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J Bone Joint Surg Am. 2001 Apr;83-A(4):509-19.

Treatment of severely comminuted intra-articular fractures of the distal end of the radius by open reduction and combined internal and external fixation.

Rogachefsky RA¹, Lipson SR, Applegate B, Ouellette EA, Savenor AM, McAuliffe JA.

Author information

Abstract

BACKGROUND: Severely comminuted AO type-C3 intra-articular fractures of the distal end of the radius are difficult to treat. Failure to achieve and maintain nearly anatomic restoration can result in pain, instability, and poor function. We report the results of a retrospective study of the use of a standard protocol of open reduction and combined internal and external fixation of these fractures.

METHODS: Seventeen of twenty-five patients treated with the protocol were available for follow-up evaluation. Six had an AO type-C3.1 fracture; eight, type-C3.2; and three, type-C3.3. Eleven fractures required a dorsal buttress plate and/or a volar buttress plate, and eleven required bone-grafting. The mean time until the external fixator was removed was seven weeks.

RESULTS: At a mean of thirty months postoperatively, the mean arc of flexion-extension was 72% of that on the uninjured side and the mean grip strength was 73% of that on the uninjured side. The mean articular step-off was 1 mm, the total articular incongruity (the gap plus the step-off) averaged 2 mm, and the radial length was restored to a mean of 11 mm. Thirteen patients had less than 3 mm of total articular incongruity. Arthritis was graded as none in three patients, mild in ten, moderate in three, and severe in one. According to the Gartland and Werley demerit-point system, ten of the patients had a good or excellent result. According to the modified Green and O'Brien clinical rating system, five had a good or excellent result. One patient had a fracture collapse requiring wrist fusion, one had reflex sympathetic dystrophy, and three had minor Kirschner-wire-related problems. Total articular incongruity immediately postoperatively had a moderately strong correlation with the outcome as assessed with both clinical rating systems ($r = 0.70$ and 0.74 for the Gartland and Werley system and the Green and O'Brien system, respectively; $p < 0.05$).

CONCLUSIONS: Open reduction and combined internal and external fixation of AO type-C3 fractures can restore radiographic parameters to nearly normal values, maintain reduction throughout the period of fracture-healing, and provide satisfactory functional results.

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[Bioelectromagnetics](#). 2004 May;25(4):260-70.

Use of a permanent magnetic field to inhibit the development of canine osteoarthritis.

[Rogachefsky RA](#)¹, [Altman RD](#), [Markov MS](#), [Cheung HS](#).

Author information

Abstract

This study was designed to determine the potential of a permanent magnetic field to inhibit the progression of osteoarthritis (OA) in a canine model. The magnetic field was created by 72 domino-sized ceramic magnets with surface field strength of 1100 G (0.11 T). The magnetic field strength at the surface of the mattress was 450-500 G (45-50 mT) and was equally distributed over the mattress surface. Eighteen animals had closed resection of their right stifle anterior cruciate ligament. Their kennel floors were covered in one of three ways: no floor mattress (OA) (N = 6); a floor mattress with domino-sized ceramic pieces placed between two layers of foam (sham control OA-MAT) (N = 6); or a floor mattress with domino-sized ceramic permanent magnets placed between two layers of foam (OA-MAT-MAG) (N = 6). Animals were kept in their cages except for 4 h of exercise each day. The left stifle of six animals served as the normal control. The stifle joints were examined at 12 weeks for synovial effusion, gross anatomic appearance, microscopic anatomic appearance (Mankin score), and metalloproteinase (MMP)-1 and -3. Macroscopically, the OA-MAT-MAG group appeared to have less synovitis, less synovial effusion, less disruption of the cartilage surface, and less cartilage ulceration than did the OA group or the control mattress group. The mean Mankin score for the OA-MAT-MAG group was less than that for the OA group (4.2 +/- 0.8 vs. 6.7 +/- 0.3; P <.05) and the control mattress group (4.2 +/- 0.8 vs. 5.2 +/- 0.8; P >.05), but greater than that for the normal left group (4.2 +/- 0.8 vs. 1.0 +/- 0.4; P <.05). These scores show a trend of improvement for OA-MAT-MAG group but the difference with the sham control OA-MAT group was not statistically significant. In immunohistochemical studies, the OA-MAT-MAG group cartilage was stained less heavily for MMP-1 and MMP-3 than were the OA group cartilage and the control mattress group cartilage, but did not differ significantly in MMP-1 and MMP-3 from the normal left group cartilage. The OA-MAT-MAG group did not differ from the normal left group in MMP-3 as determined by Western blot analysis. The study suggests that OA of the medial femoral condyle developed in a canine model exposed to a magnetic field may be inhibited beyond the benefit provided by mattress. Further studies are needed to delineate more precisely the effect of the magnetic field in reducing the severity of OA.

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TREATMENT OF SEVERELY COMMUNUTED INTRA-ARTICULAR FRACTURES OF THE DISTAL END OF THE RADIUS BY OPEN REDUCTION AND COMBINED INTERNAL AND EXTERNAL FIXATION

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University of Miami School of Medicine, Miami, Florida*

Background: Severely comminuted AO type-C3 intra-articular fractures of the distal end of the radius are difficult to treat. Failure to achieve and maintain nearly anatomic restoration can result in pain, instability, and poor function. We report the results of a retrospective study of the use of a standard protocol of open reduction and combined internal and external fixation of these fractures.

Methods: Seventeen of twenty-five patients treated with the protocol were available for follow-up evaluation. Six had an AO type-C3.1 fracture; eight, type-C3.2; and three, type-C3.3. Eleven fractures required a dorsal buttress plate and/or a volar buttress plate, and eleven required bone-grafting. The mean time until the external fixator was removed was seven weeks.

Results: At a mean of thirty months postoperatively, the mean arc of flexion-extension was 72% of that on the uninjured side and the mean grip strength was 73% of that on the uninjured side. The mean articular step-off was 1 mm, the total articular incongruity (the gap plus the step-off) averaged 2 mm, and the radial length was restored to a mean of 11 mm. Thirteen patients had less than 3 mm of total articular incongruity. Arthritis was graded as none in three patients, mild in ten, moderate in three, and severe in one. According to the Gartland and Werley demerit-point system, ten of the patients had a good or excellent result. According to the modified Green and O'Brien clinical rating system, five had a good or excellent result. One patient had a fracture collapse requiring wrist fusion, one had reflex sympathetic dystrophy, and three had minor Kirschner-wire-related problems. Total articular incongruity immediately postoperatively had a moderately strong correlation with the outcome as assessed with both clinical rating systems ($r = 0.70$ and 0.74 for the Gartland and Werley system and the Green and O'Brien system, respectively; $p < 0.05$).

