



IFSSH Scientific Committee on Degenerative Arthritis – Distal Radioulnar Joint

Chair: Luis R. Scheker (USA)

**Committee: Chris Milner (United Kingdom)
Ilse Degreeef (Belgium)
Gregory I. Bain (Australia)
Eduardo R. Zancolli III (Argentina)
Richard A. Berger (USA)**

Report submitted April 2014

Part 1: Overview of Degenerative Arthritis – Distal Radioulnar Joint

Introduction

Disease of the distal radioulnar joint (DRUJ) has challenged the medical profession for centuries and has been approached through a diverse spectrum of medical and operative strategies. Where for decades, the mainstay of treatment for advanced DRUJ pathology has taken the form of distal ulna ablation, the modern era of advanced biomaterials has now coupled with new insights into the structure and function of the DRUJ to culminate in a complete repertoire of techniques to effectively address DRUJ pathology in all its forms, without sacrificing its essential role in hand function.

This review has been compiled by an international panel of hand surgeons, all with extensive expertise in treating DRUJ pathology even though collectively they have a broad range of opinion on the subject. Part 1 begins by summarizing the latest ideas regarding osteoarthritic joint degeneration and its medical management, before looking at the structure and function of the DRUJ. This is followed by an evaluation of how OA impacts the DRUJ. Part 2 includes a history of how DRUJ OA has been surgically addressed and details current techniques including how these can help in the salvage situation following DRUJ ablation.

Articular Cartilage and Degenerative Joint Disease

Structure, Function and the Pathobiology of Osteoarthritis

Articular (hyaline) cartilage is a 2-4mm thick white layer of highly specialized tissue that forms the interfacing surface between bones that articulate within diarthrodial synovial joints¹. The functional requirement of articular cartilage is to withstand and efficiently transmit load across the joint under both static conditions and during movement of the joint surfaces during articulation. Successful dynamic load transfer requires the articular cartilage to maintain a very low frictional coefficient even where local pressures reach high levels and this role must be maintained throughout the lifespan of the individual. Therefore, the health and function of the joint is dependent upon its correct initial formation during embryogenesis, maintenance during use and repair after injury. The structure of articular cartilage reflects these requirements and consists of highly specialized articular chondrocytes embedded within a tightly regulated extracellular matrix (ECM) scaffold of collagen and ground substance. Through the careful arrangement of structural collagen types II and IX around the extremely hygroscopic aggrecan-containing ground substance, articular cartilage is able to maintain a very smooth surface at the joint line in conjunction with structural

resilience to applied loads. The synovial fluid contains lubricin and hyaluronan (HA) that both minimise frictional resistance and also deliver oxygen and nutrients to the isolated but metabolically active synoviocytes locked within the cartilage matrix. Finally, the highly vascular synovium controls synovial fluid composition and plays an essential role in cartilage homeostasis and repair following injury ².

Traditional descriptions of OA classify the disease into either primary or secondary types. Primary OA develops in previously intact joints with no obvious cause, whilst secondary OA follows a defined pre-disposition such as trauma, septic arthritis, joint instability or other identified syndromes with recognized joint involvement. However, these distinctions have increasingly lost their simplicity as evidence now demonstrates an inextricable interdependence between cause and effect in what is considered to be a multifactorial disorder involving interplay between genetic and environmental components ³⁻⁵.

Regardless of what initiates the cartilage damage in OA, a pathophysiological vicious circle of progressive cartilage damage and ineffective repair is triggered that ultimately leads to the typical signs and symptoms of OA. There is now no doubt that inflammation has a central role in driving this destructive process⁶. This evidence comes from numerous angles of investigation that demonstrate a physiological inter-dependence of all joint tissues including the synovium, subchondral bone, support ligaments, muscle and the articular cartilage itself ^{2,4,6-8}. Inflammatory joint synovitis in early-stage OA demonstrates hyperplasia, cellular infiltration, vasculogenesis and fibrosis ^{2,7}. The associated endothelial activation allows both the loss of lubricating HA and lubricin molecules and ingress of inflammatory cells and complement in the joint space, bathing the articular surface in hostile factors instead of the nutritive properties of normal synovial fluid ⁹. This, together with possible direct injury to the cartilage itself, produces a phenotypic switch in the resident chondrocytes from their quiescent state to that of hypertrophic calcifying chondrocytes, normally only seen during embryogenesis of bone ¹⁰. These changes are induced in response to circulating cytokines including IL-1 β and TNF and are central to the pathological destruction of the articular matrix through their expression of bone-related MMPs 3, 9 and especially 13 ³. Despite the ECM destruction, articular chondrocytes attempt repair by synthesizing new ECM components, but these fail to distribute and assemble correctly ¹¹. At a macroscopic level, the accelerated and disorganized ECM remodelling process results in swelling and microscopic surface roughening of the cartilage surface known as fibrillation that is associated with a reduction in gliding properties ¹¹. Clinically, this is reflected in the loss of sheen of healthy articular cartilage when viewed through an arthroscope or by the naked eye. Fibrillation renders the joint susceptible to further friction-induced surface wear every time the joint is moved that exacerbates the damage and potentiates the inflammatory stimulus. In addition to ineffective remodelling of the ECM, articular chondrocytes also calcify the remaining cartilage in keeping with their hypertrophic phenotype, and this thins the overall depth of articular surface covering the subchondral bone. The subchondral bone also alters, undergoing sclerosis, with peri-articular osteophyte formation and reduced overall mineralization. This results in a weakened foundation for the overlying articular cartilage that unfortunately occurs right below areas of greatest

applied joint surface load ⁴. These osseous changes reflect the typical bone oedema seen on MRI scanning of subchondral bone in joints affected by OA.

Epidemiology and the worldwide burden of OA

Osteoarthritis (OA) is the most common form of arthritis and ranks amongst the top three causes of disability in the USA ^{12,13}. OA is increasingly prevalent in older age, with a female preponderance that is typically more severe, with hand and knee involvement seen more frequently when compared to disease in male patients. OA is a heritable condition, varying by site and with an inherited component of between 50 and 65% ^{14,15}. Familial studies have revealed higher rates of OA in monozygotic versus dizygotic twins and it is more common in first degree relatives and siblings of affected individuals than in the general population ¹⁶. Racial patterns of susceptibility also exist with high rates of hand and hip OA in Caucasian populations as compared to people of Asian descent, whereas the reverse holds true for knee arthritis.

At the population level, 12.1% of the US population were shown to have clinically apparent OA in at least one joint, giving a figure of 26.9 million from population census figures for 2005 ¹². If this figure is extrapolated forward to indicate the proportion of the US population with OA in 2013 it rises to 28.8 million (data from US Census Bureau). Assuming similar prevalence rates throughout the world, this gives a worldwide figure of 648.8 million people with OA, and given the high immigrant representation within the US population, this estimate of world OA burden may not be an entirely unreasonable one. Despite increasing incidence by age, there is still a significant proportion of individuals affected by OA who are of working age and several studies have examined the socio-economic impact associated with loss of productivity secondary to symptomatic OA ^{13,17,18}. Using the 2009 National Health and Wellness Survey, DiBonaventura found that workers with symptomatic OA were more likely to be older, female and with a higher BMI, and there was also a significantly higher usage of healthcare resources, including medical costs 1.5 times higher than those associated in workers without OA. OA has also been shown to develop in younger age groups who are involved in heavy manual labour, with other studies estimating up to 12% of symptomatic OA following trauma when considering disease of the hip, knee or ankle. This is associated with a potential healthcare bill of 0.15% of the total health care cost per annum ^{18,19}.

