INTRODUCTION
Fractures of the wrist are among the most common of all skeletal injuries. They have been estimated to account for more than one-sixth of all fractures seen and treated in emergency departments.[1] The complex anatomy of the wrist contributes to an equally complex variety of traumatic injuries, many of which permanently compromise wrist function.

Distal radius fractures are the most common, both traumatic and pathologic wrist fractures. These have a bimodal distribution characterized by two groups[1, 2]: 1) mostly female patients in their 5th and 6th decade of life who sustained wrist trauma in extension in low energy falls (osteoporosis-related fractures), and 2) younger, mostly male patients who are injured in high-energy trauma such as motor vehicle collisions (MVCs) or high height falls, and received direct blunt trauma to the wrist in flexion or extension[3].

It is evident that fractures of the wrist represent significant costs to the health system and affect the quality of life of our patients[4]. An estimated of 850,000 fractures occur annually in the United States among persons aged equal or greater than 65 years[4, 5]. Most of the patients are osteoporotic. The annual cost of treatment of fractures in older adults was $13.8 billion in 1995 and continues to increase[6]. The Medicare costs (US government health insurance for patients older than 65 years of age) for a patient with a fracture of the distal radius averaged $2564 in 1995, and these costs are also increasing. The cost is not only economical; epidemiological studies have shown rates of patient-reported loss in quality-adjusted life years (QALYs) at one year after fracturing the wrist of 0.13 QALYs[4, 6]. This is a significant higher value when compared to the reported loss in patients that suffered vertebral fractures (0.83 QALY) or hip fractures (0.63 QALY).[7] The QALY scale goes from 0 to 1, 0 being equivalent to death and 1 equivalent to perfect health (the lower the values the higher the patient impairment) (7). These statistics reflect the severity of impairment caused by distal radius fractures in our patients and the importance of researching and providing new effective treatments that decrease costs and improve patient life quality. The high costs situation caused by distal radius fractures is similar in other countries. The, total average costs during the four-months period after confirmed fractures was 16,000 SEK in Scandinavia (SEK= Swedish Krona = 1,773 Euros) for wrist fractures in 1995 and this increasing trend in costs continues today[6, 8].

The prevalence of distal radius fractures underscores the potential costs to the health system. Cost effective treatments are therefore important. These have proved difficult to identify as seen in the substantial variety of available therapeutic
options and surgical techniques for the treatment of distal radius fractures. From cast immobilization, to percutaneous pinning and external fixation, to open reduction and internal fixation using one of several plates or approaches, all have been associated with some success, and yet none are universally accepted. In other words, we have not agreed on the optimal treatment, and have only addressed cost effectiveness to a very limited degree.

There are points of controversy in the treatment of distal radius fractures like rehabilitation after the fracture, and management of complications. Subsequent to a review of the literature and my exposure as a research fellow in the Upper Extremity and Hand Surgery Service at the Massachusetts General Hospital, I found that materials for osteosynthesis (Titanium vs. Stainless Steel); fixation of distal radius fractures (percutaneous methods vs. open reduction and internal fixation); dorsal shearing fractures of the distal radius (adequacy of dorsal plating); rehabilitation of the wrist (early vs. late); and lastly the treatment of malunions of the Distal Radius after trauma; are some of the points of controversy and represent areas where more research is warranted.

The aim of this project is to provide some new evidence in order to clarify the points of discussion and controversy.

The man that knows his past understands better the present and can plan a better future...

Surgery of the wrist and treatment of distal radius fractures is probably as old as human civilization itself. This is not surprising since the wrist with the hand and the forearm is one of the body parts more exposed to trauma whether from injuries while hunting, from accidents, falls, or simply from battling. The treatments and knowledge obtained from the Greek culture for the treatment of fractures are of interest. The Epidaurus Museum in Greece, where the first Asclepion was established in the fifth century B.C., has surgical instruments that seem to be tools for the treatment of fractures. Hippocrates (460 – 356 B.C.) documented all the contemporary knowledge of his time in 28 volumes; he included one section entitled "Fractures and Reduction of Dislocations". Vesalius (1543) described and illustrated the anatomy of the distal radius in his anatomy text book "The Humani Corporis Fabrica" [9].