Conclusions: Open reduction and combined internal and external fixation of AO type-C3 fractures can restore radiographic parameters to nearly normal values, maintain reduction throughout the period of fracture-healing, and provide satisfactory functional results.

Severely comminuted intra-articular fractures of the distal end of the radius are challenging to treat. Restoration of congruity of the articular surface is the most critical factor for a good functional result¹⁻⁷. Restoration of radial length (the distance from the radial styloid process to the distal head of the ulna), radial tilt angle, and volar tilt angle is also important^{1-6,8}. Failure to achieve and maintain nearly anatomic restoration can lead to degenerative arthritis, distal radioulnar

and midcarpal instability, and ulnar impaction syndrome, with resultant pain, decreased motion and strength, and poor function^{3,5,9-14}.

Since 1990 we have addressed the problem of loss of postoperative stability during fracture-healing by using a combination of internal and external fixation for the most severely comminuted intra-articular fractures of the distal end of the radius. The indication for this treatment protocol is a fracture classified as AO type C3 on preoperative radiographs because, in our judgment, these fractures have a high probability of collapse during healing. The aim of the protocol is to obtain nearly anatomic reduction with internal fixation and to



A video supplement to this article will be available from the *Video Journal of Orthopaedics*. A video clip will be available at the JBJS web site, www.jbjs.org. The *Video Journal of Orthopaedics* can be contacted at (805) 962-3410, web site: www.vjortho.com.

maintain the reduction by applying an external fixator to assist in neutralizing forces across the radiocarpal joint during fracture-healing¹⁵.

We report the results of a retrospective study of the use of open reduction and combined internal and external fixation of AO type-C3 fractures in seventeen patients who were followed for a minimum of two years.

Materials and Methods

We reviewed retrospectively hospital and clinical records of all patients who underwent surgical treatment of an intra-articular fracture of the distal end of the radius at the University of Miami School of Medicine/Jackson Memorial Medical Center from January 1990 to August 1994. Seventy-eight patients with a total of eighty-one fractures were identified. Fifty-six fractures were classified as AO type B2, B3, C1, or C2. Twenty-five AO type-C3 fractures were treated with open reduction and combined internal and external fixation according to our protocol.

We examined the records and radiographs of the twenty-five patients (twenty-five fractures) who were treated with the combined technique. In all patients, the combined

technique was applied after attempts to manage the fracture by closed reduction alone had failed. The specific radiographic criterion for considering closed reduction a failure was more than a 2-mm step-off of the distal articular surface of the radius¹⁶. Data on age, gender, handedness, mechanism of injury, fracture characteristics, concomitant ipsilateral injuries of the forearm and wrist, systemic injuries, type of fixation, surgical procedures, postoperative management, and complications were obtained from the patients' records. Informed consent was obtained from the patients in accordance with the guidelines of the United States Food and Drug Administration and the sponsoring institution.

Seventeen patients were available for follow-up evaluation at least two years after the injury. Data for eight male patients with a mean age of thirty-nine years who were lost to follow-up within two years after the injury were not included in our analysis but were examined separately. All eight of these patients were treated with a single surgical approach. External fixation was applied to all eight fractures and, in addition, Kirschner wires were used for seven; a dorsal buttress plate, for four; and a volar buttress plate, for four. Three corticocancellous and two cancellous bone grafts were used for five frac-



Fig. 1-A



Fig. 1-B

Anteroposterior and lateral radiographs of the left wrist of a thirty-three-year-old male firefighter who sustained an AO type-C3.3, Gustilo¹⁶ grade-II open fracture of the distal end of the radius. Comminution of the anterior and posterior metaphyseal and diaphyseal cortices is extensive. An initial procedure involved application of an external fixator, carpal tunnel release, and excision and débridement of the open wound. Six days later, open reduction and internal fixation was performed with use of Kirschner wires, a large corticocancellous iliac crest bone graft, and dorsal and volar buttress plates. Injuries to the volar capsule and the scapholunate and lunotriquetral ligaments were repaired and pinned.

tures. Seven of the eight patients were followed until after the fixator was removed, at a mean of six weeks, and three patients were noted to have a total of four complications at the last follow-up visit. One of these patients had poor rotational motion that required an arthroplasty of the distal radioulnar joint, one had poor digital motion and also required removal of a plate that was causing pain, and one had limited radioulnar motion.

Demographic Data

The seventeen patients who returned for long-term follow-up evaluation included fourteen men and three women who ranged in age from twenty-seven to fifty-nine years (mean, forty-three years). Sixteen patients presented initially at our institution, and one was referred secondarily. The dominant wrist was injured in five patients and the nondominant wrist, in twelve. The initial injury resulted from a high-energy mechanism in eleven patients: seven were injured in a fall from a height; one, in a motorcycle accident; one, in an airplane crash; one, in an automobile-pedestrian accident; and one, in

an explosion. The injury resulted from a lower-energy mechanism in six patients: three fell while walking or running, two were injured in a bicycle accident, and one was injured while roller-blading. Eleven patients had a heavy-duty job, and six had a lighter-duty job.