For OA specific to the hand, the prevalence was found to be 27.2% overall in the Framingham study of 2400 participants of age 26 or greater, rising to over 80% in older individuals (with values considerably lower than this found in another study which identified symptomatic OA in patients over 60 years of age to be only 8%) ^{12,20}. Extrapolating these values for hand OA to a national level, Lawrence et al estimated the prevalence of symptomatic OA to be in excess of 13 million people in the USA based on population statistics for 2005. OA figures specific to the DRUJ are harder to evaluate, as there are few studies that provide epidemiological data that includes disease in this joint. Nevertheless, in a cross-sectional study of ulnar sided wrist pain, Katayama et al

found 12.3% of 1128 patients had radiographic evidence of primary OA of the DRUJ ²¹. Due to the selective nature of subjects included in this study, it is impossible to relate DRUJ OA to overall rates of hand or total OA at a population level.

Current Approaches to Medical Treatment of Osteoarthritis

Unlike the revolutionary development of disease modifying drugs available for rheumatoid arthritis (RA), OA remains frustratingly elusive to similar attempts at arresting the pathological disease process. Therefore, whilst there are tried and tested techniques of pain management, the inexorable progression of joint damage in OA is often addressed through surgical joint reconstruction and the expansion in the arthroplasty industry reflects this. The current paradigm for non-surgical management in OA in general is therefore to address pain and optimise joint function such that the morbidity of the disease can be reduced to a minimum for the longest period of time possible before surgery becomes unavoidable.

In general terms, preservation of joint function is achieved through a combination of physical therapy, patient education, and pain control ²². For pharmacological pain management in mild to moderate OA, there is a major reliance on simple drugs such as acetaminophen and NSAIDS. Opioid drugs are useful in moderate to severe OA pain but again bring their own side effects including constipation and possible dependence. In patients who eventually fail to obtain durable pain control from these analgesics, temporary joint splintage and intra-articular or oral steroid therapy can bring effective symptom control. Such patients frequently undergo serial steroid administration in an attempt to stave off surgery for as long as possible. Other attempts to improve joint function and pain control have seen some success through the intra-articular injection of HA, especially in its highly cross-linked form. Nevertheless, HA is expensive and has not been shown to arrest disease progression or attain a clear advantage for symptom control over NSAIDS. Likewise, Glucosamine and Chondroitin sulphate have been purported to have a beneficial effect on symptomatic OA but their beneficial effect has yet to be conclusively demonstrated in clinical trials.

The use of biological disease modifying drugs (DMDs) that have been so effective in RA have so far shown mixed results in OA despite the core inflammatory process at the heart of both disease processes ⁶. The mixed results seen with anti-TNF and anti-IL-1 drugs may be due to the small number of existing human studies, compounded by the diverse modes of drug administration used. Ongoing trials in this area may hopefully replicate the positive results and definitive inhibition of joint deterioration conclusively seen in animal studies.

Finally, there is increasing interest in the use of mesenchymal stem cells (MSC) to treat OA. It is postulated that the pluripotent nature of MSC make them well placed to counteract the OA phenotype through down-regulation of the inflammatory process, and restitution of the correct articular cartilage framework both through modulation of the behaviour of resident chondrocytes and direct ECM generation ²³. Certainly, there is

now clear in-vitro evidence for chondrocyte behaviour control by MSC, and initial reports of its therapeutic use in animals are encouraging. To date, the very limited reports of MSC use in human OA have not demonstrated successful reconstitution of lost articular cartilage, but have reported symptomatic improvement²⁴. Concerns with MSC therapy include unwanted cell migration distant from the site of joint administration and secondary expression of unwanted phenotypic behaviour such as bone formation. There are also concerns over the generation and /or potentiation of neoplastic cell growth and disease transmission during the in-vitro cell processing stages prior to clinical use.

Osteoarthritis and the Distal Radioulnar Joint

Basic Anatomy and Function of the DRUJ

The DRUJ forms the distal half of the bicondylar articulation between the forearm bones that, in association with the proximal component, provides for up to 150 degrees of pronosupination of the forearm²⁵. This motion makes up a great proportion of hand functionality and is essential for activities of daily living. The difference between the DRUJ and other bicondylar joints such as the knee and the digital interphalangeal joints is that in the forearm, each bone has a condyle at one end. The proximal condyle (radial head) of the radius articulates with the lesser sigmoid notch or radial notch of the ulna. Distally, the ulnar condyle (ulnar head) articulates with the radius at the sigmoid notch. The two areas of contact between the radius and ulna form the radioulnar joint, with the proximal half known as the proximal radioulnar joint (PRUJ) while the distal half is the DRUJ. Both halves move together, and pathologies affecting one part will affect the other. The radius and ulna have different functions and their anatomy reflects this. The ulna is relatively straight in shape and, through its articulation with the humerus, provides flexion and extension of the elbow by virtue of the insertion of the brachialis distal to the coronoid process of the ulna and the triceps insertion into the olecranon. In contrast to the ulna, the radius has a curved “S” profile, with a broad funnel-shaped distal end composed mainly of cancellous bone that is responsible for accepting axial load and transferring it through its shaft towards the radial head and capitellum. The radius is attached to the ulna by the annular ligament proximally and the triangular fibrocartilage complex (TFCC) distally. At the DRUJ, the radius and ulna have differential radii of curvature, making this hemi-joint incongruent with only a thin line of direct cartilage contact, akin to the contact point of a car tyre to the road surface. This discrepancy permits slight translation of the radius in the antero-posterior plane during pronation and supination as it rotates around the head of the ulna. If the TFCC were tight enough to prevent translation in neutral rotation, there would be no pronosupination possible. Indeed, much work has been performed to understand the exact role of the deep and superficial fibres of the distal radioulnar ligaments (DRUL) that regulate the tightly controlled transition from full pronation to full supination²⁵⁻²⁷. As the sigmoid notch moves from full supination to full pronation,

its contact area with the seat of the ulna reduces to as little as 10% of the available joint surface in full pronation ^{28,29}. In considering the part played by the interosseous membrane (IOM) in DRUJ stability, it is erroneously ascribed the function of axial load transfer between the radius and ulna. As shown by Skahen et al, the tension in the central band of the IOM during axial loading of the forearm is actually very little unless the radial head is excised, indicating a major load transfer directly to the humerus via the capitellum of the radius ^{30,31}. Rather, the two most important functions of the IOM are firstly to unify the radius and ulna into a single unit during full supination for the purposes of lifting; a situation where the IOM is under tension and thereby converts the radius and ulna biomechanically into a single structure that the biceps and brachialis can act in concert upon as pure elbow flexors. The other function of the IOM is that of preventing excessive bowing of the curved radius as seen in boxers like Frank Bruno, who could generate 1420lb or 53g of acceleration to the head of their opponent ³². Whilst there are additional stabilizing roles ascribed to the ECU tendon and subsheath, ulnocarpal ligaments and pronator quadratus, the principal stabilizing structures at the DRUJ are the dorsal and volar distal radioulnar ligaments of the TFCC complex.

Functionally, the forearm has the important task of placing the hand in the positions necessary for its work and, in so doing, has to handle two discreet sets of forces acting upon it. Firstly, the forearm must handle axial loads that pass principally through the radiocarpal interface such as in hand grip or pushing against resistance such as in opening a door. Secondly, the hand and any associated carried load must be supported against the force of gravity and this is the function of the ulna ^{28,33,34}. Whilst the biceps and brachioradialis have been described as having roles in forearm flexion, biophysical studies have demonstrated that elbow flexion is principally the action of the brachialis muscle where it inserts into the coronoid process of the ulna. The biceps is primarily a supinator until full supination is reached (see above) whilst brachioradialis cannot voluntarily be activated without simultaneous triceps activation and therefore acts principally as a modulator of elbow movement ³⁵. If this is appreciated, then the importance of the joint reaction force provided by the head of the ulna in supporting the hand and radius can be realized ³⁶. It was with the dynamic radiographic studies performed by Lees and Schecker that the loss of the supporting function of the ulnar head was emphatically demonstrated in patients who had previously undergone ulnar head removal during the Darrach or Sauve-Kapandji procedures ³⁷. In these experiments, painful impingement of the ulnar stump against the radius was easily reproduced when the patient was asked to bear weight in the ipsilateral hand (Figure 1). Therefore, in evaluating any existing or proposed new DRUJ reconstructive procedure, it is essential to evaluate the lifting capacity of the forearm before passing judgement on its success or otherwise. Finally, if the supporting role of the ulna is appreciated, then the manner of current reference to DRUJ instability can become misleading. For example, instability, subluxation and dislocation of the DRUJ are typically defined on the basis of the ulnar head placement relative to the radius and radiocarpal joint. For example, if the ulnar head is prominent dorsally, it has traditionally been referred to as “dorsal dislocation of the ulna”. In reality, these positions of joint instability are brought into being through gravitational forces acting on

the unsupported radiocarpal unit and it is in fact, the ulna that is in the correct position. It is therefore the radius that has subluxed or dislocated.

