Posttraumatic rotation deficit of the forearm, including synostosis

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Prono-supination takes place over the full length of the forearm, the whole forearm thus being one single joint. Any change to the configuration of the proximal (PRUJ) or distal (DRUJ) radioulnar joints or to the forearm diaphyses and the connecting interosseous membrane (IOM) can result in loss of forearm rotation by either mechanical interference and/or by pain induction. Capsule retraction and scar formation in the soft tissues of the forearm can make early posttraumatic limitations progressively worse. Soft tissue contracture may even be the sole cause of loss of forearm rotation as e.g. in burn victims or certain neurologic conditions. Preservation of forearm rotation should be a prime concern at all times during the care of injuries to the elbow, forearm and wrist. Judicious positioning in case of immobilization, early assisted active motion ('place and hold') and intermittent alternating endpoint splinting are basic elements of rehabilitation (Fig. 1). The minimum functional range lies between 50 to 72 degrees supination and 40 to 55 degrees pronation, deficits of the latter being more easily compensated by shoulder movement.
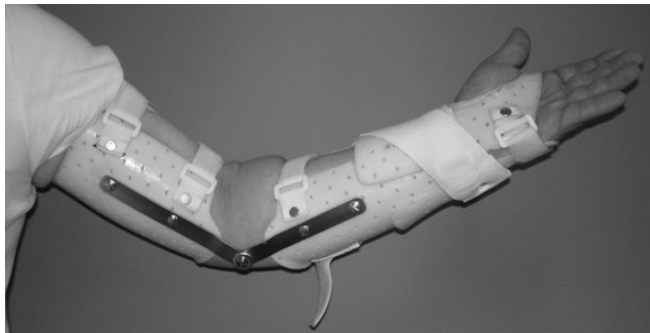

Fig. 1 : Static brace for progressive endpoint splinting

Rotation deficit following wrist and distal forearm injury

Early pronation and supination loss is not uncommon after a fracture of the distal radius, however, when reevaluated one year later, most patients have regained a normal range of forearm rotation. Also, not all patients with obvious malunion have a restriction of forearm rotation (8).

Several cadaver experiments have been performed to study the consequences of different types of deformity. The reported figures, describing the deformity under scrutiny and the produced limitation of mobility, vary considerably and conclusions may even be conflicting. This is most likely due to differences of methodology and specifically whether the created deformity was in a single plane or multiplanar (7). The following deductions can safely be made : dorsal angulation of the radius (recurvatum / extension deformity) and dorsal translation are more likely to diminish pronation. Cut-off values for extension deformity lie between 20 and 30° (i.e. 10 to 20° of dorsal tilt). Palmar angulation (flexum) tends to affect supination. Radial shortening disturbs pronation more than supination, with problems starting between 2.5 an 5 mm. Ulnar translation of the distal radial fragment affects forearm rotation more than radial translation.

The situation in real patients is even more complex. The deformity is more often multiplanar than not. Standard X-rays usually suffice to assess extra-articular distal radius malunion but malrotation is often missed. Malrotation was found on CT by Prommersberger in nearly 2/3 of patients with symptomatic malunions of the distal radius, but this was not the decisive element of the deformity when considering limitations of forearm rotation. Loss of supination

was seen in radius malunions which combined a palmar angulation with a pronatory malrotation > 10°(15). CT-scanning with the option of 3D reconstruction has become the tool of preference to evaluate intra-articular fractures and malunions, and the distal radioulnar relationship in particular. Ishikawa studied 22 patients with rotation deficits following distal radius fracture. When pronation was decreased, the ulna was subluxed palmarly with severe dorsal tilting of the radius. When supination was restricted, the distal ulna was subluxed dorsally with severe ulnar positive variance (9).

Gradual changes of the soft tissues, both contractures and distensions, secondary osteo-arthritic changes and pain further confound the situation. In clinical series, many patients seem to get away with considerable deformity. CT-scan may confirm the absence of boney impingement in spite of the deformity and thus prove 'normal' kinematics but at the same time show an ominous proximal shift of the joint surface contact area in the DRUJ. Also lengthening of the dorsal radioulnar ligament was found on CT by Crisco (4).

