the opposite sides of each joint, to determine if a relationship exists between local bone density and the risk of articular surface fracture.

Results: There was a statistically significant difference in density between the two opposing surfaces, with the convexity 19% more dense than the concavity ($p = 0.0001$). The knee exhibited the largest difference (55%), followed by the hip (18%); in the ankle, an inverse relationship was observed, and the concave surface was paradoxically denser (5%). There was no significant difference between those cases where the concavity failed in isolation compared to those where the convexity also failed ($p = 0.28$).

Conclusion: When the results were pooled for all three joints, there was a statistically significant higher local bone density demonstrated on the convex side of an intra-articular fracture. However, while this relationship was clearly exhibited in the knee, this was less evident in the other two joints; in the ankle the reverse was true, and the local bone adjacent to the concavity was found to have greater density. This suggests local bone density plays only a minor role in determining the nature of intra-articular fractures.

Introduction

When the major joints of the lower limb are subjected to an abnormal axial load to the point of failure it is most often the concave side of the joint that fractures [25]. In clinical practice fractures of the tibial pilon, tibial plateau, and acetabulum far more commonly observed than fractures of the matching talus, femoral condyles and femoral head [25]. During any traumatic injury event Newtonian mechanics dictate that both surfaces are subjected to an equal and opposite force; why, then, does one side fail so much more often?

Loads applied to the surface of a convexity are converted to compressive forces by the geometry of the macrostructure [23], and bone tolerates compressive loads very well [2–4,8,19,24]. If instead loads are applied from within a concavity the macrostructure is subjected to tensile forces [23]. When loaded in tension bone provides far less structural support, and fails under much smaller loads [2–4,8,19,24].

Another potential mechanism for the preferential failure of the concavity may be a discrepancy in local bone density. Frost has proposed that bone growth, remodelling, and trabecular patterns very closely follow the loads applied to that bone [6,7]. Areas of higher stress during normal physiological loads become denser than those areas subjected to lesser stress, as can be seen in impact-loading athletes; their distal tibiae exhibit significantly

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higher bone density, cortical thickness, and load to failure, as compared to controls from non-load-bearing athletes [21].

For example, Haverstock, et al. [9], demonstrated the antero-lateral quadrant of the radial head has the lowest bone density and is also correspondingly the region most prone to fracture. The posteromedial quadrant is an area of greater load bearing, with the highest bone density; this was the least likely region to fracture [9]. Iwasaki, et al. observed a statistically significant between group difference in bone mineral density in patients with insufficiency fractures that showed either progression or no progression of the disease, with those who progressed having a lower bone mineral density [11].

Local differences in bone density may be an important consideration, although the architecture of the surrounding bone has already been identified as a significant factor in determining the pattern of failure observed in intra-articular fractures [25]. The purpose of this study was therefore to investigate whether the relative density of local bone on the two opposite sides of a joint is associated with failure of the less dense side. We hypothesized that there would be no significant differences in bone density when comparing the concavity to the convexity as matched pairs on the opposing surfaces of an intra-articular fracture.

Materials and methods

IRP Approval was obtained from our institutions Human Research Ethics Committee. In a previous publication we have identified 1003 intra-articular fractures, and reported that 95% of all intra-articular fractures involved the concave surface of the joint [25]. The inclusion criteria here included fractures of the hip, knee or ankle. Upper extremity fractures were specifically excluded. From a subset of 368 lower extremity fractures which all had undergone CT scanning as a routine part of their clinical care, a random sample of 129 cases was selected. An a-priori sample size calculation indicated that a random sample selection of 94 cases was needed to limit the margin of error to five percent. A further sample size analysis indicated that 72 cases were needed to detect a 20% difference in bone density between the concave and convex joint surface (two sided alpha = 0.05, power 0.9). The current study is restricted exclusively to this subset of cases, and periarticular bone density was specifically examined on both sides of each of these 129 cases.