In order for the forearm to perform its functions correctly, all of its anatomical components must be maintained, and therefore it is essential to address and restore normal anatomy following fracture or ligamentous injury.

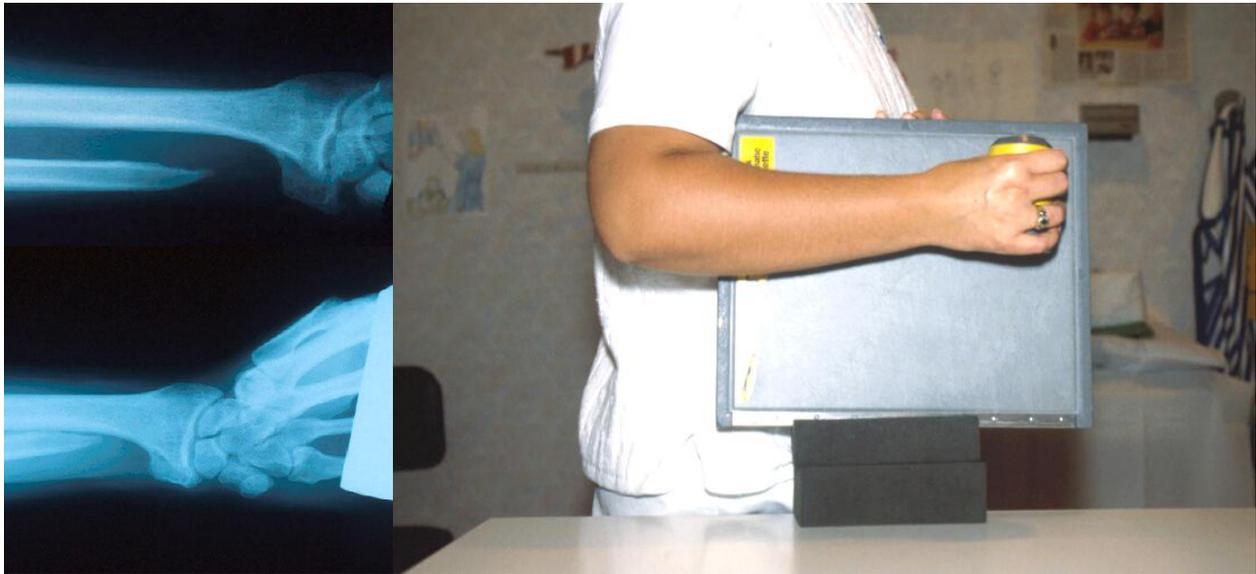


Figure 1: *Dynamic lateral forearm radiograph demonstrating ulna impingement upon the radius as it supports the carpus and hand against the force of gravity. Upper X-ray – conventionally acquired A-P view, lower X-ray – dynamic film taken with the patient holding a weight against gravity. Note the wear pattern on the contact surface of the ulna from regular such impingement during activities of daily living.*

Osteoarthritis at the DRUJ

Osteoarthritis can affect any synovial joint and the DRUJ is no exception. As in other areas of the body, DRUJ OA develops from both primary and secondary causes. In addition to the acquired abnormalities of ECM component structure and function discussed above, primary OA specific to the DRUJ is more common in females, and is associated with positive ulnar variance ^{21,38}. Secondary causes of DRUJ OA are extensive but generally result from either pathological incongruence or instability at the DRUJ, and follow either direct or indirect trauma from fracture or injury to the soft tissue stabilizing structures, namely the distal radioulnar ligaments. Instability describes the abnormal path of articular contact that occurs either during or at the end of the range of motion and may follow an alteration in joint surface congruence, as well as deficiencies in the controlling distal radioulnar ligaments that permit excessive movement and shear force across the joint. Incongruence at the DRUJ describes an alteration to the precise point of contact between the joint surfaces that can produce

unnatural joint loading and accelerated wear, as seen in congenital DRUJ abnormalities such as the Madelung deformity, following direct articular damage from distal radial fractures, or after acute or longstanding loss of normal joint biomechanics through instability (For the purposes of the rest of this document, incongruence is used in reference to pathological joint mechanics and not the physiological incongruence of the curvatures of the normal radioulnar interface at the DRUJ). Specific causes of instability include direct TFCC component damage (including Galeazzi fracture dislocations), distal radial malunion, and instability following radial head excision in the Essex Lopresti injury. Other causes of DRUJ dysfunction include arthrosis following infection and the instability associated with rheumatoid arthritis that fall outside the remit of this review.

If early, treatable joint pathologies are not appropriately addressed, DRUJ arthrosis can develop and manifests clinically with pain on pronosupination of the forearm, especially under load. Assessing the functionality of the DRUJ under such loadbearing conditions is easy and can be achieved by examiner-placed pressure on the patient's wrist whilst the patient is asked to pronosupinate the forearm. This motion loads the DRUJ and will elicit pain if articular wear has developed ³⁹. More advanced OA of the DRUJ is associated with all of the radiographic hallmark features of OA including osteophyte formation, joint space narrowing and sclerosis as well as the so-called scallop sign of sigmoid notch erosion originally described in rheumatoid arthritis (Figure 2) ⁴⁰. More advanced joint destruction can mirror some features characteristic of rheumatoid arthritis at the DRUJ, with volar subluxation of the radius. When joint degeneration reaches this stage, the extensor tendons frequently suffer attrition-rupture over the prominent ulnar head akin to that seen in Vaughan-Jackson syndrome ⁴¹⁻⁴⁴. The functional significance of DRUJ loadbearing and the development of OA are of relevance for two reasons. Firstly, as described above, there is only a small point of direct bony contact across the DRUJ leading to locally high pressures exerted on the articular cartilage. In addition, the movement of this bone contact through pronosupination generates high shear forces across the joint as the radius moves progressively into pronation or supination from neutral at which shear force is zero. With so little direct contact at an incongruent joint interface, the health and integrity of the DRUJ articular cartilage is heavily reliant upon the maintenance of correct joint alignment afforded principally by the distal radioulnar ligaments of the TFCC complex, and to a lesser extent, the secondary DRUJ stabilizers including the interosseous membrane, ECU and subsheath and pronator quadratus fibres ^{26,29,38}.

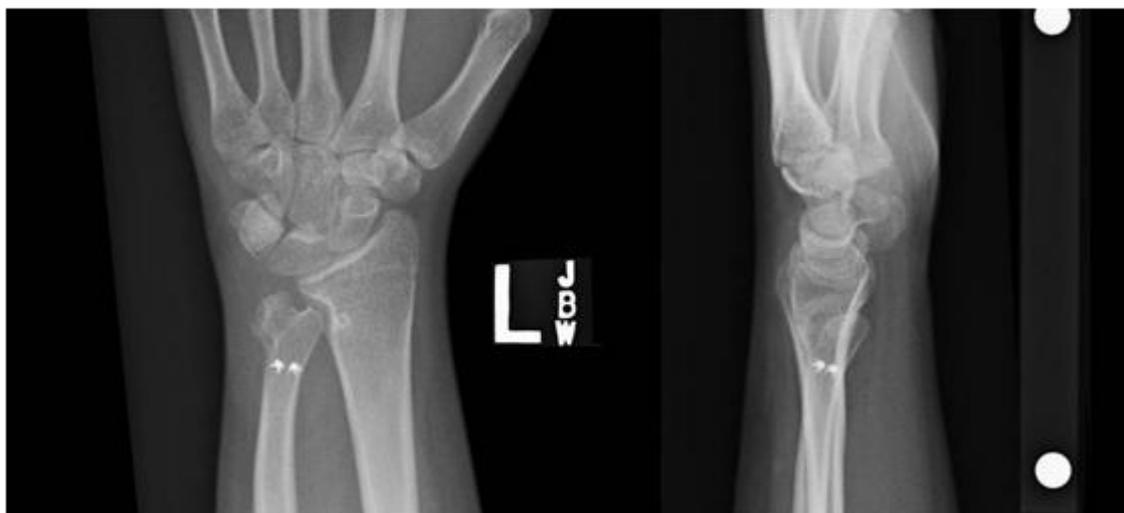


Figure 2: Demonstration of the ‘scallop sign’ in the sigmoid notch of the radius as seen in advanced osteoarthritis of the DRUJ. This X-ray was taken of a 16 year old patient with advanced DRUJ arthrosis following previous forearm fracture and multiple corrective surgeries.