Fractures of the distal ulnar styloid routinely accompany distal radius fractures. Displaced proximal styloid fractures should raise suspicion of avulsion of the triangular ligament, which is the main stabilizing ligament of the DRUJ. The ulnar styloid fracture should also be fixed, if following internal fixation of the distal radius, the DRUJ proves unstable during gentle ballotment testing. Significant radius shortening (> 5mm) in a Colles fracture should raise suspicion of concomitant DRUJ instability. The instability of the DRUJ can be grotesque in combination with a distal fracture of the radial diaphysis and must not be missed (Galleazi lesion) ! Subcapital fractures of the distal ulna may lead to a displacement of the axis of rotation. The resulting deformities of the ulna affect rotation in an inverse manner compared to radius malunion : loss of pronation in ulnar flexum, supination deficit in ulnar recurvatum.

It is clear that prevention of loss of forearm rotation begins with an adequate assessment of the initial injury pattern, bearing in mind the aforementioned data. In children under 9 years of age enough potential of remodeling is still present to allow for spontaneous correction of considerable residual deformity. When the deformity lies near the physis as in distal radius fractures, angulations of 20 to 30°can be expected to correct spontaneously depending on the age of the child (13).
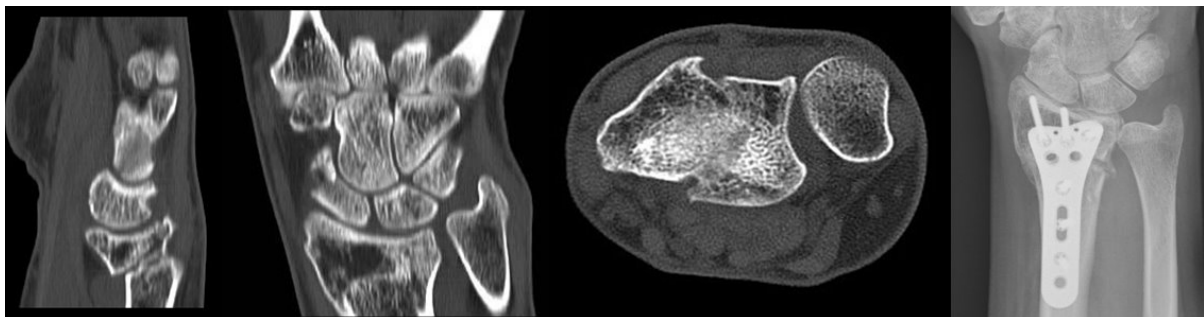

Fig. 2 : Supination deficit (P/S 70/0/0) due to palmar translation and pronatory radius malunion. Restoration of almost full rotation (P/S 75/0/75) by corrective osteotomy, using volar plate fixation and bone allograft.

Since 1982, many surgeons have proven that corrective osteotomy of distal radius malunion, possibly combined with ulnar shortening, can improve the range of pronation and supination (Fig. 2)(6). Accuracy in restoration of the anatomic configuration (radial length, palmar tilt, radial inclination and axial rotation) is rewarded with greater gains in mobility, including prono-supination, through optimal realignment of the sigmoid notch with respect to the ulnar head. Computer assisted surgery (CAS), making use of virtual 3D-models from CT-data, can be helpful to achieve this goal. Virtual surgery can be practiced on these models. Real 3D models and patient-specific surgical tools (custom-made guides for either drill or sawblade) can be manufactured accordingly. CAS is therefore particularly useful for breaking up and

realigning intra-articular malunions obviating the need for a wide arthrotomy (18). Corrective osteotomy of an intra-articular malunion of the radial sigmoid notch, which is undoubtedly a delicate undertaking, may thus become feasible.

Isolated dislocation of the DRUJ (with or without ulnar styloid fracture) is a less common injury. Dorsal dislocation of the ulna occurs during hyperpronation e.g. as result of a blocking drill or more often a forward fall on the outstretched hand. Supination is restricted or impossible and an AP X-ray view shows widening of the DRUJ. Volar dislocation occurs during hypersupination as in a backward fall on the outstretched hand. Pronation is impossible and the AP view shows an overlap of the distal radius and the ulnar head due to the convergent pull of the pronator quadratus muscle. Closed reduction and immobilization in the stable position of rotation in a long-arm cast can be a very successful treatment. Closed reduction may be impossible due to boney blocking or soft tissue interposition (esp. ECU in Galleazi lesion). Open reduction is then required followed by reinsertion of the TFC at the ulnar fovea using a bone anchor or transosseous sutures. The repair is usually temporarily protected by a radioulnar K-wire.