In the 19th century, long before the advent of radiography, surgeons were describing fractures of the upper extremity and their treatment. Hind published an
illustrated manual in 1836 entitled "Fractures of Extremities", describing his dissections of the upper extremity, including descriptions regarding how fractures may occur and what deformity patterns can be expected according to the muscle insertions and their actions.[10] Astley Cooper from Guy’s Hospital in London wrote a “Treatise on Dislocations and Fractures of the Joints”[11] in 1822 based on his prior lectures. It included detailed descriptions of distal radius fractures. Both Guy and the French surgeons Petit (1723) and Pouteau (1783), described the so-called Colles’ Fracture (a dorsally displaced extra-articular fracture) prior to Colles in spite of Colles’ belief that the fracture “had not been described by any other author”[12]. But it was not until Lippman’s work in 1932 that the dorsally displaced distal radius fracture was described in detail[13]. Other important surgeons in France at that time such as Goyrand (1832), Diday (1837), Nelaton (1844) and Malgaine (1850) were treating distal radius fractures and were referenced by Buxton in 1966 for their various contributions.[14]

A surgeon from Ireland, Robert William Smith (1807-1873), described an extra-articular fracture with volar displacement in 1847[15]. Barton, a surgeon from the United States, working in Pennsylvania, described the anteroposterior fracture-dislocations of the wrist, in particular those in which the carpus was displaced volarly upon fragments broken from the anterior articular surface of the lower end of the radius[16]. Barton’s fracture and his opposite homologous, the reverse Barton’s fracture, are difficult to treat and hold in a reduced position. Following Ellis recommendation for volar plating in 1965, this is one of the few fracture types for which the treatment is agreed upon.

Several books written in the 1870’s established immobilization with a wooden splint as the standard treatment. In 1852 the Dutch army surgeon Matthijsen developed a way to impregnate bandages with plaster of Paris. The immobilization of fractures through this method did not change over a century and still is in current use, especially for non-complicated extraarticular distal radius fractures and wrist fractures in the pediatric population[17].

The use of fixation devices started at the end of the XIX century when Parkhill used half pins connected by plates to a central clamp to hold fracture fragments [18]. Lambotte[19], from Belgium, was the first to employ percutaneous half pins to a rigid external bar in 1902. This “external fixation” device was the prototype for the current available external fixators. Anderson and O’Neil[20], reported their results using external fixation of comminuted and unstable distal radius fractures. Subsequently, in 1969, Vidal [21] and collaborators improved the biomechanics of this device by
adding the concept of quadrangular constructs and double bars upright the fractured bone. Bohler[22, 23] created the pins and plaster technique, which was one of the most commonly used treatment methods until recently. During the 1970s and 1980s, reduction and maintenance of Colles’ fractures by “ligamentotaxis” became very popular besides Bohler’s technique.

Distal radius fractures were generally felt to be straightforward to treat with relatively limited impact on function until Bacorn and Kurtzke[24], and Gartland and Werley[25] emphasized the potential impact of these fractures. The former[24] demonstrated the direct correlation of residual angulation and decreased motion and disability, and the later[25] reported high rates of unsatisfactory outcome with cast immobilization. This relative complacency persisted until the 1980’s when several reports emphasized the potential for functional problems with malunion of the distal radius.

In the 1980’s, external fixation was promoted as superior to cast immobilization by Cooney[26], Vaughan[27] and Nakata[28]. Melone [29], in 1984 proposed his four part classification for intraarticular comminuted distal radius fractures and their predictable components. He highlighted the need for open reduction and internal fixation of the volar lunate facet fragment.

In 1986, Knirk and Jupiter[30] emphasized the occurrence of arthritis when radiocarpal articular incongruity is present. Furthermore, they pointed out that ligamentotaxis could reduce the die-punch fragment only in 49% of the cases. In 1990, Bartosh and Saldana[30] demonstrated in a cadaveric model that ligamentotaxis could not always restore the radiocarpal alignment to preinjury status, especially for palmar articular fragments. This report confirmed the common clinical finding that some distal radius fractures cannot be reduced by closed means.