Clinical Aspects of DRUJ Degeneration

Establishing the nature of DRUJ dysfunction in symptomatic patients is an essential task to perform before embarking upon treatment and this must include an appreciation of the load-bearing role of the ulna, be it a problem of incongruence, instability or both. In our experience, the treatment plan should be tailored after assessing the presence, direction and degree of instability, the congruency of the DRUJ, and the ulnar variance. Pathology affecting any of these areas can result in pain, decreased strength, limited range of motion, and loss of forearm function. The following discussion will concentrate on the pathology associated with DRUJ dysfunction that can lead to OA.

Clinical DRUJ instability progresses from dynamic to static in four stages. In stage 1 (dynamic instability), the patient complains of a “giving away” sensation with no obvious clinical or radiographic sign ³⁶. In stage 2 (secondary dynamic instability), the symptoms are the same as in stage 1, but the joint can be subluxed or dislocated. In stage 3 (static instability), limited motion and pain become prominent features. The joint rests in an unstable position, but can be reduced and plain radiographs demonstrate subluxation and malalignment. In stage 4 (advanced static instability), limited motion is the predominant feature, and a fixed deformity is established at the DRUJ, with an increased risk of osteoarthritis. From a pathological standpoint, Bowers has identified four types of instability based on abnormalities within the different structures that make up the DRUJ ⁴⁵. Group 1 includes ligamentous defects, group 2 has loss of ligamentous tension due to deficiencies in intra-articular joint conformation, group 3 comprises a combination of ligamentous and articular surface problems whilst group 4 demonstrates ligamentous deficiency with extra-articular problems, such as distal radius metaphyseal malunion. Although the Bowers classification system is useful for identifying DRUJ pathology, appropriate management is usually based on the stage of

the disease, not the initial pathology. Scheker, Ozer and Babb ⁴⁶ have classified the instability of the DRUJ as:

Stage 1: TFC attenuation.

Stage 2: TFC disruption (no DRUJ dislocation or distal radius fracture).

Stage 3: TFC disruption, DRUJ dislocation (no distal radius fracture).

Stage 4: TFC disruption, DRUJ dislocation, fracture (distal radius fracture, malunion)

Stage 5: Radial instability following ulnar head resection.

References

1. Sophia Fox AJ, Bedi A, Rodeo SA. The basic science of articular cartilage: structure, composition, and function. *Sports Health*. 2009;1(6):461-468.
2. Scanzello CR, Goldring SR. The role of synovitis in osteoarthritis pathogenesis. *Bone*. 2012;51(2):249-257.
3. Li Y, Xu L, Olsen BR. Lessons from genetic forms of osteoarthritis for the pathogenesis of the disease. *Osteoarthritis Cartilage*. 2007;15(10):1101-1105.
4. Lories RJ, Luyten FP. The bone-cartilage unit in osteoarthritis. *Nat Rev Rheumatol*. 2011;7(1):43-49.
5. Pitsillides AA, Beier F. Cartilage biology in osteoarthritis--lessons from developmental biology. *Nat Rev Rheumatol*. 2011;7(11):654-663.
6. Kapoor M, Martel-Pelletier J, Lajeunesse D, Pelletier JP, Fahmi H. Role of proinflammatory cytokines in the pathophysiology of osteoarthritis. *Nat Rev Rheumatol*. 2011;7(1):33-42.
7. Oehler S, Neureiter D, Meyer-Scholten C, Aigner T. Subtyping of osteoarthritic synoviopathy. *Clin Exp Rheumatol*. 2002;20(5):633-640.
8. So A, Busso N. Osteoarthritis: Crystal-gazing into the pathogenesis of osteoarthritis. *Nat Rev Rheumatol*. 2011;7(12):688-689.
9. Lotz MK, Kraus VB. New developments in osteoarthritis. Posttraumatic osteoarthritis: pathogenesis and pharmacological treatment options. *Arthritis Res Ther*. 2010;12(3):211.

10. Drissi H, Zuscik M, Rosier R, O'Keefe R. Transcriptional regulation of chondrocyte maturation: potential involvement of transcription factors in OA pathogenesis. *Mol Aspects Med.* 2005;26(3):169-179.
11. Heinegard D, Saxne T. The role of the cartilage matrix in osteoarthritis. *Nat Rev Rheumatol.* 2011;7(1):50-56.
12. Lawrence RC, Felson DT, Helmick CG, et al. Estimates of the prevalence of arthritis and other rheumatic conditions in the United States. Part II. *Arthritis Rheum.* 2008;58(1):26-35.
13. Dibonaventura M, Gupta S, McDonald M, Sadosky A. Evaluating the health and economic impact of osteoarthritis pain in the workforce: results from the National Health and Wellness Survey. *BMC Musculoskelet Disord.* 2011;12:83.
14. Michou L. Genetics of digital osteoarthritis. *Joint Bone Spine.* 2011;78(4):347-351.
15. Zhang Y, Jordan JM. Epidemiology of osteoarthritis. *Clin Geriatr Med.* 2010;26(3):355-369.
16. Simonet WS. Genetics of primary generalized osteoarthritis. *Mol Genet Metab.* 2002;77(1-2):31-34.
17. Maetzel A. The economic burden associated with osteoarthritis, rheumatoid arthritis, and hypertension: a comparative study. *Annals of the Rheumatic Diseases.* 2004;63(4):395-401.
18. Rossignol M, Leclerc A, Allaert FA, et al. Primary osteoarthritis of hip, knee, and hand in relation to occupational exposure. *Occup Environ Med.* 2005;62(11):772-777.
19. Brown TD, Johnston RC, Saltzman CL, Marsh JL, Buckwalter JA. Posttraumatic osteoarthritis: a first estimate of incidence, prevalence, and burden of disease. *J Orthop Trauma.* 2006;20(10):739-744.
20. Dillon CF, Hirsch R, Rasch EK, Gu Q. Symptomatic Hand Osteoarthritis in the United States. *American Journal of Physical Medicine & Rehabilitation.* 2007;86(1):12-21.
21. Katayama T, Ono H, Suzuki D, Akahane M, Omokawa S, Tanaka Y. Distribution of primary osteoarthritis in the ulnar aspect of the wrist and the factors that are correlated with ulnar wrist osteoarthritis: a cross-sectional study. *Skeletal Radiol.* 2013;42(9):1253-1258.
22. Brandt KD. Non-surgical treatment of osteoarthritis: a half century of "advances". *Ann Rheum Dis.* 2004;63(2):117-122.