A thorough clinical assessment is essential when a subacute or chronic TFC-lesion is suspected. Active DRUJ rotation under loading, radioulnar ballotment-testing in different positions of rotation and foveal palpation between the ulnar styloid and the FCU should be routine. Findings of structural alterations of the TFCC at MRI or CT-arthrography should be interpreted with caution as, with the exception of a foveal TFC avulsion (Palmer 1B) the correlation of any type of TFCC damage with DRUJ instability is still unclear. Axial CT or MRI scan in different positions of rotation allows for evaluation of the radioulnar subluxation ratio, which presently appears to be the most reliable parameter to quantify DRUJ translation (14). Arthroscopic evaluation followed by either TFC suture to the peripheral wrist capsule and the ECU subsheath, or mini-open foveal reinsertion using a bone-anchor, are standard techniques for treating relatively fresh lesions. Ligament reconstruction of one or both limbs of the triangular ligament is probably preferable for chronic DRUJ instability.

Loss of rotation due to diaphyseal malunion

Galleazi fractures of the radius, Monteggia fractures of the ulna and diaphyseal 2-bone-fractures of the forearm carry a risk for development of a disabling malunion. It is rarely seen following ulnar nightstick fractures. Deformity patterns can be very complex, combining multiplanar deformities of the 2 bones. The effect of diaphyseal malunion on forearm rotation is far more deleterious than that of a distal malunion, degree by degree. Cadaver experiments yield the following conclusions : angular deformity over 15° of the radius towards the IOM, effectively diminishing the depth of the radial bow, reduces rotation in the 2 directions. Both a change to the depth of the bow (with a tolerance of 1.5 mm) as a shift of the apex along the longitudinal axis (with a tolerance of 4%) affect prono-supination (16). Angular malalignment of both bones up to 10° may be well tolerated in the distal third, less so in the middle third. Rotational malunion of the ulna moves the arc of motion in the direction of the malunion, with only pronatory malunion of the ulna being possibly problematic. Pronatory malunion of the radius reduces supination. Supinatory radius malunion has the most severe impact, diminishing both pronation and supination (5). As a general rule of anatomy the tip of the radial styloid process should lie 180° opposite to the proximal tuberosity. Anatomic open reduction and internal fixation has become the benchmark procedure in treating forearm fractures in adults. Again, in children, bone healing in less than anatomic position is still compatible with later unrestricted function, due to the spontaneous corrective potential during skeletal growth. Noonan accepts 15° of angulation, 45° of malrotation and complete overriding of fragm ents in diaphyseal true fractures in children under 9 years of age (13). Proximal one-third angulation, rotational malunion, and flattening of the radial bow remodel less predictably, particularly in the age group older than 10 years. In children, a particular type of 'plastic' osseous deformity is seen following so

called 'bowing fractures'. Remodeling of bowing fractures is poor over age 6 years, and closed reduction is advised if the deformity is clinically visible in this group (21).