Concomitant Injuries

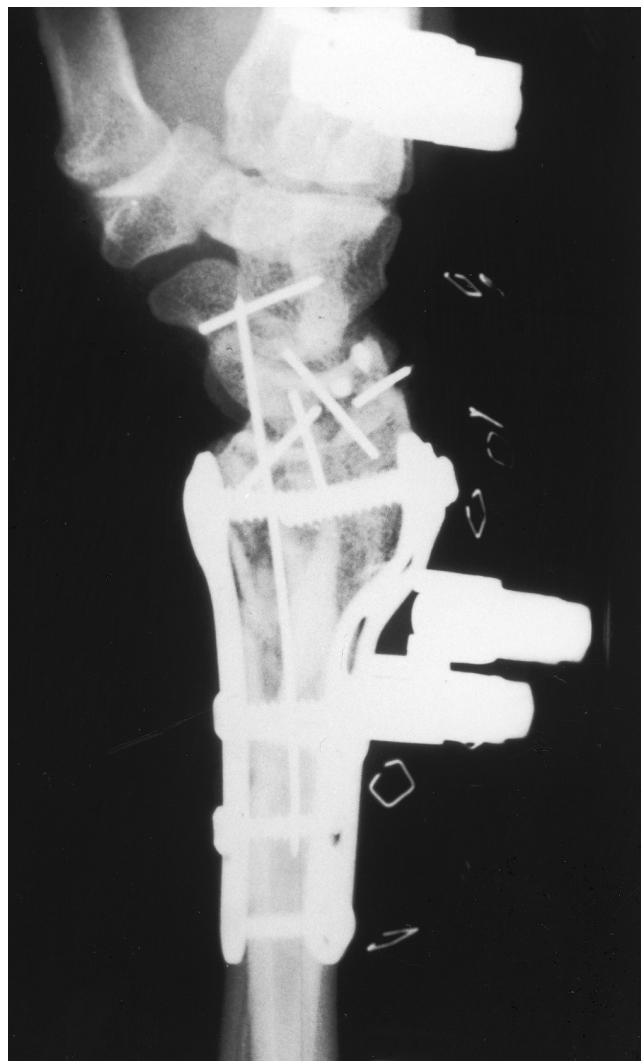
Concomitant ipsilateral injuries of the wrist and forearm in seven patients included an isolated tear of the scapholunate ligament in three patients, an open wound at the site of the fracture of the distal end of the radius in three patients (a Gustilo¹⁶ grade-I fracture in two patients and a Gustilo grade-II fracture in one patient), a forearm compartment syndrome in three patients, a fracture of the ulna in two patients, a fracture of the scaphoid and capitate in one patient each, and tears of the scapholunate and lunotriquetral ligaments and the volar capsule in one patient. Injuries to other areas in four patients included a fracture of the patella and a subdural hematoma in one patient; a fracture of the acetabulum in one patient; a testicular injury and severe burns to the face and

Plain anteroposterior and lateral radiographs made immediately after the operation show satisfactory reduction.

Fig. 1-C



Fig. 1-D



torso in one patient; and fractures of the contralateral humeral shaft, the femur, and the tibial plateau in one patient.

Surgical Technique

Open reduction combined with internal and external fixation was performed, if possible, within one week after the injury. In patients with systemic injuries, the surgery was performed as soon as the patient's condition had stabilized. In patients who presented with an acute carpal tunnel syndrome, the carpal tunnel was released emergently and open reduction and internal and external fixation was performed during the same operation. In patients with an open fracture or massive swelling that precluded early open reduction and internal fixation, external fixation alone was performed initially and then definitive open reduction and internal fixation was done when the

wound was clean and the swelling had decreased.

A general anesthetic was administered to thirteen of the seventeen patients, and an axillary block was used in four. The external fixator was initially placed, with use of standard technique^{10,17}. An open technique was used for placement of the fixator pins. Pins were placed in the neck and base of the second metacarpal¹⁸. The most distal pin in the radius was placed at least 2 cm from the fracture site, and the proximal pin was placed at least 2 cm proximal to the distal pin. Two types of external fixator were used, depending on the surgeon's preference. An AO fixator (Synthes USA, Paoli, Pennsylvania) with 4.0/3.0-mm Schanz pins was used in sixteen patients, and a double-stacked frame was constructed for stability¹⁰. An Orthofix wrist external fixator (Orthofix, Richardson, Texas) with 3.0 to 3.3-mm tapered pins was used in one

Plain anteroposterior and lateral radiographs made at the final follow-up visit, thirty-two months after the injury, show good anatomic restoration of the distal end of the radius. Radial length was 10 mm, and total articular incongruity was 2 mm. Scapholunate widening was noted. The patient attained 53° of flexion and 47° of extension and had a total arc of flexion-extension that was 68% of that on the uninjured side. He had 90° of pronation and 80° of supination. He returned to restricted employment and sports activities and reported no pain.

Fig. 1-E



Fig. 1-F



TABLE I Functional Outcome for Seventeen Patients at Final Follow-up Visit

| Outcome Measure | Injured Wrist* | Uninjured Wrist* | Injured Wrist as Percentage of Uninjured Wrist*† |
|-----------------------------------|----------------|------------------|--|
| Extension | 46° ± 18° | 65° ± 11° | 71% ± 27% |
| Flexion | 47° ± 15° | 64° ± 9° | 73% ± 23% |
| Total arc of flexion-extension | 93° ± 31° | 129° ± 17° | 72% ± 24% |
| Supination | 76° ± 14° | 85° ± 5° | 89% ± 15% |
| Pronation | 82° ± 15° | 89° ± 3° | 93% ± 17% |
| Total arc of supination-pronation | 159° ± 19° | 174° ± 7° | 91% ± 11% |
| Radial deviation | 17° ± 9° | 26° ± 7° | 66% ± 33% |
| Ulnar deviation | 27° ± 11° | 35° ± 9° | 77% ± 25% |
| Total arc of radioulnar deviation | 44° ± 16° | 61° ± 9° | 71% ± 24% |
| Grip strength | 31 ± 8 kg | 45 ± 12 kg | 73% ± 17% |
| Pinch strength‡ | 8 ± 2 kg | 10 ± 3 kg | 80% ± 19% |

*The values are given as the mean and standard deviation. †The value for the injured wrist as a percentage of the value for the uninjured wrist was calculated for each patient, and the mean of these individual percentages was then calculated. ‡Available for fifteen patients.

patient, and the frame determined the pin placement in the second metacarpal and the radius². Maximum manual traction was placed on the fixator to help to reduce the fracture and to correct radial length and displacement through ligamentotaxis¹⁹. The reduced position of the fracture fragments was checked with fluoroscopy, and it was determined, in all seventeen patients, that use of external fixation alone was inadequate to reduce articular comminution and to correct and maintain radial length.

The surgical approach depended on the direction of the displacement of the fracture and the location of the comminution⁴. The approach was dorsal for thirteen fractures with dorsal displacement and comminution, and an anterior Henry approach was used for three fractures with volar displacement and comminution¹. One fracture required both approaches because the severe comminution and instability involved both the volar and the dorsal cortex² (Figs. 1-A and 1-B).

In the dorsal approach, a straight incision is used to release the extensor retinaculum at the third extensor compartment and to allow retraction of the extensor pollicis longus tendon⁷. The fourth compartment is raised off the distal end of the radius subperiosteally and is retracted ulnarly, and the second compartment is raised and is retracted radially, exposing the fracture site⁴. The dorsal capsule is released off the dorsal surface of the radius in a "T" configuration to allow visualization of the articular fragments¹. Every attempt is made to avoid dissection in the fourth compartment to minimize scarring of the extensor tendons. Upon closure, the extensor retinaculum is repaired and the extensor pollicis longus is positioned superficial to the retinaculum.

