Advancements in classification, treatment and outcome of radial head fractures
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Part V: General discussion

CHAPTER 8
Discussion

Thierry G. Guittton
Discussion

Advancements in technology, further insight into patient related factors, and the availability of long-term functional outcome data potentially allowed us to improve the classification, treatment and outcome of radial head fractures. We applied these recent advancements to radial head fracture treatment: 1) to gain further insight in radial head fractures and 2) to function as a model for general improvements in orthopedic trauma surgery.

This discussion will be continued with a more detailed address of each chapter separately and finally summarized in a conclusion:

CHAPTER 2

This chapter was the successful validation of our Q3D-CT modeling technique. Additionally, we derived linear regression models capable of estimating the volume and proximal articular surface area of the radial head prior to fracture. The limitations of this investigation included the fact that the accuracy of this Q3D-CT modeling technique depended on the quality of the CT scan. Because CT scans do not account for articular cartilage, our measurements will differ from those based on MRI or direct measurements of fresh cadaveric bone. We did not thoroughly evaluate inter- and intra-observer variability in creation of the models because our method was time and resource intensive and, based on experience with 2 observers doing several models during training; the method leaves limited room for bias. When one person created the same model five times, we found very little variation in the measures of volume and surface area. The differences between surface area calculated using our formula and that using simple geometry probably reflect the ovoid shape of the radial head. In the final multivariable models height, weight and radial neck diameter did not significantly contribute to the fit of the model (as gauged by adjusted R²) and were therefore not used.

The strong points of this investigation included the fact that we used: 1) a relatively large number of CT scans; 2) a consistent algorithm for bone identification (on CT slides); and 3) automated curve and polygon mesh creation, which left limited room for judgment or bias on the part of the individual creating the model. The relatively small standard deviations of the measured volumes and surface areas, the relatively narrow 95% confidence intervals of the predictive linear models, and the fact that our multivariable models account for over 70% of the variability of volume and surface area, all indicated that we could make reasonable and useful estimation of these parameters in fractured radial heads.

To our knowledge, measurement of proximal articular surface area and radial head volume has not been attempted. We produced equations capable of estimating the volume and proximal articular surface area of the intact radial head—on the basis of parameters usually available in fractured radial heads—with an average relative percent difference of 0.5%. The ability to estimate the volume and surface area of the bone prior to fracture provides useful information when we analyze a fractured radial head. For instance, it allowed us to measure the percentage of the surface area involved in the fracture, which is one criterion in Broberg and Morrey’s modification of Mason’s classification. Keeping in mind the many shortcomings of our approach, we believe that it will, nonetheless improve our analysis and characterization of radial head fracture patterns.

These Q3D-CT methods are, at least initially, more important for clinical research. We will be using this technique to study fracture fragment size and injury pattern, and the ability to estimate percentage involvement helps make the results more intuitive for clinicians. For instance, in radial head fracture classifications and management, decisions often refer to 30% of the surface area, but it’s not clear that this is an important cutoff, that we can make this measurement accurately from radiographs, or that it is representative of the fracture patterns that actually occur. More detailed analysis with these sophisticated techniques may help to clarify these issues. This Q3D-CT modeling technique can be applied to any intact or fractured bone in the human body and therefore has a huge potential in orthopedic trauma surgery, but additional work is needed to better define the accuracy and reliability of our method and determine how sensitive it is to the quality of the CT scan and the person doing the analysis.

CHAPTER 3

In this chapter, quantitative analysis of CT scans provided measurements of the volume and articular surface area of radial head fracture fragments. The strengths of this investigation include the fact that we developed this technique with widely used software. A consistent algorithm was used for bone identification (on CT slides) and automated curve and polygon mesh creation, which left limited room for judgment or bias on the part of the individual creating the model.

The limitations of this paper include the fact that we could not use the opposite radial head for volume and surface area estimates, and the estimates of bone loss based on formulae are less precise. Additionally, we used both volume and articular surface area measurement. The volume measurements are straightforward whereas the articular surface area measurements may be less reliable. Finally, our definition of a small fragment was a mathematical and arbitrary categorization that, from our experience seems reasonable, but might not reflect the actual clinical situation.