During the late 90s, internal fixation was promoted and several distal radius specific implants were introduced. Dorsal plates with lower profile for better tolerance of the tendons, plates with shapes designed specifically to fit the distal radius, and—most importantly—plates with angular stable screws (fixed angle locking screws) were introduced. [31-44].

Current areas of controversy include debate regarding the superiority of external fixation versus open reduction and internal fixation. External fixation is associated with pin-track infection; the cumbersome nature of fixator wear; the potential for stiffness after prolonged immobilization; and a potentially higher risk of non-anatomic reduction. Open reduction risks include tendon irritation or injury, perhaps more so if
the implant is made of Titanium.[45-48]. Many surgeons and implant manufacturers claim that internal fixation will allow earlier wrist motion, thereby improving ultimate function.

**Aims of the Thesis**

The aim of this thesis is to focus in the following points:

1. To determine if there is any difference in terms of inflammatory response between Titanium and Stainless Steel when using plates made of either material when plating distal radius fractures.

2. To establish if there is a difference in terms of clinical outcomes between patients that have received percutaneous fixation pins and/or external fixators as treatment for a distal radius fractures, to those that received open reduction and internal fixation with a volar plate, in a cohort with comparable fracture types.

3. To discuss the dorsal shearing fractures of the distal radius (reverse Barton’s fracture) and report the outcome of a 21 patient cohort that received surgical treatment through open reduction and internal fixation based on a combined approach.

4. To verify if there is any difference in terms of functional and subjective outcome between patients, that after open reduction and internal fixation of distal radius fractures with a volar plate, received early rehabilitation (within two weeks after surgery), to those that received late rehabilitation (four weeks after surgery).

5. To evaluate the long-term outcome after corrective distal radius osteotomy of posttraumatic distal radius malunions in a retrospective cohort of patients as we determine maintenance of correction and functional improvement in final result through one way ANOVA analysis.

6. To propose and evaluate a new corrective osteotomy surgical technique based on volar fixed angle devices and Norian cement for the treatment of posttraumatic distal radius malunion by assessing the functional outcome of this group of patients.
OUTLINE OF THE THESIS

Chapter 1

Chapter one is a general review of the anatomy of the distal radius. It explains in a very concise manner basic anatomic concepts and landmarks from the distal radius necessary to understand ideas and statements further in the thesis. It is part of a book chapter written by the PhD candidate to ‘The Handbook of Fractures’

Chapter 2

There is an increasing trend in the treatment of distal radius fractures towards open reduction and internal fixation instead of closed reduction and any type of percutaneous fixation, especially if the fracture involves the articular surface.[2, 49-51] Two materials are used for internal fixation devices: 316L stainless steel and titanium alloy (titanium-6-aluminum, 4-vanadium). Both have demonstrated to provide adequate fracture fixation in clinical human research and animal models; however, there is no evidence indicating whether stainless steel or titanium is better suited for osteosynthesis of fractures of the hand or wrist. Some advocate for Titanium due to its less stress shielding forces when compared to steel[52-54], its biocompatibility[2, 55], and its markedly decreased artifact streaking and scatter during radiological imaging exams[45, 56, 57]. Others prefer stainless steel due to the tissue blackening caused by titanium black debris generation[58, 59], and the increased cytokine production documented with this material[60, 61] in addition to the higher cost that represents its use[62]. Also it is widely documented that stainless steel implants are easier to remove than those made from titanium, facilitating in numerous occasions subsequent treatment after the initial
In this study we analyzed the soft-tissue response to both, titanium and stainless steel implants, when used to fix distal radius fractures in a rabbit model. The bone implant interface, tenosynovium, and overlying extensor tendons and muscles were studied histologically to determine the soft-tissue and inflammatory response to both materials and their time correlation.

The primary hypothesis tested in this animal model was that production of metallic and particulate debris is a consequence of active excursion of the undersurface of the extensor tendons over the dorsal surface of the implant. These particles then will be uptaken by macrophages, which will activate fibroblasts and inflammatory cells. These particles then will become surrounded by collagenous fibers. The cytokines produced by inflammatory cells ultimately will compromise the infrastructure of the tendon causing its final rupture. We have hypothesized a correlation between time and the number of both generated debris particles and cells.