The volar approach is made between the flexor carpi radialis tendon and the radial artery^{2,7}. Dissection is extended down to the pronator quadratus, and the muscle is freed from the volar aspect of the distal end of the radius, exposing the

fracture^{4,6}. The volar capsule is not dissected off the volar aspect of the radius in order to maintain the strong ligamentous support². Release of the volar articular fragments from the soft tissue should be limited to the extent necessary to allow visualization and to ensure anatomic reduction of the articular surface⁴.

To correct radial shortening and malalignment, the articular surface should be elevated as a unit to the level of the scaphoid and lunate and then reduced⁶. During this process the carpus is used as a template to judge the anatomic position of the distal fragments.

After the articular fragments had been anatomically reduced, fourteen fractures required stabilization with various internal fixation devices depending on fragment size. Eleven fractures with smaller fragments were stabilized with 0.045-mm Kirschner wires, two with larger fragments were stabilized with 3.5-mm cortical screws^{11,12}, and one was stabilized with a 0.045-mm Kirschner wire and a 3.5-mm cancellous screw. Articular stabilization of the other three fractures was provided by a 3.5-mm distal radial plate (Synthes USA); a dorsal plate was used in one patient, and a volar plate was used in two others.

Defects in eleven fractures were filled with bone graft to provide stability and to prevent collapse^{1,6,12,19,20}. Indications for bone-grafting were an AO type-C3.2 or C3.3 fracture in which defects in the metaphysis alone or in the metaphysis and diaphysis were noted after reduction of the articular surface. Eight fractures had metaphyseal defects alone, and three fractures had combined metaphyseal and diaphyseal defects. The type of bone graft depended on the size of the defect. Cortico-cancellous iliac crest bone graft was used for five fractures with larger defects. The graft was placed in the defect with the cortex positioned so that it offered optimal resistance to displacement or collapse of the articular fragments—that is, posteriorly in a dorsally displaced fracture and anteriorly in a

volarly unstable fracture. Cancellous bone graft was then packed into the remaining spaces of the fracture. Of six fractures with smaller defects, five were treated with cancellous bone and one was treated with bone substitute (Collagraft; Zimmer, Warsaw, Indiana).

A Synthes AO 3.5-mm distal radial plate (Synthes USA) was applied to eleven fractures to buttress the cortex for added stability^{4,19}. A dorsal plate was used in two patients, a volar plate was used in eight patients, and plate fixation of both cortices was performed in one patient who had extensive comminution of both the anterior and the posterior metaphyseal and diaphyseal cortices (Figs. 1-C through 1-F).

The external fixator was maintained across the wrist postoperatively to provide slight distraction and to unload the radiocarpal joint. Approximately 30% to 50% of the distraction force was released at the end of the operative procedure. Satisfactory reduction with slight distraction of the radiocarpal joint was confirmed with fluoroscopy or plain radiographs¹⁰.

The external fixator remained until bone-healing was demonstrated on plain radiographs; it was removed at a mean of seven weeks (range, five to nine weeks) postoperatively. Bone-healing was determined radiographically by the appearance of bridging trabeculae across the fracture site and clinically by the fracture site being nontender to palpation. Ten of the patients had the Kirschner wires removed when the fixator was removed. The wires were removed earlier from two patients who had pin-track-related problems.

Twenty-eight concomitant procedures performed on the

ipsilateral wrist and forearm included excision and débridement of an open fracture, open reduction and internal fixation of an open fracture of the ulnar shaft, and repair of intercarpal ligament injuries with bone anchors and pinning or with pinning alone. Carpal tunnel release was performed in fifteen patients who had had signs and symptoms of median-nerve compression preoperatively or were at risk for compression because of extensive swelling of the wrist and forearm^{1,9}. Three patients who had an acute forearm compartment syndrome were treated with immediate fasciotomy. Two of them later had delayed primary wound closure, and one had split-thickness skin-grafting.

The time from the injury to the definitive operation ranged from one to fifteen days (mean, seven days). Two patients with severe associated injuries had a staged approach that included emergency stabilization of systemic injuries, placement of external fixation across the wrist to stabilize the fracture of the distal end of the radius, and decompression of the carpal tunnel. Excision and débridement was performed on an open ulnar fracture in one of these patients and on a grade-II open fracture of the distal end of the radius in the other. Open reduction and internal fixation of the distal end of the radius was delayed until the condition of each of these two patients had stabilized and the wounds were clean, nine and six days after the injury. The two patients with a grade-I open fracture of the distal end of the radius had open reduction and internal fixation at the same operation as the initial excision and débridement.

TABLE II Radiographic Findings for Seventeen Fractures of the Distal End of the Radius in Seventeen Patients

| Radiographic Parameter | Injured Wrist* | | | | Uninjured Wrist at Final Follow-up* |
|--|----------------|----------------|---------------------------|--------------------|-------------------------------------|
| | Immed. Preop. | Immed. Postop. | Prior to Ex. Fix. Removal | At Final Follow-up | |
| Radial tilt angle† (deg) | 12 ± 9 | 21 ± 2 | 21 ± 3 | 22 ± 6 | 23 ± 3 |
| Radial length† (mm) | 4 ± 6 | 11 ± 3 | 11 ± 2 | 11 ± 4 | 12 ± 2 |
| Tilt angle of distal part of radius†‡§ (deg) | 1 ± 22 | -1 ± 8 | 1 ± 7 | 3 ± 8 | 11 ± 3 |
| Radial shortening† (mm) | 5 ± 4 | 1 ± 1 | 1 ± 1 | 1 ± 2 | 0 ± 0 |
| Ulnar variance†§ (mm) | 5 ± 4 | 0 ± 2 | 0 ± 2 | 1 ± 2 | 0 ± 1 |
| Gap† (mm) | 4 ± 2 | 1 ± 1 | 1 ± 1 | 1 ± 2 | 0 ± 0 |
| Step-off† (mm) | 3 ± 2 | 1 ± 1 | 1 ± 1 | 1 ± 1 | 0 ± 0 |
| Total incongruity†# (mm) | 7 ± 4 | 2 ± 2 | 2 ± 2 | 2 ± 2 | 0 ± 0 |
| Scapholunate angle (deg) | 54 ± 7 | 50 ± 7 | 51 ± 6 | 52 ± 5 | 51 ± 3 |
| Carpal height index** | 0.5 ± 0.1 | 0.5 ± 0.1 | 0.5 ± 0.1 | 0.5 ± 0.1 | 0.5 ± 0.1 |
| Revised carpal height index§ | 1.5 ± 0.1 | 1.6 ± 0.1 | 1.5 ± 0.1 | 1.5 ± 0.1 | 1.5 ± 0.1 |