We found that partial head (Mason II) fractures are usually multi-fragmented (73%) and often have small fragments that are difficult to repair by volume and...
surface area criteria (23 fractures [88%]) particularly when the fracture is displaced and unstable. We conclude that small fragments are most common with partial head fractures, at least among the unstable fractures associated with elbow dislocation or fracture of the ulna. Interestingly, small partial head fractures have not been addressed much in the literature, and it may be commonly assumed that these are more straightforward to repair simply because a large part of the articular surface is not fractured.

Another important finding is that, according to the surface area criterion, many of the Mason 2 fractures involved less than a third of the radial head (12 out of 26). This means that about half of these fractures would not satisfy the Broberg and Morrey criterion of greater than 30% of the articular surface area to be considered Type 2 fractures 3, 19.

Quantitative analysis of 3D-CT scans is a useful technique for analyzing articular fracture pattern and morphology. Using this technology we identified: 1) that partial head (Mason 2) fractures frequently involve less than a third of the radial head surface area; 2) that partial head fractures have more small and difficult to repair fragments than whole head fractures (Mason 3); and 3) that whole head fractures with more than 3 fragments are relatively uncommon (4 patients, 23% of Mason type 3 and 8.7% of total), but some 3 fragment-fractures have small fragments. These findings may influence our conception and classification of radial head fractures. For now, this technique is primarily designed for research purposes and not for patient care, but with further development Q3D-CT might prove useful in management decisions for individual patients.

CHAPTER 4
This chapter investigated if classification and characterization of fractures of the radial head is more accurate with 3D-CT images and 3D models than 2D-CT images and radiographs, using a prospective study design with intraoperative inspection as the reference standard.

The limitations of this investigation include the fact that images were usually rated after surgery (in part due to the inherent delay in receiving the physical 3D model), so that ratings of the radiological images were in essence–retrospective; the injuries were relatively complex resulting in a spectrum bias in terms of all fractures of the radial head, although our work is representative of the types of fractures that would be studied with CT and operated on; two patients (one with addition of a capitellum/trochlea fracture and one anterior-transolecranon fracture dislocation) had non-nondisplaced fractures of the radial neck, which are relatively unusual—both fractures were seen only on operative exposure; and multiple physicians were involved in the ratings at two sites, which makes the results more generalizable, but less consistent. These data should also be interpreted in light of the fact that the first assistant was usually a resident or fellow, so that the observer variability may largely reflect differences in training and experience. The strengths of this investigation include the prospective design, the relatively large number of patients, and an intraoperative reference standard.

This study found that increasing levels of sophistication in imaging/modeling: 1) improved the sensitivity for diagnosis of numerous fracture characteristics using the surgeon’s interpretation of the intraoperative findings as the reference standard; and 2) decreased observer variation between surgeon and first assistant. This is in concordance with prior studies that have demonstrated improved agreement in characterization and classification of fractures with 3D-CT compared to 2D-CT and radiographs alone 5, 4, 7, 10, 11, 14, 15, 28, 29. Prior studies that addressed the classification of radial head fractures specifically found substantial observer variation 5, 20, 21 when fractures were evaluated by radiographs only. However, these studies differed in that they are based upon retrospective data in small groups of observers/patients and the reference standard was based upon surgeon recollection and the medical record (e.g. operative notes).

We interpret this combination of findings to indicate that fracture classification and characterization based on 3D imaging and models is more accurate and reliable, essentially helping to narrow the experience and training gap. While experienced surgeons sometimes suggest that little is added by more sophisticated imaging, science is establishing that more sophisticated imaging does improve our understanding of the injury. However, recommendations regarding the use of a new technology should be based on both diagnostic performance characteristics and clinical impact. The next steps are to investigate whether more sophisticated imaging leads to more effective treatment as measured by fewer complications with less functional impairment.

CHAPTER 5
This chapter investigated in a large web-based collaborative of experienced orthopaedic surgeons if 3D-CT improve the interobserver reliability of the classification of radial head fractures according to the Broberg and Morrey modification of the Mason classification.

