Advancements in classification, treatment and outcome of radial head fractures

Guitton, T.G.

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Part I: Current Issues

CHAPTER 1

Introduction

Thierry G. Guitten
Introduction

With the evolution from homo-sapiens to the human being of today the elbow evolved from a weight bearing joint to a complex non-weight bearing articulation. The elbow joint is now a so-called ginglymus or hinge joint and consists of the humerus, radius and ulnar bones. In combination with the development of the brain, the human became able to perform complex motions with this joint. From an anatomical point of view the elbow is very complex; it consists of relatively small bones, complex shapes of articulations and numerous adjacent neurovascular structures that all increase the difficulty of operative treatment.

Paul of Aegina (625-690 A.D.) made the first description of radial head fractures: "The ulna and radius are sometimes fractured together and sometimes one of them only either in the middle or at one end as at the elbow or the wrist" 1. However, Sir Astley Cooper, an English surgeon and anatomist who made historical contributions to medicine, never recognized this injury in his book titled: "Dislocations and Fractures" in 1822 2. Earlier recognition of this injury was probably hindered because of "thick muscle covering" 3, 4. On the other hand, the often poor results of radial head fracture treatment were noted early: Helferich recommended resection of the radial head to prevent late deformity in 1899 5a.

The incidence of radial head fractures is reported to be between 1.7 to 5.4 percent of all fractures 6, 7. Radial head fractures are considered common injuries, found in nearly 20% of all elbow fractures 8, 9. Loss of elbow motion after a radial head fracture can have a substantial impact on upper extremity function and people’s overall health status 10. A relatively simple radial head fracture can cause great impairment and disability. With the increased emphasis in healthcare on quality of life, there has been an increased interest in development of treatments for radial head fractures. As life expectancy increases, the older population continues to grow and at the same time, live more active lives. As a consequence, the incidence of radial head fractures can be expected to increase 10. As a result there will be an increased scientific, clinical, and economic interest in the treatment of radial head fractures.

The classification of radial head fractures underwent several changes over the past years. Scharplatt and Allgower based the classification of elbow fractures on the direction of force of the injury 10. Early classification of radial head fractures by Carstam 11, Bakalim 12 and Mason 13 were only based on radiographs. They failed to take associated injuries into account. At this point, the most commonly used classification system is that proposed by Mason 13. Mason classified fractures of the radial head as nondisplaced (Type 1), displaced partial head (Type 2), and displaced whole head fractures (Type 3). Several authors suggested a fourth category in which there is involvement of an elbow dislocation 13a, 14, 23, 24. More complex sub classifications are proposed based on different degrees of displacement and comminution 25, 26, 37. Broberg and Morrey modified Mason’s classification as follows 3. Type 1 fractures involve less than 30% of the articular surface or are displaced fewer than 2 millimeters; Type 2 fractures are partial head fractures involving at least 30% of the articular surface and displaced at least 2 mm; Type 3 fractures are displaced articular fractures involving the entire head of the radius; and Type 4 fractures have an associated elbow dislocation 31. As most classification systems are imperfect, there is often debate in distinguishing between fracture types. For example, the percentage of involvement of the radial head or the amount of displacement that should be present for a Mason 2 fracture is arbitrary. As of today, no “ideal” classification for radial head fractures exists 3. More detailed analysis with sophisticated techniques may help to clarify these issues.

To my knowledge, measurement of proximal articular surface area and radial head volume has not been attempted. If a system was developed which quantified fracture fragment size and injury patterns, and added the ability to estimate percentage involvement, it would make classification systems more intuitive for clinicians.

The technological advances in imaging of the upper-extremity have taken an immense leap in the last decade. Our group has developed a technique to quantitatively investigate broken bones with the use of Computed Tomography (CT). This Quantitative Three-dimensional CT (Q3D-CT) modeling technique creates a polygon mesh. This is a collection of vertices, edges and faces that defines the shape of a polyhedral object in 3D computer graphics and solid modeling, consisting of triangles, only explicitly representing the surface. In other words, a hollow 3D model of solely the outer surface of the bony structures and fragments can be generated. This Q3D-CT modeling technique has several potential opportunities. First, it provides the opportunity to learn more about fracture patterns. For example, one can calculate volume and articular surfaces of bones. Secondly, more detailed and quantitative information can be derived from this technique concerning the specific anatomical aspects of bone that could assist the clinician in reconstruction surgery.