*The values are given as the mean and standard deviation. †There was a significant improvement from the preoperative radiographic examination to that performed immediately postoperatively ($p < 0.002$). ‡Positive value = volar tilt, and negative value = dorsal tilt. The change in the tilt angle of the distal part of the radius from the preoperative radiographic examination to that performed immediately postoperatively was calculated for each fracture with reference to the norm of 11° of volar tilt^{3,14,23,38} because the wide variation in values (range, 50° of dorsal tilt to 40° of volar tilt) disallowed a direct comparison of the means. §A significant difference was found between the radiographs made immediately postoperatively and those made at the final follow-up visit ($p < 0.05$). #Total incongruity = gap + step-off. **Available for fifteen patients immediately preoperatively, fourteen patients immediately postoperatively, twelve patients just prior to removal of the external fixator, twelve patients at the final follow-up visit, and fifteen uninjured wrists.

Postoperative Management

All seventeen patients began active and passive range-of-motion exercises of the hand, forearm, elbow, and shoulder on the day after the operation⁴. To prevent finger flexion contractures, volar static splints were worn at night for approximately one to two weeks.

Fracture Classification and Follow-up Assessment

Fracture classification and radiographic assessment were performed retrospectively by three raters—two fellowship-trained full-time hand surgeons and a chief resident in orthopaedics—who independently measured the parameters on each radiograph. Two of the raters were blinded to the identity of the patients. Objective and subjective clinical results were determined from a physical examination and an interview conducted by one of us (R.A.R.) at the time of final follow-up.

Fracture classification: Fractures were categorized on preoperative radiographs (without traction or computed tomographic scans) within the AO type-C3 classification and according to the Frykman system^{5-7,21-23}. Type-C3 fractures, the most severe within the AO system, are divided into three subclassifications according to whether the comminution involves the articular surface (C3.1), metaphysis (C3.2), or diaphysis (C3.3)^{3,19,22}. An injury score was assigned to each fracture on the basis of the number of fracture fragments and the number of intercarpal injuries: 1 point was assigned for each fragment, and 1 point was assigned for each injury⁷.

Objective assessment: At the final follow-up examination, patients were tested for range of motion, for grip strength with a Jamar grip dynamometer (Sammons Preston, Bolingbrook, Illinois), and for pinch strength with a pinch dynamometer. Measurements of the contralateral side served as controls⁷. A sensory evaluation with Semmes-Weinstein monofilament testing was performed. The wrist and the distal radioulnar joints were palpated for tenderness.

Subjective assessment: At the final follow-up visit, a questionnaire was given orally regarding the level of pain, return to work, type of work, and participation in sports activities. Patients were asked if they were very satisfied, satisfied, or not satisfied with the result of the surgery and whether they would undergo the surgery again under similar circumstances.

Assessment of radiographic parameters: Standard guidelines were utilized to determine selected radiographic parameters^{3,4,7,15,24,25}, which were analyzed retrospectively on anteroposterior and lateral radiographs made at four time points: preoperatively before any reduction maneuvers, immediately after the operation, just before removal of the external fixator, and at the final follow-up evaluation. Values for the contralateral side were determined from anteroposterior and lateral radiographs made at the final follow-up examination⁷.

Assessment of arthritis: The severity of arthritis at the radiocarpal joint was determined retrospectively on anteroposterior and lateral radiographs made preoperatively and at the final follow-up examination. Arthritis was graded as none, mild, moderate, or severe according to the system of Knirk and Jupiter⁵.

Clinical rating systems: The outcome for each patient was evaluated with use of two scoring systems. The clinical scoring system of Green and O'Brien²⁶, as modified by Cooney et al.²⁷, provides a score based on subjective and objective clinical data (pain, work activity, range of motion, and grip strength). The demerit-point system of Gartland and Werley^{28,29}, as modified by Sarmiento et al.³⁰, provides a score based on subjective and objective clinical and radiographic data (amount of residual deformity, pain, range of motion, grip strength, and complications). Each system allows grading of the final outcome as excellent, good, fair, or poor^{27,28,30}.

Statistical Analysis

The independent t test (two-tailed) or one-way analysis of variance was used to test for differences between groups. The Pearson correlation coefficient was used to examine for relationships between variables. Chi-square analyses were conducted on nominal variables. The probability of a type-I error (alpha) was set at ≤ 0.05 for all statistical analyses. Kappa and intraclass correlations (3,1) were used to examine the interrater reliability³¹.

Results

The mean duration of follow-up of the seventeen patients was thirty months (range, twenty-four to sixty-one months).

Fracture Classification and Outcome

The values provided by the three raters for fracture classification and radiographic parameters were not averaged because interrater reliability was poor (kappa values of < 0.5). For this report, we used only the values supplied by one of us (R.A.R.), a full-time hand surgeon.

Fracture Classification

Within the AO type-C3 classification, six of the seventeen fractures were subclassified as 3.1; eight, as 3.2; and three, as 3.3. Three fractures were classified as Frykman type VII and fourteen, as Frykman type VIII. The mean injury score (and standard deviation) was 4.2 ± 1.25 points (range, 3 to 8 points). Three fractures were open; two of them were classified as Gustilo grade I and one, as Gustilo grade II.

Objective Outcome

The mean values for range of motion, grip strength, and pinch strength for the seventeen patients are given in Table I. The mean total arc of flexion-extension at the final follow-up evaluation was 93° (range, 0° to 140°), 72% of the value for the uninjured side; the mean total arc of supination-pronation was 159° (range, 115° to 180°), 91% of the value for the uninjured side; and the mean total arc of radioulnar deviation was 44° (range, 0° to 64°), 71% of the value for the uninjured side.

The mean grip strength on the injured side was 31 kg (range, 12 to 43 kg), 73% of the grip strength on the uninjured side. The mean pinch strength, known for fifteen patients, was 8 kg (range, 5 to 12 kg), 80% of that on the uninjured side.

At the final follow-up evaluation, all patients demon-

strated normal sensibility, which ranged from 1.65 to 2.83 on the Semmes-Weinstein monofilament test.