23. van der Kraan PM. Stem cell therapy in osteoarthritis: a step too far? *BioDrugs*. 2013;27(3):175-180.
24. Pastides P, Chimutengwende-Gordon M, Maffulli N, Khan W. Stem cell therapy for human cartilage defects: a systematic review. *Osteoarthritis Cartilage*. 2013;21(5):646-654.
25. Hagert E, Hagert CG. Understanding stability of the distal radioulnar joint through an understanding of its anatomy. *Hand Clin*. 2010;26(4):459-466.
26. Acosta R, Hnat W, Scheker LR. Distal radio-ulnar ligament motion during supination and pronation. *J Hand Surg Br*. 1993;18(4):502-505.
27. Schuind F, An KN, Berglund L, et al. The distal radioulnar ligaments: a biomechanical study. *J Hand Surg Am*. 1991;16(6):1106-1114.
28. Bell MJ, Hill RJ, McMurtry RY. Ulnar impingement syndrome. *J Bone Joint Surg Br*. 1985;67(1):126-129.
29. Huang JI, Hanel DP. Anatomy and biomechanics of the distal radioulnar joint. *Hand Clin*. 2012;28(2):157-163.
30. Skahen JR, 3rd, Palmer AK, Werner FW, Fortino MD. Reconstruction of the interosseous membrane of the forearm in cadavers. *J Hand Surg Am*. 1997;22(6):986-994.
31. Skahen JR, 3rd, Palmer AK, Werner FW, Fortino MD. The interosseous membrane of the forearm: anatomy and function. *J Hand Surg Am*. 1997;22(6):981-985.
32. Atha J, Yeadon MR, Sandover J, Parsons KC. The damaging punch. *Br Med J (Clin Res Ed)*. 1985;291(6511):1756-1757.
33. Hagert CG. The distal radioulnar joint in relation to the whole forearm. *Clin Orthop Relat Res*. 1992(275):56-64.
34. Kleinman WB. Stability of the Distal Radioulnar Joint: Biomechanics, Pathophysiology, Physical Diagnosis and Restoration of Function. In: Slutsky D, ed. *Principles and Practice of Wrist Surgery*. First ed. Philadelphia: Saunders Elsevier; 2010:41-55.
35. Boland MR, Spigelman T, Uhl TL. The function of brachioradialis. *J Hand Surg Am*. 2008;33(10):1853-1859.
36. Kleinman WB. Stability of the distal radioulna joint: biomechanics, pathophysiology, physical diagnosis, and restoration of function what we have learned in 25 years. *J Hand Surg Am*. 2007;32(7):1086-1106.

37. Lees V, Scheker, LR. The Radiological Demonstration of Dynamic Ulnar Impingement *Journal of Hand Surgery European Volume*. 1997;22B:448-450.
38. Zimmerman RM, Kim JM, Jupiter JB. Arthritis of the distal radioulnar joint: from Darrach to total joint arthroplasty. *J Am Acad Orthop Surg*. 2012;20(10):623-632.
39. Scheker LR, Ozer K. A simple method of physical examination for the diagnosis of distal radioulnar joint incongruity. *European Journal of Plastic Surgery*. 2004;27(1):42-43.
40. Freiberg RA, Weinstein A. The scallop sign and spontaneous rupture of finger extensor tendons in rheumatoid arthritis. *Clin Orthop Relat Res*. 1972;83:128-130.
41. Couturier CA, Alnot JY. [Non-traumatic osteoarthritis of the distal radio-ulnar joint: a consecutive series of 11 wrists with 42 months follow-up]. *Rev Chir Orthop Reparatrice Appar Mot*. 2002;88(6):573-581.
42. Tanaka T, Kamada H, Ochiai N. Extensor tendon rupture in ring and little fingers with DRUJ osteoarthritis without perforating the DRUJ capsule. *J Orthop Sci*. 2006;11(2):221-223.
43. Yamazaki H, Uchiyama S, Hata Y, Murakami N, Kato H. Extensor tendon rupture associated with osteoarthritis of the distal radioulnar joint. *J Hand Surg Eur Vol*. 2008;33(4):469-474.
44. Cho CH, Lee SW. Extensor tendon rupture caused by instability of the ulnar head with an osteoarthritic distal radioulnar joint: a case report. *J Med Case Rep*. 2013;7(1):281.
45. Bowers WH. Instability of the distal radioulnar articulation. *Hand Clin*. 1991;7(2):311-327.
46. Scheker LR, Ozer K, Babb BA. Distal Radioulnar Joint Problems and Solutions. *Surgery of the Injured Hand - Towards Functional Restoration*. New Delhi: Jaypee Brothers Medical Publishers © Ltd.; 2009:458-474.

Part 2 - Management of Distal Radioulnar Joint Degeneration

Non-Operative Management

Non-surgical management of distal radioulnar joint (DRUJ) osteoarthritis (OA) includes supportive general measures including analgesia and steroid or hyaluronan (HA) injections into the joint itself. As the pattern of wear across the joint surface may be restricted to certain zones of pronosupination, dynamic splintage can be used to restrict motion away from these areas in favour of healthy cartilage contact.

The Evolution of Surgery at the DRUJ

Many procedures have been described for the management of DRUJ dysfunction, reflecting the varying spectrum of pathology that is encountered. Until recently, the DRUJ was a poorly understood joint and hence problems associated with it were addressed with little grounding in the necessary basic biomechanical principles. This has led to sub-optimal outcomes from diverse attempts at surgical improvement through a wealth of different operations that typically indicate the lack of any single successful intervention.

The earliest reference to distal ulnar resection was by Bernard and Huette from the illustrated manual of operative surgery and surgical anatomy ⁴⁷. This was first published in French in the year 1851 and was translated to German in 1855 and English in 1857. Another reference to this procedure was made in a book written by Malgaigne in 1855 ⁴⁸. He suggested resection of the ulnar head when it was dislocated and protruding through skin. Further reference to distal ulnar resection was made by George in his book on his observations of the American civil war in the year 1876. Moore in 1880 and Tillmans in 1891 made further reference to distal ulnar resection but mostly in the acute situation. Von Lesser reported a subperiosteal resection of the ulnar head to improve the range of pronosupination in a patient with post traumatic OA as a result of a malunited distal radius fracture in 1886. Lauenstein (1887), van Lennep (1897), Angus (1908), Darrach (1912), Douglas (1914), and Bazy and Galtier (1935) also described excision of the ulnar head for a similar indication ⁴⁹. Smith- Petersen et al (1943) described excision of the ulnar head in patients with rheumatoid arthritis. Darrach's name became the preferred eponym for excision of the ulnar head following reports by Hucherson in 1941 and Dingman in 1952 ⁵⁰. Destot in 1908 observed that the absence of a portion of the ulnar diaphysis with an ankylosed DRUJ provided improved pronosupination. He did not propose intentional pseudoarthrosis though. This was later proposed by several authors including Baldwin, Colalian and Wheeler. Baldwin in 1921 reported restoration of pronosupination after excision of a segment of ulnar diaphysis in a patient with a malunited distal radius fracture. In most of these cases the DRUJ had undergone ankylosis and was not intentionally arthrodesed. The earliest report of surgical arthrodesis of the DRUJ was by Berry from New Zealand in 1931. He performed this procedure in a 20 year old patient who had a nonunion of the ulnar

styloid process with chronic instability. He felt that the surgery was a good option for malunited distal radius fractures as compared to distal ulnar excision. He also advocated this procedure in Madelung's deformity. Arthur Steindler in his text book "*The traumatic deformities and disabilities of the upper extremity*", mentions two cases of DRUJ arthrodesis with ulnar diaphysis excision. He wrongly attributed this to Lauenstein when in fact he had proposed only a distal resection of the ulna. In the USA the fusion of the DRUJ with a small segment of the metaphysis of the ulna, was for a long time, known as the Lowenstein procedure until Taleisnik indicated that this was the work of Sauvé and Kapandji who published the description in 1936^{51,52}. Outside of the USA, the eponym became popular after reports by Vergoz and Baciu. Because of forearm instability that results after the above mentioned procedures, Bowers in 1985 proposed the hemi-resection with pronator quadratus interposition and Watson in 1986 described the matched resection of the ulnar head^{53,54}. As these two operations proved to be as unsatisfactory as straightforward ablation, in 1998 Wolfe et al described the wide excision of the distal ulna to solve the problems of pain due to radioulnar impingement with similarly dismal results⁵⁵. Although widely accepted, these ablative procedures at the distal end of the ulna do not restore the normal biomechanics of the forearm and bring with them known adverse consequences as described by Bell et al. known as the ulnar impingement syndrome²⁸.