Our second hypothesis stated that there also might be a difference in the degree of inflammation and tissue response to titanium and stainless steel implants.

Chapter 3

Lozano Calderón SA, Doornberg J, Ring D. “Retrospective comparison: Volar plate vs. Percutaneous Fixation of Distal Radius Fractures.” In Press Hand

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The operative treatment of unstable fractures of the radius has become well accepted in order to limit the potential for re-displacement in a cast, arthritis, stiffness, weakness, and pain related to malunion[1, 2, 50, 51, 64, 65]. External fixation was associated with stiffness of the hand and wrist and an increased potential for reflex sympathetic dystrophy (now known as chronic regional pain syndrome type I)[66], even though the etiology of this condition has not been totally clarified. Recent evidence from animal models has suggested P substance signaling as the main mechanism explaining the complex regional pain syndrome type I (CRPS-I). According to Guo's and Offley's findings, P substance is responsible for the vascular changes and the altered nociceptive response observed in a model where rats developed CRPS-I after casting or sustained
tibial fractures. However, the connection between the methods of fixation and the probability of any of them causing P substance release or other physiologic mechanisms etiologically responsible of CRPS-I have yet to be addressed.

More recently, it has been recognized that the wrist is like the hand in that external fixation and other percutaneous fixation techniques have the benefit of not causing additional trauma and scarring of the tendons. In particular, dorsal plates have been problematic in this regard and have been associated with diminished results with respect to external fixation in a prospective randomized trial of the treatment of articular fractures. (Ellis, weiland, 2006)

Volar plate fixation has gained acceptance recently as a means of providing stable internal fixation, while avoiding the tendon problems associated with dorsally applied plates. There is more room for a volar implant, and there have been fewer complications when volar implants are used for volar Barton’s (shearing) fractures or for Smith’s fractures (extra-articular volar bending fractures), although rupture of the flexor pollicis longus is occasionally observed. Volar plate fixation of dorsally displaced fractures is most reliable when a plate with screws that lock to the plate is used—so-called angular stable fixation.

We reviewed a single surgeon’s consecutive experience with extra-articular and simple articular fractures of the distal radius to determine whether volar plates are comparable to percutaneous fixation or if they are associated with stiffness and tendon problems similar to dorsal plates. Because the surgeon changed his preferred treatment option at a relatively discrete point in time, but not the indications for surgery, a retrospective cohort study looking at patients treated percutaneously and those treated with a volar plate has value. Both groups were assessed in terms of functional outcomes and complication rates. Our hypothesis stated that there are not statistically significant differences between patients treated with either method of fixation in terms of function, complications or final radiographic result.

Chapter 4


The original Barton’s fracture—a shearing fracture of the margin of the articular surface with subluxation of the radiocarpal joint—seemed to be volar in
direction. However, currently at least in North America, the eponym “Barton fracture” is used to refer to the more common and prevalent volar shearing fracture of the distal radius[75-80]. It has become clear that volar marginal shearing fractures with volar radiocarpal subluxation are far more common. As a result, the eponym Barton now refers more commonly to this volar fracture. While numerous papers have been written regarding volar shearing fractures of the articular surface, very little data have been provided regarding dorsal shearing fractures, with the exception of one area of overlap with dorsal shearing fractures—radiocarpal fracture-dislocations.

In this chapter, we present a retrospective case series of 20 patients with this type of distal radius fracture, presenting their functional outcome after open reduction and internal fixation through single dorsal, single volar and combined volar dorsal approach. Pitfalls for treatment and some guidelines of pattern fracture evaluation are suggested to understand this uncommon fracture of the distal radius. Our hypothesis stated that dorsal shearing fractures involve a wider spectrum of fracture patterns that do not fit in any of the conventional classification systems. These different patterns may be characterized into a subclassification system that could guide treatment and proportionate pitfalls that might improve the final outcome of a severe injury in which currently prognosis is not particularly good.