Subjective Outcome

Sixteen patients were very satisfied with the outcome, and one patient was not satisfied. The rating of very satisfied, even when given by patients with wrist stiffness and/or moderate pain, reflected the patients' appreciation of the substantial recovery that they achieved after a severe wrist injury. All seventeen patients indicated that they would have the surgery again under similar circumstances. Seven patients reported no pain at the final follow-up examination, and seven had only mild or occasional pain. Two patients reported moderate but tolerable pain. The patient who was unsatisfied with the outcome reported severe, intolerable pain. He had been incarcerated after removal of the external fixator and had not been given an opportunity for physical therapy. Three patients described pain at the distal radioulnar joint and had tenderness on palpation of the joint. Two of these patients had had an ulnar styloid fracture on preoperative radiographs.

Fourteen patients had returned to work by the time of the final follow-up evaluation, and ten had resumed their pre-injury employment. Eight of the eleven patients who had held a heavy-duty job before the injury returned to work; five of them had no restrictions and three had some restrictions. The mean time until the patients returned to work was ten months (range, 0.25 to thirty months). Of the three patients who were not working at the time of follow-up, one was permanently disabled because of multiple medical problems unrelated to the wrist fracture, one was able to work but could not find employment, and one was incarcerated.

Twelve patients reported that they had participated in sports before sustaining the wrist injury. By the time of the final follow-up evaluation, all twelve had returned to sports, including football, fishing, billiards, golf, and skiing. Eight of them had returned to the same sports activities in which they had participated before the injury. The mean time until the patients returned to sports was ten months (range, two to thirty months).

Radiographic Outcome

At the final follow-up examination, fifteen patients had <2 mm of articular step-off, thirteen had <3 mm of total articular incongruity, and twelve had ≥ 10 mm of radial length (Table II). Using repeated-measures analysis of variance, we found a significant improvement in eight parameters ($p < 0.002$ for all) when radiographs made immediately postoperatively were compared with those made preoperatively. With the numbers available, no significant change in the mean scapholunate angle, carpal height index, or revised carpal height index could be detected. Also, we detected no significant differences in eight parameters when the final follow-up radiographs were compared with those made immediately postoperatively. However, significant differences in the mean revised carpal height index, ulnar variance, and tilt angle of the distal part of the radius ($p < 0.05$) were found (Table II).

Comparison of the injured and uninjured wrists at the final follow-up evaluation demonstrated, with the numbers available, no significant differences in the mean radial tilt angle, radial length, ulnar variance, scapholunate angle, carpal height index, or revised carpal height index. Statistical comparisons of the injured and uninjured wrists were not conducted for the mean articular gap, articular step-off, total articular incongruity, or shortening because the values for the uninjured wrists were zero; however, the mean values for the injured wrists were within normal limits (Table II). The mean tilt angle of the distal end of the radius for the injured wrists at the final follow-up visit was significantly less than that for the uninjured wrists ($p < 0.05$).

Arthritis

Three of the seventeen patients had no radiographic signs of arthritis at the final follow-up visit, ten had mild arthritis, and three had moderate arthritis. One patient, who had demonstrated mild arthritis on preoperative radiographs, had severe arthritic changes with joint incongruity, osteophyte formation, and bone-on-bone contact at the final follow-up evaluation⁵.

Outcome of Evaluations with Clinical Rating Systems

According to the modified clinical scoring system of Green and O'Brien²⁶, the functional result was excellent for one patient and good for four (29% good or excellent results); the result was fair for eight patients and poor for four. The mean score (and standard deviation) was 66.5 ± 17.3 points (range, 25 to 90 points). The mean pain score was 20 points (range, 0 to 25 points), and the mean return-to-work score was 21 points (range, 0 to 25 points).

According to the demerit-point system of Gartland and Werley^{28,29}, eight patients had an excellent result and two had a good result (59% good or excellent results); four patients had a fair result, and three had a poor result. The mean demerit-point-system score was 7.6 ± 7.8 points (range, 0 to 22 points).

Complications

Five of the seventeen patients had a total of six complications (two major and four minor⁹). In one patient with an AO type-C3.2 fracture, loss of reduction and collapse of the fracture at six weeks led to the development of moderate arthritis at the radiocarpal joint. A wrist fusion and a Sauvé-Kapandji procedure was performed four months after the injury to eliminate pain and to improve function. Although the patient had a poor result according to both clinical rating systems at the final follow-up visit, sixty-one months after the injury, he had only occasional pain and a stable wrist and he was very satisfied with the ultimate outcome.

Reflex sympathetic dystrophy developed in one patient; it resolved with physical therapy after removal of the fixator at nine weeks. The patient had a fair result according to both clinical rating systems. At the final follow-up visit, forty-four months after the injury, the patient reported occasional pain and was very satisfied with the result. He had returned to his preinjury sports activity and to his previous job as a counselor.

Four minor complications involving Kirschner wires

(tendon irritation or superficial infection) were noted in three patients. All symptoms resolved after removal of the wires.

Effect of Preoperative Factors on Surgical Technique

We analyzed whether the mechanism of injury, injury score, Frykman classification, AO type-C3 subclassification, or presence of associated injuries influenced the type of fixation used (Kirschner wires, screws, or a buttress plate), the number of fixation methods used, or the use of a bone graft in the seventeen patients. Chi-square analysis demonstrated a significant relationship between the AO type-C3 subclassification and the use of bone-grafting ($p < 0.03$). The need for a bone graft increased with increasing severity of comminution. No other significant relationships were noted.

Effect of Radiographic Factors on Outcome as Measured by Clinical Rating Systems

We examined the relationship of radiographic parameters and the final outcome. The Pearson correlation coefficient indicated that total articular incongruity immediately after the operation showed a moderately strong correlation with the final outcome according to both rating systems ($r = 0.70$ and $p < 0.002$ for the outcome according to the demerit-point system; $r = 0.74$ and $p < 0.0008$ for the outcome according to the Green and O'Brien system). As the total articular incongruity increased, the final outcome worsened. There was a moderate correlation between both the articular step-off and the articular gap immediately after the operation and the final outcome ($r = 0.64$ and 0.61 , respectively, and $p < 0.01$ for the outcome according to the demerit-point system; $r = 0.72$ and 0.61 , respectively, and $p < 0.01$ for the outcome according to the Green and O'Brien system).