Current Surgical Management of DRUJ Pathology and Salvage Techniques

DRUJ pathology and its treatment options can be truly challenging⁵⁶. A well-balanced DRUJ that retains the mobility needed for daily function necessitates a stable, congruent joint with healthy articular cartilage that is free from degenerative change.

Maintaining the health of the DRUJ can be considered under the following categories, and should always be approached with the overall intention of establishing joint integrity and the preservation the health of the articular cartilage wherever possible.

- 1: Restoration of DRUJ ligamentous support and joint stabilization.
- 2: Acute fracture management with restoration of DRUJ congruence and simultaneous assessment and correction of DRUJ ligament injury.
- 3: Secondary correction of DRUJ incongruence following fracture malunion.
- 4: Alignment of radioulnar length to decompress positive ulnar variance or improve joint congruity.
- 5: Treatment of established degenerative joint disease with joint arthroplasty techniques
- 6: Secondary reconstruction / salvage following previous ulnar head ablative procedures and in cases of bone loss necessitated through resection for other disease such as neoplasia.

Surgical planning to address DRUJ pathology requires the consideration of a number of factors as there is frequently an inter-dependence between several of the categories listed above. Perhaps the most important aspect lies in the timing of DRUJ treatment, where a domino effect of joint deterioration occurs, passing through biomechanical disruption, cartilage damage, established joint degeneration, clinical pain and loss of function. Successful restoration of lost DRUJ stability, for example, will only be fruitful if performed before instability-induced arthrosis has set in. After this window of opportunity has lapsed, stabilization may still be required, but in addition to a joint resurfacing procedure. How fast this progressive deterioration takes place may vary from one situation to another but must always be considered at the outset during decision making for DRUJ reconstruction.

Surgical Approaches

Surgical approaches can be divided into open versus arthroscopic techniques. Minimally invasive techniques have the advantage of both detailed visualization of joint anatomy and faster recovery from minimised scarring and associated joint stiffness. Wrist arthroscopy has become a widely accepted technique for the evaluation and treatment of injuries of the TFCC^{57,58}. Wrist and DRUJ arthroscopy both help in the evaluation and diagnosis of TFCC lesions, wrist instability and arthritic joint surfaces. Arthroscopic treatment options include synovectomy and TFCC repair/resection^{57,59}. However, any cartilage ablative procedure has no place in reconstructive DRUJ surgery and should not be considered. This includes the arthroscopic 'wafer' removal of the distal pole of the ulna for ulnocarpal abutment correction.

DRUJ Stabilization

DRUJ instability following acute, isolated dorsal or volar dislocation is typically reduced to congruency in neutral forearm position and if this is possible, six weeks of immobilization in a neutral long arm cast is usually satisfactory. If closed reduction is not possible, open reduction should be attempted to remove any interposition. Chronic instability without associated forearm fracture malunion can be treated by soft tissue reconstruction. However, before such surgery is contemplated, the DRUJ must be congruent, with stable radiocarpal and ulnocarpal ligaments and the integrity of these structures must be assessed individually. If satisfactory radiocarpal or ulnocarpal stability is absent, attempts should be made to stabilize those structures before attention is paid to the DRUJ, and if the DRUJ is not itself congruent, soft tissue reconstruction procedures are destined to fail. Soft tissue stabilizing procedures aim to restore DRUJ stability, and may or may not be associated with reconstruction of the TFCC itself. Well known procedures include the anatomical palmaris tendon DRUJ stabilization techniques developed by Scheker in 1994 and the subsequent palmaris

graft approaches of Adams in 2002 or the brachioradialis transfer developed by Gupta⁶⁰⁻⁶⁴. Pure dorsal radioulnar ligament defects can be addressed by the Herbert plasty, where the extensor retinaculum is used for reconstruction⁶⁵. More recently, arthroscopic techniques for TFCC reconstruction with tendon grafting to stabilize the DRUJ are gaining popularity^{57,59}.

Acute Fracture Management

Acute fractures of the distal radius and ulna require optimal reduction and restoration of DRUJ congruence and stability, paying close attention to fractures involving the volar, ulnar region of the sigmoid notch in an attempt to limit direct chondral injury within the DRUJ. Surgically treated distal radial fractures require assessment of DRUJ stability following bone fixation and soft tissue repair of the TFCC as indicated. Likewise, remote fractures that impact upon the DRUJ such as the Galeazzi fracture dislocation similarly require assessment of DRUJ stability and repair as necessary.

Congruence Surgery and Correction of Malunion

In situations where the radial articular surface is abnormally flat, DRUJ congruency and therefore stability can be improved by an osteotomy of the sigmoid notch^{66,67}. This technique is reserved for specific cases in which an abnormally flat sigmoid notch or post traumatic joint deformity can be improved by addressing volar or dorsal rim insufficiency of the otherwise intact DRUJ. Similarly, early signs of degenerative arthritis at the DRUJ can sometimes be successfully treated by minor re-alignment of the chondral contact surfaces within the DRUJ through ulnar shortening osteotomy⁶⁸. Malunion of the distal radius that produces an incongruent DRUJ should likewise be addressed through corrective opening or closing wedge osteotomy techniques.

Adjustment of Ulnar Variance

Ulnar shortening plays an important role in the restoration and maintenance of DRUJ health. Isolated positive ulnar variance is associated with primary DRUJ OA and also underlies the ulnocarpal abutment syndrome⁶⁹. As the joint itself is involved in many of the wide range of available shortening techniques for positive variance, careful consideration needs to be given towards technique selection in order to avoid inadvertent DRUJ damage. The ulna should be shortened at either of two different levels, via a shortening osteotomy either within the DRUJ or at the ulnar diaphysis. Ulnar shortening within the DRUJ has the potential to damage the joint surfaces and therefore may not be feasible in severe ulna plus pathology^{70,71}. In these cases, a diaphyseal shortening osteotomy may be preferred. This osteotomy should be done as distal as possible to minimize risks of nonunion, which is a well-known complication of

ulnar shortening osteotomy. Diaphyseal ulnar shortening can also be used to tension the TFCC in cases of mild instability and also realign the ulnar head and sigmoid notch in early post-traumatic OA. Scheker reported the results of using ulnar shortening to treat early DRUJ OA and achieved 57% excellent or good results^{68,72}. The osteotomy itself can be performed in a transverse, diagonal or step-cut manner; the latter two techniques increasing the bony contact surface area with the aim of optimizing union but which are more challenging to perform. Intra-articular ulnar shortening has the advantage of both faster consolidation due to the high cancellous bone content and the avoidance of plate fixation. Many variations of intra-articular ulnar shortening have been suggested. The Sennwald osteotomy with a sliding shortening osteotomy of the ulnar head has proved to be very efficient in selected cases with a stable DRUJ requiring a maximal 4 to 5 mm shortening⁷³. If cartilage on the distal ulna is intact, a subchondral cartilage-retaining wafer osteotomy of the distal ulna is an option⁷⁴.

