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Does joint architecture influence the nature of intra-articular fractures?

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ABSTRACT

Introduction: The architecture of joints has potentially the greatest influence on the nature of intra-articular fractures. We analysed a large number of intra-articular fractures with two aims: (1) to determine if the pattern of injuries observed supports our conjecture that the local skeletal architecture is an important factor and (2) to investigate whether associated dislocations further affect the fracture pattern.

Methods: A retrospective study of intra-articular fractures over a 3.5-year period; 1003 joints met inclusion criteria and were analysed. Three independent investigators determined if fractures affected the convex dome, the concave socket, or if both joint surfaces were involved. Further review determined if a joint dislocation occurred with the initial injury. Statistical analysis was performed using a one-way frequency table, and the χ^2 test was used to compare the frequencies of concave and convex surface fractures. The odds ratios (ORs) were calculated to establish the association between the frequencies of concave and convex surface fractures, as well as between dislocation and either fracture surface involvement.

Results: Of the 1003 fractures analysed, 956 (95.3%) involved only the concavity of the joint; in 21 fractures (2.1%) both joint surfaces were involved; and in 26 fractures (2.6%) only the convexity was involved ($\chi^2 = 1654.9$, df = 2, $p < 0.0001$). As expected, the concavity was 20.8 times more likely to fail than the convexity (11.2–36.6, 95% CI). However, the risk of fracturing the convex surface was 18.6 times higher (9.8–35.2, 95% CI) in association with a simultaneous joint dislocation, compared to those cases without a joint dislocation.

Conclusions: These results very strongly support the study hypotheses: the skeletal architecture of joints clearly plays a highly significant role in determining the nature of intra-articular fractures. Intra-articular fractures involving the convexity are much more likely to be associated with a concurrent joint dislocation.

Introduction

The laws of physics govern the forces responsible for traumatic injuries, and Newton's 3rd Law of Mechanics stipulates that for every action there is an equal and opposite reaction [6,15]. Whenever loads are applied to one of our joints, those forces involved are distributed equally across the two opposing surfaces of that joint. If an intra-articular fracture should occur, one might reasonably expect an equal probability of that fracture involving either side of the joint. Yet common knowledge suggests this may not be true; consider the relative frequency of acetabular fractures compared to those involving the femoral head [7,12,13]. Are unspecified local factors responsible for this observed discrepancy in the pattern of articular surface involvement with intra-articular fractures?

The hip is generally considered the archetype of "ball and socket" joints [1,16]. The external surface of the femoral head, normally almost spherical, is very closely matched in size, shape, and contour with the corresponding internal hemispherical surface of the acetabulum. Intimately apposed throughout the normal physiologic range of motion, these two surfaces are

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intended to fill two main functions [1,16]. They glide smoothly over one another, to allow joint motion as an articulation; and they transmit force across the joint, as load-bearing members supporting the function of the other components of the skeleton.

With a typical "ball and socket" joint, it is convenient to consider the convexity of the "ball" to be analogous with a dome. Similarly, it is convenient to consider the "socket" to be analogous with a vault, often regarded as a three-dimensional arch. From the perspective of architecture, the design of a dome is best suited to resist loads external to its convex surface [21], much the same as the shape of an eggshell protects its contents [5,9,11,14,23–25]. With its inverted geometry, the design of a vault is also best suited to support loads applied external to its convex aspect, and when suitably loaded (as in supporting the roof of a building) it fills this role well [21]. Unfortunately, when that load is applied from within the concave aspect of the vault it would be expected to provide far less structural support, and to almost certainly fail under much smaller applied loads [5,21].

Assume for the moment that the three-dimensional configuration of the joint surface, dictated by the architecture of the supporting bone, is in fact one of the most critical factors responsible for the failure mechanism of intra-articular fractures. If so, the vast majority of fractures would then affect the concave surface, while the convex dome would be relatively spared. Obviously high-energy traumatic injuries can be complex in nature, and other factors may also contribute. An associated joint dislocation can create conditions resulting in shear forces or point loading, conditions more conducive to injuries to the convex surface. Cognizant of the potential role of transient joint dislocation and impaction injuries to the convexity, further investigation of the relationship between dislocation and intra-articular fractures is warranted.