Effect of Duration of External Fixation and Degree of Distraction on Outcome Parameters

Chi-square analysis showed that neither the number of weeks that the external fixator had been in place nor the degree of distraction that had been applied with the fixator, as measured by the carpal height index and the revised carpal height index, influenced the final outcome according to the demerit-point system or the Green and O'Brien clinical assessment. Moreover, neither of these factors influenced the range of motion, grip strength, or score in the pain category of the Green and O'Brien system.

Discussion

The findings of our retrospective study confirm the observation by others that anatomic restoration of the articular surface is a critical part of the operative treatment of AO type-C3 fractures and has a direct influence on the final outcome^{1,5,6,19}. Bradway et al.¹⁹ and Knirk and Jupiter⁵ showed that >2 mm of articular incongruity (step-off) was associated with a high prevalence of post-traumatic arthritis and poorer functional results.

We attribute the maintenance of fracture reduction throughout bone-healing to two factors. The first was augmentation of fracture fixation by the external fixator^{3,4,6,19}. Placement of the external fixator at full distraction before

beginning the surgical approach aided fracture reduction and improved radial length and alignment^{4,10}, while removal of 30% to 50% of the distraction force at the end of the operation avoided overdistracted. As in other series in which external fixation was used^{2,10,21,32}, the distraction force across the wrist was maintained (there was essentially no change in the mean carpal height index or the mean revised carpal height index between radiographs made immediately after the operation and those made just prior to removal of the external fixator). The fixator neutralized the compressive forces across the joint, preventing collapse of the fracture during the initial two to four weeks of healing, when bone resorption and early new-bone formation are maximal.

The second factor was our use of bone graft in eleven of the seventeen fractures^{1,2,7,11,19-22}, to provide structural support and to accelerate the healing process. We attained satisfactory results using corticocancellous iliac crest bone graft for added structural support in five fractures with large defects. An important detail was the placement of the corticocancellous bone graft into the defect with the cortex positioned so that it provided maximal resistance to displacement or collapse of the articular fragments¹². The mean time to bone union for the five fractures in which corticocancellous bone graft had been used was seven weeks, only one week longer than that for the six fractures in which bone substitute or cancellous bone alone had been used.

The use of an external fixator alone, or in conjunction with percutaneous or limited internal fixation, for unstable fractures of the distal end of the radius has produced good or excellent results^{3,10,15,17-21,33-37}. Intraoperative assessment of each of our patients showed that the external fixator alone failed to reduce the severe articular comminution adequately or to correct and maintain length through ligamentotaxis^{14,38}.

We removed the fixators five to nine weeks (mean, seven weeks) after the operation, earlier than in several other series^{2,10,15,17,33,37}. Perhaps we were able to do so because we had used bone graft in conjunction with the fixation, as others have reported⁷. Earlier removal of the fixator allowed us to begin range-of-motion exercises and to avoid complications commonly associated with the prolonged use of external fixators^{3,9,10,14,18,21,33,38}.

The use of open reduction combined with internal and external fixation has been reported previously in selected cases^{4,6,19,22,23,39-41}. Bass et al. presented the results of the combined two-incision technique in a group of AO type-C3 fractures of the distal end of the radius². Good results were achieved, with a total range of wrist motion and grip strength that were 80% and 83% of the values for the uninjured side, respectively, despite the external fixator having been maintained for a mean of twelve weeks.

The seventeen patients in our series sustained the most severe type of comminuted intra-articular fracture of the distal end of the radius (AO type C3), yet the objective and subjective results are comparable with those in many series that have included less severe fractures^{1,2,4-6,19,22}. Bradway et al. reported on sixteen patients with an AO type-C2 or C3 fracture treated by open reduction and internal fixation, augmented by external

fixation in five patients¹⁹. Patients had a mean of 110° of flexion-extension, and the mean grip strength was 75% of that on the normal side. Jupiter and Lipton described thirteen AO type-C1 or C3 fractures that were treated by open reduction and internal fixation, with supplemental external fixation used in three cases⁴. The mean total arc of flexion-extension was 74% of the value for the uninjured side, and the mean grip strength was 76% of the value for the uninjured side.

Limitations of our study are the small number of patients, the retrospective design, and the lack of a control group. A randomized, prospective study of a group treated with the protocol and a control group treated with internal fixation alone would have been necessary to assess the value of supplemental external fixation.

We believe that severely comminuted intra-articular (AO type-C3) fractures of the distal part of the radius should be treated by open reduction and combined internal and external fixation. Our series demonstrates that the combined technique, supplemented by bone-grafting and plate fixation as needed, is a satisfactory treatment that can lead to a high rate of return to work and sports, a high level of patient satisfaction, and a low rate of complications. ■

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J Reconstr Microsurg. 2001 Aug;17(6):421-3.

Free temporoparietal fascial flap for coverage of a large palmar forearm wound after hand replantation.

Rogachefsky RA¹, Ouellette EA, Mendietta CG, Galpin P.

Author information

Abstract

A free temporoparietal fascial flap with a split-thickness skin graft was used to cover a large palmar forearm wound in a patient whose hand had been replanted 21 days earlier after traumatic amputation at the distal forearm level. At a 39-month follow-up, the patient had achieved an excellent cosmetic and functional result, with no alopecia or facial nerve injury. The flap is advantageous for coverage of wounds that require a large amount of thin, pliable tissue, and it leaves a concealed donor-site scar.

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Latissimus dorsi pedicled flap for upper extremity soft-tissue reconstruction.

Rogachefsky RA¹, Aly A, Brearley W.

Author information

Abstract

The latissimus dorsi often is used as a functional muscle transfer to restore elbow and shoulder motion. Although less common, its use as a pedicled muscle flap with a split-thickness skin graft provides excellent soft-tissue coverage of large upper extremity wounds. Seven male patients ranging in age from 6-71 years were treated with a pedicled latissimus dorsi muscle flap and split-thickness skin graft for coverage of open wounds of the shoulder, arm, or elbow with exposed vital structures (mean wound size: 15x10 cm). The flap also was used as a functional muscle transfer in one patient to replace destroyed anterior and middle portions of the deltoid. Wounds resulted from trauma in three patients, infection following trauma in two, and sarcoma excision in two. All flaps healed well, and donor site morbidity was minimal. At mean 16-month follow-up (range: 3-41 months), all muscle flaps had contoured well, producing satisfactory cosmesis. Functional results were good, and all patients were satisfied with their outcome. The tendinous insertion is left intact to guard against excessive traction on the pedicle when the flap is used for soft-tissue coverage only.