Anteroposterior (AP) and lateral radiographs may not provide an accurate representation of the individual fracture pattern of radial head fractures 5a. The addition of a 45 degree oblique radiograph is helpful in recognizing the size and orientation of the fracture fragments. However, the value of Magnetic Resonance Imaging (MRI) and CT scans remain under continuous scrutiny 32. Several retrospective studies have demonstrated improved injury characterization with two-dimensional (2D) CT images as compared to standard radiographs alone. These studies found that 3D reconstructions of CT scans may have advantages over standard 2D images 43, 44, 45. Three-dimensional reconstructions are relatively new, and are becoming more read-
ly available in most hospitals. Three-dimensional reconstructions might be more intuitive and may lead to improved identification of fracture characteristics such as fragments, fracture edges and articular surfaces. Three-dimensional physical models of elbow fractures can now be created with the use of special 3D printers. Three-dimensional physical models can even increase the advantages of the 3D reconstructions. Three-dimensional imaging and 3D physical models should allow better pre-operative planning in terms of implants and equipment. Additionally, the surgeon will have better mental and psychomotor preparation. Three-dimensional imaging is also more intuitive for patients and could lead to better understanding and improved decision making and compliance. High quality prospective and multi-rater studies could identify the potential advantages from 3D imaging and 3D physical models over radiographs and 2D-CT.

Immobilization of three to four weeks 79, passive motion and avoidance of “operative treatment” 80, removal of the fracture fragment 81 and excision of the entire head for severe comminution 82 were all recommended treatments for radial head fractures in the early 1900’s. Evidence can now be found for nearly any type of treatment. Although the radial head has been subject to research in the past, the majority consists of retrospective studies and case series. There is a lack of high quality randomized and comparative trials available. Therefore the debate regarding the best treatment continues 85-89. The focus has mainly been on the technical side of management. There is an increased interest in the recent literature in orthopedics on the psychosocial aspect in treatment of elbow trauma. The psychosocial aspects in treatment of radial head fractures could help unveil the ideal management. It was found that psychosocial factors (depression in particular) may best explain the discrepancy between impairment and disability 44. As many psychosocial factors are amenable to treatment, additional research along these lines is merited. For example, it can be counter-intuitive to intentionally cause pain in the setting of an injury. Vulnerability is enhanced by automatic thoughts such as “pain indicates harm”, “the pain is permanent”, or other aspects of a maladaptive pain response that psychologists have termed pain catastrophizing. There is a strong interaction between depression and pain catastrophizing and both may be important. This needs further investigation.

Post-traumatic arthritis is a form of arthritis that is caused by forced inappropriate motion of a joint or ligament that is damaged because of a fracture. An intra-articular fracture such as a radial head fracture may increase the forces on the articular cartilage, and the articular surface will wear out faster, finally leading to arthritis. Little has been published regarding risk factors for arthritis after elbow injury, especially in the long term. Data from multiple long-term follow-up studies of injured elbows provide the opportunity to assess the risk factors for post-traumatic elbow arthrosis after radial head fracture.

The advancements in analyzing techniques, 3D imaging and modeling, increased interest in psychosocial aspects of treatment and the recent availability of multiple long term outcome studies gives us the opportunity to further investigate the classification, treatment and outcome of radial head fractures. This all could lead to improved treatment and possible better outcomes for patients. The aim of this thesis is to apply these advancements to the radial head 1) to gain further insight in classification, treatment and outcome of radial head fractures and 2) to function as a model for general improvements in orthopedic trauma surgery.

In conclusion, the purpose of this thesis is: 1) to validate the Q3D-CT modeling technique; 2) to apply this new Q3D-CT modeling technique to improve the understanding of radial head fracture morphology; 3) to evaluate prospectively with a multi-rater study the influence of 3D images on classification and treatment of radial head fractures; 4) to further investigate the psychosocial aspects in radial head fracture treatment; 5) to identify predictors for long term consequences of radial head fractures.

Outline of the Chapters

CHAPTER 2
QUANTITATIVE MEASUREMENTS OF THE VOLUME AND SURFACE AREA OF THE RADIAL HEAD
Thierry G. Guitton, MSc, Huub J. van der Werf, MD, David King, MD PhD

The morphology of the healthy radial head has been investigated with calliper ruler, osteometric board, coordinator measuring machine (CMM), X-ray, Computed Tomography (CT), Magnetic Resonance Imaging (MRI) and Computer-Aided Design (CAD) software in the past. 4, 8, 10, 13, 14, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56. We developed a quantitative 3-dimensional computed tomography (Q3D-CT) modeling technique that can measure size, shape and proximal articular surface area.