An established malunion with functional rotational deficit and/or a painful and unstable DRUJ is better corrected within one year of injury to obtain favourable results. In the young age group, corrective surgery yields better results if performed before the age of 10 years. Reports mention corrective osteotomies of either the radius only (single or double) or of both forearm bones, booking more success when tackling supination deficits than pronation deficits (12). Preparatory radiographic evaluation of diaphyseal malunions is not easy, especially in patients with bowing, where no clear fracture site can be localized. This can be overcome by using templates on tracer paper for comparison with the other side by simple superposition. Still, any 2D preoperative planning technique remains approximate and often requires peroperative adjustment. Rotational radius malunion can only be quantified on CT or MRI by measuring the radial torsion angle (2). More explicitly than for the correction of distal malunion, 3-D evaluation and CAS has almost overnight become the gold standard for correcting diaphyseal malunion. MRI, using special protocols, can replace CT for data acquisition, taking away concerns about irradiation. Different strategies of correction can be compared in the virtual model. A custom made guide for the osteotomy facilitates a precise osteotomy. The fixation plate can be used as an assembly guide on which the bone ends are joined in the correct position simply by tightening the screws in the predrilled holes. Complex surgery is thus rendered controlled and straightforward (Fig. 3)(18). Still, the technique relies on a 'normal' other side. The intra-individual difference e.g. between the radial torsion angles of both radial bones in normal subjects is low (mean 4.9°) but interindividual differences can be considerable (2). Bilateral deformity is therefore still a challenge as there is no generic forearm bone model available yet. Also soft tissue restraints are not taken into account in the virtual model. Release of the IOM can safely be done if, following corrective osteotomy and internal fixation, forearm rotation is still markedly reduced during peroperative mobilization.
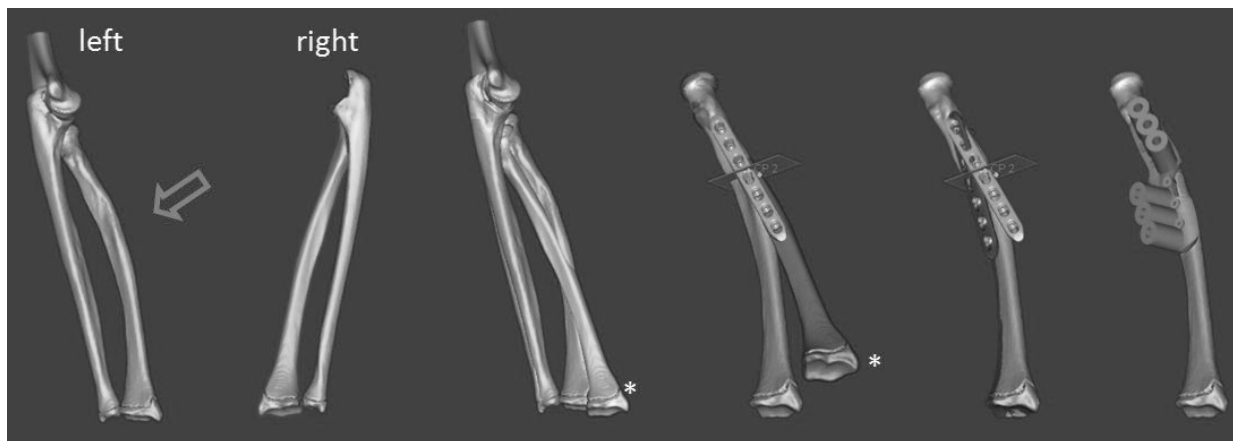

Fig. 3 : Surgical planning on a virtual model with left sided bowing of the radius (* = the mirrored normal right radius). Guided bone cutting and drilling ensures 'automatic correction' by assembly on the fixation plate. Courtesy F. Stockmans.

Rotation deficit following radial head fracture and elbow injury

Radial head fractures are the most common elbow injuries threatening forearm rotation. Signs of valgus laxity of the elbow (MCL injury and coronoid fracture in the so-called 'terrible triad') and longitudinal forearm instability (DRUJ injury and IOM rupture in the Essex-Lopresti lesion) should be sought after and investigated by US and MRI. Isolated marginal radial head fractures with limited displacement, and without limitation of rotation after one week of rest, possibly following aspiration of the hemarthrosis and lidocain infiltration, can safely be left alone. Possibly all the other fracture types, involving the radial head partially or in its entirety,

and whether or not being part of a wider injury complex, form a surgical indication. Protruding material on the outside of the radial head should be avoided or should be placed on the non-articular sector of the radial head. This area spans about 110° and encompasses a 90° angle between the radial styloid and Lister's tubercle (3). It lies opposite to the radial notch on the ulna when the forearm is in the neutral position of rotation. New radial neck plates with angular stable screws, with the option of puzzling the head together on the table, certainly allow for tackling even relatively complex fracture patterns. Reconstruction of the radial neck, respecting the individual correct length, offset (±15°) and orientation remains a challenge. The offset points to the lateral side and is maximal on an AP-view with the forearm rotated in 58.6° of supination (11). One sh uld remember that any fixation must be stable without making the head to bulky, to allow for early rotation. A peroperative valgus stress test of the elbow should be done when radial head resection is considered. The radius pull test allows for intra-operative prediction of longitudinal forearm instability. If the radius moves proximally by 3 mm or more (measured by fluoroscopy at wrist level) when it is pulled on at its neck by a 9.1 kg weight, then the IOM has ruptured (17). Certainly in complex injury, the assembled radial head should be able to withstand early axial loading in spite of postoperative immobilization or splinting with hinged braces. Radial head arthroplasty using a metal implant may be the easier and safer solution in these circumstances. Different IOM repairs and ligamentoplasties have been described. Such a procedure is not necessary when radial length can be restored. Radial head resection still is the most reliable long-term solution for isolated comminuted radial head fractures without instability.