Periarticular bone density adjacent to both the concave and convex sides of each joint was measured in Hounsfield units. This measure has been shown to be an accurate and reproducible estimate of bone mineral density, and compares favourably to either dual X-ray absorptiometry or to mechanical testing of subchondral bone strength [15–17,22,26]. Measurements were done using the standard tools of the IMPAX (AGFA HealthCare, Greenville, SC, USA) radiology imaging software package. The oval HU tool allows a particular region of bone to be selected, displaying the length and width of the region under observation (Fig. 1). The software simultaneously calculates the area covered while also providing a measure of the mean Hounsfield units of the region circumscribed by the tool at any time. In addition to the bone density measured in each case, we further recorded routine demographic information including the patients' age, gender, the joint affected, the side of the body injured, and the surface of the joint involved (concavity or convexity).

Observations were conducted using a rigorously standardized technique to minimize the risk of introducing any measurement bias. No observations were conducted within 3 mm of the fracture site itself, to avoid the potential effects of local bone compaction, comminution, or fracture gaps. The margins of each joint were avoided, and no measurements were made within 5 mm of the periphery of a joint. The oval HU tool was maintained as a constant size and shape for any given case; all ten observations, five on each side of every joint, were conducted by translating the same size and shape oval tool to a separate and distinct area of bone for each measurement. The oval shape was selected specifically to limit potential duplication of regions of bone covered, difficult to avoid with a circular shape. The selected oval configuration was 7–12 mm in length, and 2.5–3.5 mm in width, with a target width to length ratio of 0.3. The tool was carefully positioned immediately beneath the articular surface to capture both the subchondral plate as well as periarticular cancellous bone, recognizing both contribute to local bone density. The tool was positioned perpendicular to the joint surface, to facilitate consistency of observations incorporating both the subchondral plate and periarticular cancellous bone.

Two independent research associates performed all measures. Five independent measurements were recorded on both sides of every joint by each of the investigators, and the highest and lowest values on each side were dismissed; data analysis was conducted

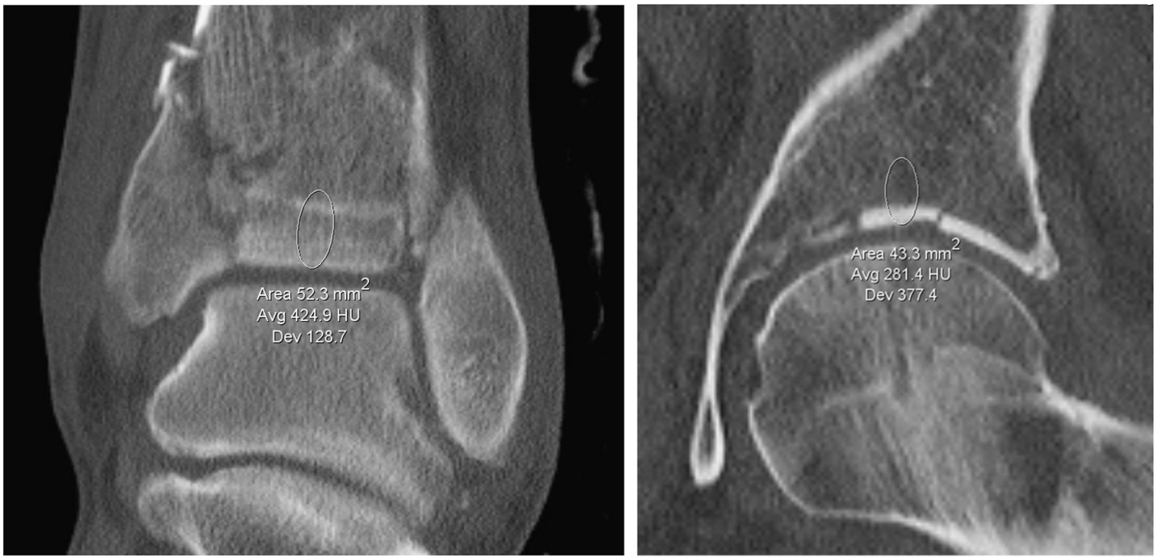

Fig. 1. Periarticular bone density measurement using the oval HU tool. The tool was positioned immediately beneath the articular surface to capture both the subchondral plate as well as periarticular cancellous bone, recognizing both contribute to local bone density.