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J Bone Joint Surg Am. 2001 Apr;83-A(4):509-19.

Treatment of severely comminuted intra-articular fractures of the distal end of the radius by open reduction and combined internal and external fixation.

Rogachefsky RA¹, Lipson SR, Applegate B, Ouellette EA, Savenor AM, McAuliffe JA.

Author information

Abstract

BACKGROUND: Severely comminuted AO type-C3 intra-articular fractures of the distal end of the radius are difficult to treat. Failure to achieve and maintain nearly anatomic restoration can result in pain, instability, and poor function. We report the results of a retrospective study of the use of a standard protocol of open reduction and combined internal and external fixation of these fractures.

METHODS: Seventeen of twenty-five patients treated with the protocol were available for follow-up evaluation. Six had an AO type-C3.1 fracture; eight, type-C3.2; and three, type-C3.3. Eleven fractures required a dorsal buttress plate and/or a volar buttress plate, and eleven required bone-grafting. The mean time until the external fixator was removed was seven weeks.

RESULTS: At a mean of thirty months postoperatively, the mean arc of flexion-extension was 72% of that on the uninjured side and the mean grip strength was 73% of that on the uninjured side. The mean articular step-off was 1 mm, the total articular incongruity (the gap plus the step-off) averaged 2 mm, and the radial length was restored to a mean of 11 mm. Thirteen patients had less than 3 mm of total articular incongruity. Arthritis was graded as none in three patients, mild in ten, moderate in three, and severe in one. According to the Gartland and Werley demerit-point system, ten of the patients had a good or excellent result. According to the modified Green and O'Brien clinical rating system, five had a good or excellent result. One patient had a fracture collapse requiring wrist fusion, one had reflex sympathetic dystrophy, and three had minor Kirschner-wire-related problems. Total articular incongruity immediately postoperatively had a moderately strong correlation with the outcome as assessed with both clinical rating systems ($r = 0.70$ and 0.74 for the Gartland and Werley system and the Green and O'Brien system, respectively; $p < 0.05$).

CONCLUSIONS: Open reduction and combined internal and external fixation of AO type-C3 fractures can restore radiographic parameters to nearly normal values, maintain reduction throughout the period of fracture-healing, and provide satisfactory functional results.

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Ann N Y Acad Sci. 1994 Sep 6;732:392-4.

Treatment of canine osteoarthritis with sodium pentosan polysulfate and insulin-like growth factor-1.

Rogachefsky RA¹, Dean DD, Howell DS, Altman RD.

Author information

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Tech Hand Up Extrem Surg. 1999 Sep;3(3):203-9.

Intraoperative use of an external fixator distraction device for corrective distal radius osteotomy.

Rogachefsky RA¹, Mendelsohn RB.

Author information

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Reverse radial forearm fascial flap for soft tissue coverage of hand and forearm wounds.

Rogachefsky RA¹, Mendietta CG, Galpin P, Ouellette EA.

Author information

Abstract

Six patients with severe hand and forearm injuries involving open wounds and exposed structures were treated with reverse radial forearm fascial flaps and split-thickness skin grafts for soft tissue cover. There were five men and one woman aged between 16 and 36 years. Injuries included soft tissue avulsion on the dorsum of the hand and fingers, extensive flexor and extensor tendon damage, multiple phalangeal fractures, a grade IIIB open dislocation of the index to little carpometacarpal joints, a grade III open metacarpal fracture and a finger amputation. The average wound size was 9 cm in length and 7 cm in width. The mean duration of follow-up was 12 months (range, 5-20 months). All flaps healed well, and all patients were satisfied.

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Treatment of canine osteoarthritis with insulin-like growth factor-1 (IGF-1) and sodium pentosan polysulfate.

Rogachefsky RA¹, Dean DD, Howell DS, Altman RD.

Author information

Abstract

The potential therapeutic effects of insulin-like growth factor-1 (IGF-1) and sodium pentosan polysulfate (PPS) were evaluated in an anterior cruciate ligament-deficient canine model of osteoarthritis (OA). A control group of animals received no treatment or surgery (N). The remaining four groups of animals received anterior cruciate transection and either no treatment (OA), intra-articular IGF-1 (IGF-1), intra-muscular PPS (PPS), or a combination of intra-articular IGF-1 and intra-muscular PPS (IGF-1/PPS). All therapy was begun 3 weeks after surgery and continued for 3 weeks. At 6 weeks, articular cartilage from the femoral condyle was evaluated for anatomy, histology (Mankin grade) and biochemistry. Anatomically, only cartilage from dogs in the IGF-1/PPS group approximated that found in N. Mankin scores indicated less severe disease in both PPS and IGF-1/PPS groups compared with the OA group. Consistent with histology, the level of active neutral metalloproteinase was lower in cartilage from the PPS group compared with the OA group. Active and total neutral metalloproteinase, tissue inhibitor of metalloproteinases (TIMP), total collagenase, uronate and hydroxyproline contents were all near normal in the IGF-1/PPS group. In a model of mild OA, therapeutic intervention with IGF-1 and PPS appeared to successfully maintain cartilage structure and biochemistry. From these data, it is hypothesized that proteinase activity was successfully blocked by PPS, and that this allowed the observed growth factor induced effects. As we unravel the various factors that regulate cartilage metabolism, it is becoming apparent that combinations of agents will be needed to effectively control cartilage repair in OA. The addition of PPS to IGF-1 shows promise as a therapeutic intervention and introduces a new rational approach to therapy of OA.

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Synovial chondromatosis of the distal radioulnar joint: a case report.

Rogachefsky RA¹, Zlatkin MB, Greene TL.

Author information

Abstract

The most definitive method for confirming the diagnosis of synovial chondromatosis is the identification of cartilaginous metaplasia within the synovium on histologic examination. In advanced stages of the disease, plain radiographs and magnetic resonance imaging (MRI) scans demonstrate calcified and cartilaginous bodies, respectively, but in earlier stages, plain radiographic findings may be normal and MRI scans may reveal only nonspecific increased fluid. Although rare in the wrist, synovial chondromatosis must be considered in the differential diagnosis in a patient presenting with pain and swelling of the distal radioulnar joint. Surgical exploration of the joint and synovectomy, alone or in combination with removal of loose bodies, is the recommended treatment.

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J Bone Joint Surg Am. 1994 Feb;76(2):269-73.

Gout presenting as infectious arthritis. Two case reports.

Rogachefsky RA¹, Carneiro R, Altman RD, Burkhalter WE.

Author information

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