Chapter 5

Lozano Calderón SA, Jupiter JB, Mudgal Ch, Ring D. “Prospective Randomized Comparison of Early and Late Wrist Mobilization after Volar Plate Fixation of a Fracture of the Distal Radius” In Press Journal of Bone and Joint Surgery [Am]

Over the last three decades, operative treatment of distal radius fractures has become increasingly common compared to non-operative treatment[64, 69, 81-88]. Over the last 15 years there has been a trend towards more invasive, internal plate fixation of fractures of the distal radius[89, 90]. One argument in favor of internal fixation for these fractures is that, similar to other periarticular fractures, it would be beneficial to allow early movement of the wrist articulation. There is not, however, any data to support this statement. In fact, data regarding external fixation that either immobilizes the wrist or allows wrist motion suggest that early wrist mobilization is not as important as the overall alignment of the bone in terms of final wrist motion. This question is important in patient care and in decision-making regarding these fractures.
Additionally, many companies use this claim as a marketing point in spite of the lack of evidence. We performed a prospective controlled randomized trial in which we compared the functional results at three and six months in patients who sustained wrist fractures and were treated surgically with volar plates, after receiving either early or late rehabilitation protocols. Our primary hypothesis stated that not significant differences would be seen in terms of DASH scores when comparing both groups, early vs. late rehabilitation-. Secondary hypotheses stated no significant differences between both groups in regards final range of motion, level of pain and grip strength.

Chapter 6


Union with deformity is the most common complication following a distal radial fracture[91, 92]. This deformity can be intra-articular, affecting either the radiocarpal or radioulnar joints; extra-articular characterized by metaphyseal angulation and loss of length; or it may be a combination of both[91, 92].

Corrective osteotomies have been proven to be an effective treatment for symptomatic malunion [91-101], even though it is a challenging procedure that has many pitfalls in order to achieve a good result. There is short and medium term outcome evaluation in the published literature[91-93, 95, 96, 99-158]. However, there is a lack of evidence supporting subjective and objective functional and radiological long-term outcomes in patients with distal radius malunion, treated with extra or intra articular distal radius osteotomy, [102, 127-129, 159-162]

Chapter 6 reviews retrospectively the long-term functional outcomes of a cohort of 12 patients treated at the Academisch Medical Centre (AMC), Amsterdam. Through independent student t-test and one-way ANOVA analyses, different radiological parameters are analyzed as variables susceptible to change over time. The functional results at the13-year follow-up are compared to those reported for the short-term and medium-term in other cases series to compare and test differences.

Our hypothesis states that corrective osteotomies of the distal radius for the correction of distal radius malunion is an adequate surgical treatment, which provides satisfactory radiological and functional results in the long-term follow-up (more than
6 years). The results found in the long-term may be comparable to those seen in the short- and medium-term follow-up.

Chapter 7


As previously stated, corrective osteotomies have been proven to be an effective treatment for symptomatic malunion[94, 144]. A variety of techniques have been used, however, there has remained concern regarding the indications for surgical intervention in the presence of underlying osteoporosis, as well as the recognized morbidity associated with autogenous iliac crest bone grafting[163-165]. Technical advances including the use of precontoured internal fixation devices with angular stable fixation, as well as the use of osteointegration biomaterials have offered some advantages. The contoured implants facilitate osteosynthesis by providing higher stability even in osteopenic bone.[166-172] These implants afford osseous fixation that allows early motion and rehabilitation[50]. Also their precontoured shape maintains desirable patterns of alignment, congruency and inclination of the distal radius after corrective osteotomy[2, 50, 90]. These properties reduce the probabilities of screw loosening and consequent loss of reduction [4, 20]. Following osteotomy and achievement of proper angulation and alignment, there will exist a three-dimensional defect that must be filled in order to adequately support the bone fragments [173-177]. Autogenous bone grafts have been widely used for this purpose. They have a recognized potential for donor site morbidity, in particular those involving corticocancellous variants[163, 165, 178]. Materials such as polymethylmethacrylate (PMMA) and osteoconductive biomaterials such as Norian Skeletal Repair System (Norian SRS)® offer structural support eliminating the effects of donor site morbidity [173-177]. Experience with polymethylmethacrylate (PMMA) has shown lack of osseous integration[176, 177]. In contrast, prospective randomized trials demonstrated good clinical and radiological results with osteoconductive synthetic materials such as Norian SRS®[173-177].