Resection Arthroplasty

The destruction of the DRUJ through total or partial ablation of the head of the ulna began in the 1850s and in many hand surgery facilities, persists to this day⁴⁷. With the clear demonstration of the load bearing function of the DRUJ, it must be appreciated that the removal of the ulnar head destroys its load-bearing function, and whether this translates into clinically significant radioulnar impingement or not, it is to be expected and evaluated for if we are to avoid doing the patient so-treated a great disservice. So called low-demand patients traditionally fit into the bracket of being a good surgical candidate for resection arthroplasty, as it is assumed that their frailty will mitigate against the possibility of painful impingement. This is a dangerous assumption to make and in fact these patients are the very individuals at greatest risk of serious loss of function and independence after ulnar head ablation. Impingement following resection arthroplasty can render even the most basic functions of daily living such as lifting the hand to the mouth to eat or drink, to get dressed or manage personal hygiene, a painful and disabling process. If it is accepted that even the 'low demand' individual can suffer from radioulnar impingement, there therefore is no 'ideal' patient for resection arthroplasty and patients selected to undergo the procedure should be carefully counselled pre-operatively regarding the risk of instability and impingement syndrome. Patients receiving ulnar head resection need to be followed closely after surgery and this must include an assessment of satisfactory stability and loadbearing capacity for the activities of normal daily living. It is appreciated that in certain communities, there may be little or no access to prosthetic arthroplasty techniques, and in these circumstances, ulnar head resection may continue to remain an option for severe end stage DRUJ dysfunction. In all other cases of worn-out DRUJ or symptomatic impingement following resection arthroplasty, there now exist a number of alternative implant arthroplasty techniques that are accruing an excellent track record for total DRUJ reconstruction (see following sections). Indeed, in the face of such continued evidence, the place of the Darrach and Sauve-Kapandji techniques (and their derivatives) are becoming increasingly untenable, and hopefully, in the near future, will be consigned to the pages

of history. Until then and in its simplest form, ulnar head resection in the Darrach procedure removes the pain of advanced joint wear in situations of bone-on-bone contact within the DRUJ. Greater support for the carpus can be achieved through the Sauve-Kapandji procedure with retention and fusion of the ulnar head to the sigmoid notch of the radius. Pronosupination moves to the ulnar head osteotomy site but may be lost if bone bridges back across the gap left by the 15mm or so of excised ulna.

Joint Replacement Arthroplasty

Techniques for DRUJ reconstruction now include silastic, metallic or ceramic replacement for part or all of the ulna as well as total distal radioulnar joint replacement ^{58,75,76}. In selecting the most appropriate technique for any given situation, it is important to bear in mind that hemi-arthroplasty techniques involving only one half of a load-bearing synovial joint run the risk of developing degenerative changes in the conserved half of the joint as has been well described for the hip and shoulder. Furthermore, instability of a hemi-arthroplasty and an unconstrained total joint prosthesis frequently occur and can be a difficult problem to manage. Establishing implant stability is an important key of the primary operation and begins with pre-operative planning. The joint should be assessed for stability based on clinical and radiological examination. If the joint is unstable then it is important to address the anatomical factors that contribute to instability, ie the sigmoid notch and the TFCC. If the TFCC is deficient, it must be stabilised with a TFCC repair or reconstruction, stabilisation of the TFCC to the ulnar head prosthesis, or selection of a semi-constrained prosthesis instead. To obtain stability of a uni-polar ulnar prosthesis, it needs to be correctly positioned, the soft tissue balanced and stabilised and the sigmoid notch needs to provide a volar and dorsal buttress. A good quality closure of the dorsal capsule-retinacular tissues is also important for a hemi-arthroplasty and an unconstrained prosthesis and the forearm is often immobilised in the position of maximal stability for a few weeks to allow the soft tissues to heal.

Ulnar Resurfacing Techniques

Patients with predominant degenerative changes affecting the head of the ulna can be managed with a resurfacing arthroplasty to replace only the ulnar seat, and thereby preserve the stabilizing TFCC attachments at the fovea. Examples include the Ascension and Eclipse™ ulnar head systems that replace the articulating half of the ulnar head to retain the ulnar neck, ulnar styloid, extensor carpi ulnaris groove, ulnocarpal ligament attachments, extensor carpi ulnaris sheath, and the TFCC attachments to the ulnar styloid. The Eclipse™ prosthesis is a pyrocarbon based design where the soft tissue envelope and joint wear is reduced with a bipolar ulnar construct in which the pyrocarbon arthroplasty component twists around an internal ulnar stem axis, thereby lowering friction with the radial notch ⁷⁷. Sizing of any resurfacing prosthesis is critical as, if the prosthesis is too large, the joint will be tight, producing

pain and restricting range of motion. If it is too small, the joint will be unstable and the ulnar head adjacent to the prosthesis can impinge upon the sigmoid notch during forearm rotation.

Total Ulnar Head Replacement

Complete distal ulnar replacement involves the joint surface and the remainder of the ulnar head. The uHead™ by Small Bone Innovations (SBI) and the E-Centrix by Wright Medical Tech, have the ability to capture sutures to allow repair of the TFCC for added stability. Instability of the ulnar head replacement prosthesis can occur if the soft tissues are not balanced, or if the sutures, which stabilise the prosthesis to the TFCC, rupture on the eyelets. Although positive short-term results are often touted, recurrent pain and joint instability due to the failure of the surrounding stabilizing soft-tissues represent the main challenges to success with such unconstrained unilateral joint replacement techniques⁷⁸. To address this problem, different soft tissue reconstruction techniques that aim to wrap around the arthroplasty have been described⁷⁹.

Total DRUJ Replacement

For those patients who have advanced degeneration involving both the distal ulna and the sigmoid notch, a total joint replacement can be considered. These are indicated in those cases with degeneration on both sides of the articulation, including those with instability. There are two options: unconstrained or semi-constrained designs.

Unconstrained Prosthesis

An unconstrained prosthesis involves the replacement of both the ulnar head and sigmoid notch joint surface and aim to work like a normal joint with normal kinematic motion and loading. In these systems, the articular surface of the arthroplasty is frequently intended to provide a similar stabilizing effect as in the anatomic situation (about 20%) and the soft tissue envelop needs to be intact or reconstructed to avoid gross instability. The Small Bone innovations implant utilises an ulnar component as described above for mono-polar reconstruction, partnered with a sigmoid notch replacement that has a metallic base plate with a polyethylene insert. It relies on good soft tissue stabilisation and good bone stock, and is therefore contra-indicated if these two pre-requisites are not available. The metallic base plate and the polyethylene insert introduce other potential complications including over distension of the joint, dissociation of the polyethylene liner and polyethylene wear.

Semi-Constrained Prosthesis

If the DRUJ is both degenerative and unstable, a semi-constrained prosthesis is a good option. A semi-constrained prosthesis can mobilise in its primary plane, but has limited or constrained motion in alternative planes. This has the dual advantages of both preventing prosthetic instability whilst permitting small out of plane motion that minimizes unwanted force transmission at the prosthesis / bone (or cement) interface. This approach fits the biomechanics of the DRUJ very well with the major plane of motion through pronosupination and minor proximo-distal motion from physiological ulnar variance alteration as the radius moves from full supination to pronation. The Scheker arthroplasty was developed to replace the DRUJ in such a semi-constrained manner, and allows complete stability through the full range of pronosupination whilst accommodating minor axial length changes associated with physiologic longitudinal translocation^{75,80-82}. The ulnar component of the Scheker prosthesis consists of an uncemented stem that extends to the level of the DRUJ to become the centre of rotation of the joint and on which is mounted a freely rotating polythene ball. A plate is secured to the distal radius, containing a cage that encases the polythene ball. The primary motion of the joint, forearm rotation, occurs as the polyethylene ball rotates unrestrained around the ulnar stem. Alternative axial motion and minor tilt occur at the ball-ulnar stem and ball-cage interfaces respectively. Anterior posterior motion is completely restrained and so reconstructs the stability component of the DRUJ.

Salvage Surgery

Much has been written in the literature about possible salvage procedures for the worldwide population of patients who suffer from radioulnar impingement following ablation of the ulnar head. It is the opinion of the senior author that they offer no significant benefit in addressing this problem and the reader is therefore directed to other works in the literature for historical information on these techniques. Alternatively, for those cases where the ulnar head has been removed, and in unique cases of distal ulnar loss for tumour extirpation or trauma, there are now custom implant fabrications that can be used for reconstruction, possibly in conjunction with free tissue transfer to replace and reconstruct missing bony and soft tissue elements.