The collaborative, web-based approach has facilitated large international studies of inter-rater variation 5, 10. Additionally, only fully trained surgeons, many with substantial clinical experience participated. Inclusion of surgeons from multiple countries and continents should increase the generalizability of the results. Using high-speed Internet connections and improved compression techniques, we were able to provide sophisticated reproduction images and movies via the Internet.
There are some weaknesses in this study. First, the quality of the radiographs was limited to what had been obtained at the time of injury, which reflects usual practice, but not what might be achieved with specific protocols. In addition, we provided limited information about the patient and the injury. There was also a spectrum bias by selecting cases to represent the known variety of injuries, with the result that less common complex fractures were over-represented compared to the more common minimally or slightly displaced fractures. Our study reflects what would be expected with relatively complex fractures of the radial head—the reliability would be expected to be higher if we included more of the non-displaced or minimally displaced fractures that make up the majority of radial head fractures. Another shortcoming is the fact that a small number of observers either uncommonly or never treat radial head fractures, but we did not plan for exclusions on this basis and therefore did not do so after the fact to avoid introducing bias. Finally, this is an artificial research situation given that in clinical practice clinicians would have both the 2D and 3D reconstructions available to them.

Three-dimensional CT images led to small but significant decreases in variation between observers for fracture classification and some fracture characteristics compared to 2D-CT, but a notable amount of variation remains even with more sophisticated imaging. Our belief that 3D-CT images are easier for surgeons to interpret is supported by the observation that 3D-CT produced a higher agreement for Broberg and Morrey’s modification of the Mason classification than previously reported in the literature 26-28 and 3D-CT was associated with less disagreement in classification than 2D-CT across various cultures, training, subspecialty and levels of experience. Nonetheless agreement was only fair or moderate at best even with 3D-CT. Furthermore, some might interpret this data as showing much less influence on interobserver variation than one might guess.

Other potential sources of interobserver variation include unfamiliar or unclear definitions, and differences in culture, training, and exposure. In our opinion, the fact that well-trained, experienced observers disagree indicates that there are variations in these factors that lead different experts to see different things in sophisticated images. In other words, reducing interobserver variation seems to depend on something more than better imaging. Additional research to identify and reduce sources of observer variation in the interpretation of diagnostic images is merited.

**CHAPTER 6**

This chapter investigated the psychosocial aspects of radial head fractures. More specifically, if agreement with the idea that “stretching of the elbow beyond the point were it becomes painful is important in recovery” leads to greater elbow range of motion one month after injury.

The strengths of this study included the prospective design and enrollment of patients from 6 different surgeons’ practices. Limitations include: 1) Enrollment after diagnosis, reassurance, and coaching with motion exercises, all of which were therapeutic interventions that may have affected attitudes towards pain (and may explain why the majority of patients agreed with the importance of pain for recovery); 2) Ceiling effects since most patients with minimally displaced radial head fractures regained near normal motion regardless of their paradigm; 3) Meaningless variation (or “noise”) added to the data by virtue of the fact that the measurement error of a hand-held goniometer was comparable to the small differences in elbow flexion contractures observed; 4) The measure of agreement with a statement regarding the role of pain in recovery was an indirect measure of confidence with exercises—a more direct and objective measure would be preferable; patients may state agreement on a questionnaire, but still have a hard time performing stretches beyond pain; 5) Wide range in the time that people returned for the “one-month” follow-up (although this did not correlate with any of the outcome measures); and 6) Limited power due to unequal distribution of patients among agreement groups.

In spite of these shortcomings, we did find that a patient’s paradigm with respect to the role of pain in recovery predicted motion one month after injury and that a patient’s paradigm had small but significant correlation with pain catastrophizing. The lack of correlation between attitude and disability might be due to the small number of patients in the neutral (9) and disagree (6) categories versus the agree category (55). There was a nearly 11 point difference in the mean DASH score in patients that agree (17.4) or were neutral (17.3) about the role of pain and those that disagree (28.0), which seems clinically important. Of note is that the mean DASH for patients that disagree was higher than what had been reported in patients with fractures, while the mean DASH for the other categories was lower (21).