Fig. 4 : Monteggia lesion of the posterior type (Bado II) with acceptable F/E but poor P/S

Radial head dislocation usually occurs as part of a Monteggia lesion. Normally, open reduction and internal fixation of the ulna is enough to reduce the radial head, but soft tissue interposition may prevent this. Especially the adult posterior Monteggia type with posterior fracture dislocation of the proximal radius is often complicated by stiffness (Fig 4). Isolated radial head dislocations are extremely rare and are most often neglected Monteggia lesions, e.g. in case of pediatric bowing fracture of the ulna. Radioulnar bone length discrepancy, caused by ulnar growth arrest should be excluded. Differentiation from congenital radial head dislocation, which probably should be left alone, can be difficult. In children, corrective osteotomy of the ulna with open reduction of the radial head is needed. Reconstruction of an annular ligament using a strip of triceps tendon may be necessary to keep the radial head in place (1). In adults, radial head resection is usually preferred.

Diaphyseal radius osteotomy can be useful in young patients to reset the rotation arc when rotation of the radial head is painless but limited e.g. by malunion of the radial neck.

Posttraumatic synostosis and heterotopic ossification (HO)

HO is the formation of bone as a consequence of a complex cellular response in soft tissues, typically seen in burned or head-injured patients around the elbows and in the forearm after

direct trauma (crush), local ischemia and forceful passive joint manipulation. A diathesis for HO exists in patients with Paget's disease, ankylosing spondylitis, idiopathic skeletal hyperostosis and in men with hypertrophic osteo-arthritis. HO in catastrophic proportions is encountered in the rare genetic disorder myositis or fibrodysplasia ossificans progressiva, which forms a contra-indication for surgery.
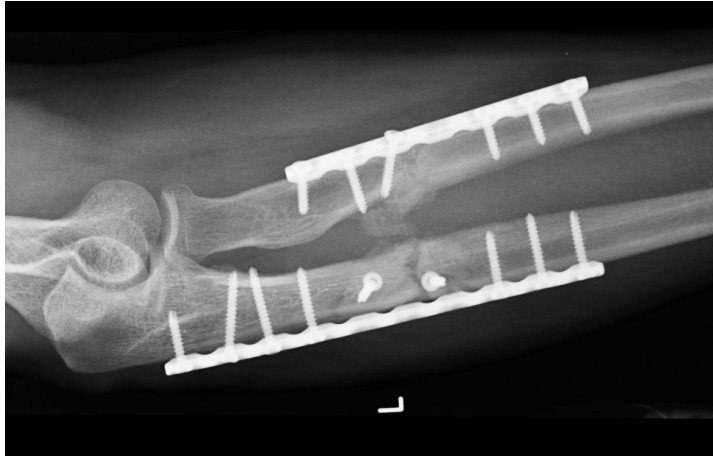

Fig. 5 : Forearm synostosis in a young male with forearm fractures following crush injury.

Synostosis is the wide formation of bone in a hematoma in continuity with a periosteal or even endosteal callus which eventually bridges the interosseous space. Local factors such as open fracture, fracture of the two bones and in that case use of a single surgical approach, poor fracture reduction with narrowing of the interosseus space and the presence of loose fragments or primary bonegrafts, inadequate internal fixation with protruding screws and delayed union may all contribute to the formation of a synostosis (Fig. 4). Skeletal immaturity is also a risk factor. It is often impossible in a situation of open complex multitrauma to make a clear distinction between HO and synostosis. Congenital radioulnar synostosis, which is located proximally and often on both sides, is a totally different condition.

Vince and Miller (20) developed a widely accepted classification for radioulnar synostosis. Type I occurs at the level of the distal radioulnar joint, type II in the middle third of the forearm and type III, which is the most prevalent, occurs in the proximal third of the forearm. Surgical resection of the synostosis yields good results in type II in contrast to type I and III, where damage to the joint and a high recurrence rate adversely affect the outcome.

Development of HO can be noticed on plain radiography within the first 4 to 6 weeks. Earlier diagnose is possible using ultrasound. Classic blood tests such as alkaline phosphatase (AP) activity are not very useful as the volume of HO development is small. Three-phase technetium bone scan is useful to assess the activity of HO. CT-scan is an essential preoperative tool to study the location and extent of the ectopic bone, so that the appropriate surgical approach can be chosen.