There are, therefore two hypotheses under investigation in this study: (1) in an analysis of a large number of intra-articular fractures, the distribution of the injuries sustained will disproportionately involve the concave surface and (2) fractures involving the convex surface will occur more frequently in association with a concurrent dislocation.

Materials and methods

We conducted a comprehensive retrospective analysis of intra-articular fractures at a major, metropolitan, tertiary referral hospital. Prior approval for this study had been obtained from our institutions Human Research Ethics Committee. We performed a systematic search of the IMPAX (Agfa HealthCare, Greenville, SC) radiology database, based on the radiologist's report text, imaging modality, patient demographics, and date. The IMPAX database was searched entering the relevant terms and Boolean operators: "intra articular fracture", "intraarticular fracture", and "intra-articular fracture". In addition, more specific parameters were used to expand the search in a more focused manner; we selected for particular joints or bones together with the word "fracture", such as "hip fracture", "acetabular fracture", or "femoral head fracture".

We have included all articulations where the radiographic profile demonstrates a convex surface paired with a concave surface clearly evident on at least one standard radiographic projection or CT slice. Joints we considered to broadly satisfy this description included the: hip, ankle, knee, shoulder, wrist (radio-scapho-lunate articulation), and elbow (radio-capitellar articulation); we also included the metacarpo-phalangeal and metatarso-phalangeal joints, as well as the proximal interphalangeal joints of both fingers and toes.

The following further inclusion criteria were applied: all intra-articular fractures between January 2010 and September 2013; patients over 18 years of age; principal mechanism of injury as given by the patient history most consistent with axial loading. Cases were excluded if (1) they involved other joints, not identified in the list above and (2) the mechanism of injury was highly unlikely to be the result of an axial load. Three investigators (RS, SDS, and AL) conducted independent analyses of the relevant plain radiographs or CT scan images for each case; disagreement was resolved by consensus between the observers.

The initial search identified over 3500 cases of an intra-articular fracture; over 2500 were excluded because they were either duplicate cases or did not meet the specified inclusion criteria. The majority of these excluded cases were fractures involving spinal facet joints This resulted in a total of 1003 cases that were selected for more complete review, and comprise the formal study set; demographic data was compiled for the study set, including age, gender, and anatomic location (Table 1). Study cases were further assessed radiographically, to identify the articular surface(s) involved: the convex surface (dome), the concave surface (vault), or both. The medical records of each case involving fracture of the convex surface (alone or together with the concave surface) were reviewed further, to look for common factors. Potential factors considered were mechanism of injury, joint dislocation, malignancy, medical comorbidities, steroid use, and smoking status.

Statistical analysis was performed with Systat (Version 13; Systat, Chicago, IL). Continuous variables are presented as means and standard deviations. Categorical variables are presented as percentages and frequencies. A one-way frequency table was created and the χ^2 test was used for two primary comparisons. First, we compared the relative proportions of concave surface fractures and convex surface fractures within our study set (Table 2). Second, we compared the percentage of dislocations associated with any fractures involving the convexity with the percentage of dislocations associated with fractures of the concavity in isolation (Table 3). Odds ratios (OR) were used to measure the association between: (1) the frequencies of concave and convex surface involvement and (2) joint dislocation and the frequency of fracture of the convex surface.

To assess the possible relationship between mechanism of injury and fractures involving either the convexity (with or without concavity involvement) or involving the concavity alone, a randomly selected subset derived from the full set of isolated concavity fractures was used. Fisher's exact test (two-tailed) was used to analyse the resulting 2×2 contingency tables; only significant p values are reported (Table 4).

Results

The complete results are presented in Tables 2–4. The three observers made a total of 3009 independent assessments; there were only 24 instances where one observer differed from the other two (99.2% agreement).

Table 1
The demographic characteristics and the anatomic distribution of the complete study cohort of 1003 intra-articular fractures.

Anatomic location	Number of cases	Age	Male	Female
Shoulder	23	48 (19–89)	12	11
Elbow (radio-capitellar)	55	43 (18–88)	30	25
Wrist	414	51 (18–96)	194	220
Hand	143	36 (18–86)	106	37
Hip	108	48 (18–92)	80	28
Knee	78	45 (18–87)	49	29
Ankle	102	42 (18–87)	68	34
Foot	80	36 (19–86)	48	32
Total	1003	45 (18–96)	587	416