In chapter 2, we will validate our Q3D-CT modeling technique and investigate the hypothesis that analysis of normal, unfractured radial heads in patients with CT scan obtained for other reasons (intact radial head) will allow us to develop a linear regression model capable of estimating the volume and proximal articular surface area of the radial head prior to fracture based on 1 or more of the following: radial head diameter, radial neck diameter, coronoid length diameter, height, weight and gender.
Radial head fractures are usually classified according to the size and displacement of the fracture fragments into partial and whole head fractures as per the Mason classification system. The quantitative aspects of the classification of these injuries, such as the thresholds of 30% surface area and 2 millimetre displacement are relatively arbitrary and based on radiographs. Additionally, the classification of radial head fractures according to Broberg and Morrey’s modification of the Mason classification has substantial observer variation. Three-dimensional computed tomography models provide more detailed information of the fractured bone and provide an opportunity to quantify fracture characteristics better than radiographs.

In chapter 3, we applied the Q3D-CT analysis technique to a consecutive series of adult patients with a fracture of the radial head with the objective of developing quantitative assessments of radial head fracture fragments that might help clarify current classification systems and decision-making.

Optimal management of radial head fractures is debated, but accurate preoperative radiological characterization of the fracture may facilitate management. Prior studies have demonstrated improved agreement in characterization and classification of various fractures with 3D-CT compared to 2D-CT images and radiographs. These studies were based upon retrospective data and the reference standard was based upon surgeon recollection and the medical record (e.g. operative notes). We believe that we can measure the accuracy of 3D-CT imaging better prospectively. In addition, 3D physical models, that are constructed based on CT images, can actually be held in the hand and may add even more to the evaluation of fracture characteristics and surgical planning.

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

The classification of radial head fractures according to Broberg and Morrey’s modification of the Mason classification has substantial interobserver variation. Treatment decisions for radial head fractures are often based on radiological criteria and measurements according to Broberg and Morrey’s modification of the Mason classification. Evidence suggests that more sophisticated images such as 3D-CT improve intraobserver reliability more than interobserver reliability. A major limitation of most studies of observer variation is the use of only a few observers, most of them typically relatively junior surgeons.

In chapter 5, a new collaboration motivated to better understand interobserver variation, consisting of observers who have completed all training and are independently treating patients, provides an opportunity to further investigate interobserver variability and how to reduce it. We will investigate if 3D-CT images improve the interobserver reliability of the classification and characterization of radial head fractures over 2D-CT and radiographs.

Isolated stable and minimally displaced fractures of the radial head (Types 1 and 2 of the Broberg-Morrey modification of the Mason Classification) are common fractures that are usually treated non-operatively. The most common sequel of these fractures is elbow stiffness. In our experience, the elbow stiffness may be a result of excessive immobilization or ineffective stretching exercises. Research suggests that fear of pain, thinking the worst in response to nociception (pain catastrophizing) and pain anxiety may be important determinants of recovery after an acute fracture. Similarly, depression hinders recovery after fracture.

In chapter 6, the influence of patients who agree or disagree that pain is useful for recovery will be evaluated. This prospective study was designed to test the hypothesis that 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.
Radiographic arthrosis is a common sequela of elbow trauma resulting from direct cartilage injury, instability, and articular incongruity. It is understood that over the long term, many patients develop radiographic signs of arthrosis after elbow trauma, although symptoms vary and few patients present for treatment. Not much has been published regarding risk factors for arthrosis after elbow injury, especially in the long term.

In chapter 7, data from multiple long-term follow-up studies of injured elbows provide the opportunity to assess the risk factors for posttraumatic elbow arthrosis on radiographs.

Summary of Introduction
The purpose of this doctoral thesis is to apply the advancements in technical analysis, imaging modalities, psychosocial aspects and long term data to the treatment of radial head fractures. More specifically, it is my goal to increase our knowledge on classification, treatment and outcome of radial head fractures. This goal will be achieved by addressing the following study questions:

CHAPTER 2
General aim: To investigate if Q3D-CT modeling technique based on anatomical and demographic data, that can measure size, shape, and proximal articular surface area, can be used to develop formulas that could predict the volume and proximal surface area of the intact radial head in patients with fractures of the radial head.
Specific study question: Are linear regression models capable of estimating the volume and proximal articular surface area of the radial head prior to fracture based on one or more of the following: radial head diameter, radial neck diameter, coronoid length diameter, height, weight and gender?

CHAPTER 3
General aim: To quantitatively analyze radial head fracture fragment morphology on Q3D-CT images in terms of size, shape, and articular surface area.
Specific study question: Do partial head (Mason 2) fractures and whole head fractures (Mason 3) have the same percentage of small fracture fragments by volume and surface area criteria?
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