The need for deferral of surgical intervention is widely accepted but the recommendations vary considerably : until 2 months post-injury in isolated soft tissue injury to the forearm, until 4 to 6 months post-injury for a type II synostosis, until 6 to 9 months or even until 'maturity' of the bone around 12 months post-injury for true HO in the proximal forearm (type III) or around the elbow. It is prudent to wait with a surgical release until bone healing is evident, provided the fractures are correctly reduced. Even then, the implants are better left in place for 12 months after consolidation, if not indefinitely. HO may resorb in children with reversible central nervous system conditions or when the ectopic bone is non-bridging. This warrants for a longer observation period in the pediatric HO group. Longstanding synostoses i.e. over 3 years old are probably better left undisturbed.

Peri-operative prophylaxis by irradiation (as a single dose of 700 cGy within 48 to 72 hours of resection) and pharmacological intervention is definitely an issue in HO around the elbow (type III), less so in type II synostosis. The classic anti-inflammatory regimen (NSAID) uses indomethacin at a dose of 75 mg twice a day for 6 weeks. Patient tolerance and compliance is low. NSAID adversely affect fracture healing. Etidronate diminishes the mineralization of the osteoid but does not interfere with its formation. The main side-effects are gastrointestinal disturbance and osteomalacia. Termination of the treatment can provoke a rebound calcification. Both n-acetylcysteine (NAC) and allopurinol proved very efficient in an animal model and administration of the combination of these 2 drugs for 6 weeks postoperatively (at doses of 600 mg NAC 2x and 300 mg allopurinol once a day) may be a valuable alternative to indomethacin (19).

Insertion of a barrier in the interosseus space following resection of the boney bridge has been advocated for decades. It is certainly useful when excising heterotopic bone at the level of the biceps tuberosity as encountered following biceps tendon reinsertion. Barrier insertion following resection of a type II synostosis is only required if either a large area of raw bone or the endosteal bone lies exposed. Different barrier materials have been proposed : silastic-rubber sheet, non-vascularized autogenous material such as fat, vascularized muscle (anconeus) and pedicled adiposofascial flaps (lateral arm, posterior interosseous) and finally allograft material e.g. fascia lata. Silicone has been shunned as an implant material in the body in recent years and there is no proof of its superiority over other materials, warranting its use here. Fascia lata allograft can nicely be wrapped around the ulna following resection of a type II synostosis.

Surgical removal of ectopic bone requires a meticulous dissection technique as there is a considerable risk for neurovascular damage, especially of the posterior interosseous nerve. Particular attention should be paid to hemostasis (bipolar electro-coagulation, suture ligatures and bone wax), evacuation of all bone dust by ample irrigation without pressure and postoperative wound drainage. Abstention of a tourniquet avoids uncontrollable bleeding at the end of the operation. Wound healing can be compromised around the elbow.

Resection of a wide type II synostosis may remove the entire IOM. If the radial head had been removed previously, a prosthetic radial head replacement is needed concomitantly with the synostosis resection. In cases of radius malunion, this will need correction and an extensive radial approach is then preferred. Otherwise, a long ulnar approach is used with the incision over the subcutaneous ulnar border, then proceeding either dorsal or volar to the ulna or on both sides according to the location of the ectopic bone on CT. The interosseus vessels may require ligation. Peroperative fluoroscopy is used to control the extent of the dissection before and after resection of the ectopic bone.

It is important in type III synostosis to differentiate the area of the radial tuberosity from the PRUJ. If the ectopic bone is limited to the radial tuberosity area, resection through an anterolateral approach is indicated, eventually restoring an interosseus space of 5 mm by resection of ulnar bone. There is a lot of support in the literature for the use of irradiation and pharmacologic prophylaxis, and for insertion of a barrier in these cases. Salvage surgery is preferred in case of isolated PRUJ synostosis either in the form of metal radial head implant arthroplasty or by joining irradiation and/or pharmacologic prophylaxis to simple radial head resection. At the moment, the only available salvage solution for an irresectable synostosis engulfing both the PRUJ and the area of the radial tuberosity, is the proximal radial resection procedure described by Kamineni. Both the IOM and the DRUJ need to be intact. A 1-cm segment of radius is resected distal to the synostosis and the bone ends are sealed with bonewax. The rotation gained by this procedure is modest but useful. The supination torque is reduced because the action of both the biceps and part of the supinator muscle is neutralized (10).

Postoperative rehabilitation obviously concentrates on early mobilization i.e. as soon as the bleeding and the soft tissue swelling are under control. This can be supported by continuous brachial plexus pain blockade via an indwelling catheter together with the application of continuous passive motion machines, and use of alternating static progressive or dynamic splints. Night splints in submaximal positions of rotation are typically worn for a minimum of 6 months.

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