Concluding remarks

Osteoarthritis is a complex disease that continues to carry a high morbidity for affected individuals and is as yet refractory to efforts at arresting the destructive process on affected synovial joints. Whilst new insights into the underlying pathobiological processes are now forthcoming, it will be a long time before reconstructive joint surgery can be consigned to the pages of history through pharmacological arrest of the disease

process. For the DRUJ, this is of great importance for two reasons. Firstly, there is now an excellent spectrum of operative procedures that can restore good function both when there remains a salvageable joint and through arthroplastic techniques when the joint is beyond repair. Secondly, there is a potentially huge population of people in the international community who have undergone previous DRUJ ablation producing radioulnar impingement. This situation has arisen through a lack of appreciation OF the essential biomechanical role that the DRUJ fulfils. This appreciation has steadily caught up with the great advances in radiocarpal pathology thanks to the research efforts of many hand surgery giants, including Hagert, Palmer, and others ^{26,33,83}. Patients with a destroyed DRUJ can now be offered salvage reconstruction techniques that have the possibility of transforming their functional capacity, alleviating pain, and offering great rewards for both the patient and treating surgeon alike.

References

47. Bernard C, Huette C. Illustrated Manual of Operated Surgery and Surgical Anatomy. In: Buren WHV, Isaacs C, ed. New York 1857.
48. Malgaigne JF. Traite des fractures et des luxations. Volume II. Paris 1855.
49. Darrach W. Anterior Dislocation of the Head of the Ulna. *Annals of Surgery*. 1912;56:802-803.
50. Dingman PV. Resection of the distal end of the ulna (Darrach operation); an end result study of twenty four cases. . *The Journal of Bone and Joint Surgery American Volume*. 1952;34(A(4)):893-900.
51. Taleisnik J. The Sauve-Kapandji procedure. *Clin Orthop Relat Res*. 1992(275):110-123.
52. Sauve L, Kapandji M. Nouvelle technique de traitement chirurgical des luxations récidivantes isolées de l'extrémité inférieure du cubitus. *J Chirurgie*. 1936;47:589-594.
53. Bowers WH. Distal radioulnar joint arthroplasty: the hemiresection-interposition technique. *J Hand Surg Am*. 1985;10(2):169-178.
54. Watson HK, Ryu JY, Burgess RC. Matched distal ulnar resection. *J Hand Surg Am*. 1986;11(6):812-817.
55. Wolfe SW, Mih AD, Hotchkiss RN, Culp RW, Keifhaber TR, Nagle DJ. Wide excision of the distal ulna: a multicenter case study. *J Hand Surg Am*. 1998;23(2):222-228.
56. Bain GI, Bergman FJ. The distal radioulnar joint: contemporary perspectives. *Tech Hand Up Extrem Surg*. 2007;11(1):37.

57. Anderson ML, Larson AN, Moran SL, Cooney WP, Amrami KK, Berger RA. Clinical comparison of arthroscopic versus open repair of triangular fibrocartilage complex tears. *J Hand Surg Am.* 2008;33(5):675-682.
58. Thomas BP, Sreekanth R. Distal radioulnar joint injuries. *Indian J Orthop.* 2012;46(5):493-504.
59. Tse WL, Lau SW, Wong WY, et al. Arthroscopic reconstruction of triangular fibrocartilage complex (TFCC) with tendon graft for chronic DRUJ instability. *Injury.* 2013.
60. Adams BD, Berger RA. An anatomic reconstruction of the distal radioulnar ligaments for posttraumatic distal radioulnar joint instability. *J Hand Surg Am.* 2002;27(2):243-251.
61. Gupta A. Brachioradialis Wrap: A New Method of Stabilizing the Distal Radioulnar Joint. In: Slutsky D, ed. *Principles and Practice of Wrist Surgery.* Philadelphia: Saunders Elsevier. 2010; 358-361.
62. Scheker LR, Ozer K. Ligamentous stabilization of the distal radioulnar joint. *Tech Hand Up Extrem Surg.* 2004;8(4):239-246.
63. Scheker LR, von Schroeder H. Dorsal stabilization of the distal radioulnar joint. *Tech Hand Up Extrem Surg.* 1998;2(4):234-241.
64. Scheker LR, Belliappa PP, Acosta R, German DS. Reconstruction of the dorsal ligament of the triangular fibrocartilage complex. *J Hand Surg Br.* 1994;19(3):310-318.
65. Dy CJ, Ouellette EA, Makowski AL. Extensor retinaculum capsulorrhaphy for ulnocarpal and distal radioulnar instability: the Herbert sling. *Tech Hand Up Extrem Surg.* 2009;13(1):19-22.
66. Tham SK, Bain GI. Sigmoid notch osseous reconstruction. *Tech Hand Up Extrem Surg.* 2007;11(1):93-97.
67. Wallwork NA, Bain GI. Sigmoid notch osteoplasty for chronic volar instability of the distal radioulnar joint: a case report. *J Hand Surg Am.* 2001;26(3):454-459.
68. Scheker LR, Severo A. Ulnar shortening for the treatment of early post-traumatic osteoarthritis at the distal radioulnar joint. *J Hand Surg Br.* 2001;26(1):41-44.
69. Milch H. Cuff Resection of the Ulna for Malunited Colle's Fracture. *Journal of Bone and Joint Surgery.* 1941;20A:959-964.
70. Lapner PC, Poitras P, Backman D, Giachino AA, Conway AF. The effect of the wafer procedure on pressure in the distal radioulnar joint. *J Hand Surg Am.* 2004;29(1):80-84.

71. Markolf KL, Tejwani SG, Benhaim P. Effects of wafer resection and hemiresection from the distal ulna on load-sharing at the wrist: a cadaveric study. *J Hand Surg Am.* 2005;30(2):351-358.
72. Nishiwaki M, Nakamura T, Nakao Y, Nagura T, Toyama Y. Ulnar shortening effect on distal radioulnar joint stability: a biomechanical study. *J Hand Surg Am.* 2005;30(4):719-726.
73. Sennwald G, Della Santa D, Beaulieu JY. A comparison of diaphyseal and metaphyseal techniques of ulna shortening. *J Hand Surg Eur Vol.* 2013;38(5):542-549.
74. Barry JA, Macksoud WS. Cartilage-retaining wafer resection osteotomy of the distal ulna. *Clin Orthop Relat Res.* 2008;466(2):396-401.
75. Laurentin-Perez LA, Goodwin AN, Babb BA, Scheker LR. A study of functional outcomes following implantation of a total distal radioulnar joint prosthesis. *J Hand Surg Eur Vol.* 2008;33(1):18-28.
76. Stanley D, Herbert TJ. The Swanson ulnar head prosthesis for post-traumatic disorders of the distal radio-ulnar joint. *J Hand Surg Br.* 1992;17(6):682-688.
77. Garcia-Elias M. Eclipse: partial ulnar head replacement for the isolated distal radio-ulnar joint arthrosis. *Tech Hand Up Extrem Surg.* 2007;11(1):121-128.
78. Willis AA, Berger RA, Cooney WP, 3rd. Arthroplasty of the distal radioulnar joint using a new ulnar head endoprosthesis: preliminary report. *J Hand Surg Am.* 2007;32(2):177-189.
79. Sauerbier M, Hahn ME, Berglund LJ, An KN, Berger RA. Biomechanical evaluation of the dynamic radioulnar convergence after ulnar head resection, two soft tissue stabilization methods of the distal ulna and ulnar head prosthesis implantation. *Arch Orthop Trauma Surg.* 2011;131(1):15-26.
80. Coffey MJ, Scheker LR, Thirkannad SM. Total distal radioulnar joint arthroplasty in adults with symptomatic Madelung's deformity. *Hand (N Y).* 2009;4(4):427-431.
81. Degreeef I, De Smet L. The Scheker distal radioulnar joint arthroplasty to unravel a virtually unsolvable problem. *Acta Orthop Belg.* 2013;79(2):141-145.
82. Scheker LR. Implant arthroplasty for the distal radioulnar joint. *J Hand Surg Am.* 2008;33(9):1639-1644.
83. Palmer AK, Werner FW. The triangular fibrocartilage complex of the wrist--anatomy and function. *J Hand Surg Am.* 1981;6(2):153-162.