This line of research should be pursued. If additional studies corroborate the role of automatic thoughts and beliefs (intuition, “gut feelings”) in recovery from injury, as well as the correlation of these thoughts with depressive symptoms and maladaptive responses to nociception, then there is room for improvement in our teaching and coaching of post-injury exercises. As Paul Brand noted in his book “The Gift of Pain”, nociception exists for our protection. It is no surprise that pain after injury may make us feel vulnerable and protective. The key may be to help our patients change their mindset from vulnerability to recovery, seeing a painful exercise more as a useful stretch exercise and the post-exercise pain more as that rewarding ache after a great work out.
This chapter assessed the risk factors for posttraumatic elbow arthrosis on radiographs after elbow injury in the long term. The limitations of this investigation included the fact that we have only cross-sectional (rather than longitudinal) data and that we did not address symptoms and dysfunction. We based assessment of arthrosis on radiographs alone, and we acknowledge the known limited relationships among radiographic evidence of arthrosis and symptoms, impairment, and disability. Interobserver variability for the radiographic arthrosis rating was not measured. Unfortunately, available reproductions of the initial injury radiographs and initial postoperative radiographs were inadequate to quantify articular incongruity, intra-articular comminution, or fracture severity, and we did not have sufficient numbers to analyze the influence of subclassification of each injury type (eg, most of the injuries in each category were of a single AO type). For instance, nearly all of the columnar distal humerus fractures were type C according to the AO classification, and we did not feel confident about measures of articular incongruity. In addition, there were a large number of surgeons involved and fixation was often performed with older techniques that would be considered nonstandard at this time.

Injury type was the only significant independent predictor of moderate or severe radiographic arthrosis. Different injury types may lead to more severe degrees of articular surface injury and realignment. Distal humerus fractures and capitellum/trochlea fractures created the greatest articular injury and were associated with the greatest risk of radiographic arthrosis. Radial head fractures and proximal ulna/olecranon fractures were associated with lower incidence of radiographic arthrosis. Unfortunately, we could not accurately or reliably measure intra-articular displacement and comminution from records available decades after treatment of these injuries. These findings are all consistent with the previous literature on post-traumatic elbow radiographic arthrosis, which notes that intra-articular distal humerus fractures are a common source of posttraumatic elbow radiographic arthrosis.

Radiographic arthrosis was not related to follow-up time, age, hand dominance, occupation, gender, or mechanism of injury. This suggests that post-injury activities and occupation are not important risk factors for the development or advancement of radiographic arthrosis. This finding is reassuring and enabling, although counterintuitive.

Consequently, this study looked broadly at general types of injuries rather than at the influence of articular incongruity or fracture pattern and concludes that isolated fractures of the radial head and olecranon are less prone to moderate or severe radiographic arthrosis in the long term than fractures of the distal humerus and fracture-dislocations. This finding is expected; nevertheless, the data objectively document and quantify the differences using long-term evaluations that are hard to come by.

Conclusion

Throughout the various chapters in this thesis, our results showed that advancements in technological, imaging, psychosocial and long-term outcome can help improve classification, treatment and outcome after radial head fracture. First, we validated our new Q3D-CT modeling technique and successfully applied this technique to radial head fractures. Measurement of proximal articular surface area and radial head volume has not been attempted before and it will improve our analysis and characterization of radial head fracture patterns. We demonstrated prospectively and in a multi-rater study that 3D images led to increased agreement in classification of radial head fractures. We also demonstrated that patients who agree that pain is a necessary part of recovery have improved outcomes after radial head fractures. Additionally, we identified predictors for arthrosis after elbow trauma in the long term. In general, these advancements can help gain more insight in the classification, treatment and outcome of fractures in orthopedic trauma surgery.

As shown in this thesis, advancements in technical analysis, imaging modalities, increased interest in psychosocial aspects of treatment and the availability of long-term outcome data can help improve classification, treatment and outcome in fractures of the radial head. Implementation and application of new technologies as they emerge in medicine are needed to allow further improvement of our current treatments. Dogmas in orthopedics on the psychosocial aspects of treatment should be set aside. With all these new technologies and advancements widely available, it is our duty to carefully evaluate them and—if proven beneficial—to use them in the treatments of our patients. It is science that created these advancements and through adequate scientific evaluation of these advancements we can continue creating more effective treatments for our patients.
References