In this chapter, we present a new surgical technique involving the use of these described technologies in order to treat elderly patients with osteoporosis and distal radius malunion. We report their functional outcome after two years of treatment.
Our hypothesis stated that the final functional outcomes after treating patients with this innovative surgical technique are comparable to those reported in other standard techniques.

**GENERAL DISCUSSION**

This part contains the general discussion of all the obtained results from the different studies involved in this thesis. Chapter by chapter, each of the previously listed controversies will be discussed in light from the available published literature and the results of our research.

*Summary of the Introduction:*

The purpose of this Doctoral Thesis is to contribute to clarify some of the issues that currently generate more controversy in the treatment of fractures of the Distal Radius, their rehabilitation and treatment of their most common complication, fracture malunion. Specifically, this Thesis will address the following study questions:

**Chapter 1:**

General Aim: To review the basic and general anatomy of the Distal Radius in order to provide a good basis for understanding the following chapters.

Specific question: What are the anatomic osseous landmarks of the Distal Radius and their clinical relevance?

**Chapter 2:**

General Aim: To determine the inflammatory response to Titanium and Stainless Steel implants when used to treat distal radius fractures in a rabbit model.

Specific questions: Is there any difference between Titanium and Stainless Steel in terms of inflammatory response? Is the production of particles or the cellular response different between these two materials? Is there any influence of factors such as the time that the implant remains in situ, tendon excursion, or the material itself?

**Chapter 3:**

General Aim: To determine if there is any difference in terms of functional and subjective outcome or incidence and type of complications between percutaneous fixation methods and volar plating for the treatment of Distal Radius fractures.
Specific questions: Is there any difference regarding DASH scores in patients treated through percutaneous fixation when compared to those that received volar plating? Are there any differences in terms of functional outcomes between these two groups when using the Modified Mayo Wrist Score and the Modified Gartland and Werley Score? Are these groups substantially different in terms of range of motion and grip strength? And to conclude, are the complications similar between both methods? Are the rates of incidence comparable?

Chapter 4:
General Aim: To report a large series of a type of fracture—dorsal shearing fracture of the distal radius—that is very infrequent and therefore poorly described in the published available literature.
Specific questions: What are the pitfalls for the surgical treatment of this type of fracture after following this series? What is the functional outcome that can be expected from patients that experience this type of injury and receive surgical treatment?

Chapter 5:
General Aim: To clarify what method of rehabilitation—Early or late protocol—has a better clinical impact in patients treated with volar plates after distal radius fractures.
Specific questions: Is subjective outcome (DASH Score) different between these two groups of patients? Are there any differences between patients that had early rehabilitation when compared to those that had late in terms of functional outcome instruments such as the Modified Mayo Wrist Score and the Modified Gartland and Werley Score? Can differences be expected in terms of final range of motion or strength? Is the pain recovery pattern similar between both groups?

Chapter 6:
General Aim: To establish the long-term follow-up in patients that were treated surgically for distal radius malunions.
Specific questions: What is the subjective outcome (DASH Score) that can be expected after this type of surgery? What is the clinical long-term outcome that can be expected in regards to range of motion and grip strength? What functional outcome follows this surgery when patients are assessed through the Modified Mayo Wrist Score and the Gartland and Werley Modified Score?
Chapter 7:

General Aim: To describe a new surgical technique for distal radius osteotomies using the benefits of two technologies: Angle fixed implants and Norian Cement.

Specific questions: What are the pitfalls of this new technique for the treatment of distal radius malunion? What is the impact of this technique in terms of patient subjective functional evaluation -DASH score-? What are the functional outcomes that can be expected in terms of motion and strength after 2 years follow-up? What is the objective functional outcome quality increase after these patients are assessed post surgically with the Modified Mayo Wrist Score and the Modified Gartland and Werley Score?

REFERENCES


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