"Intra-Articular Fractures of the Distal End of the Radius in Young Adults": Scientifically Flawed but Clinically Relevant

Brian M. Haus, M.D., Jesse B. Jupiter, M.D.
Massachusetts General Hospital

INTRODUCTION

Knirk and Jupiter's 1986 article "Intra-Articular Fractures of the Distal End of the Radius in Young Adults" published in the *Journal of Bone and Joint Surgery*[1] stands today as arguably one of the most important works on the management of intra-articular fractures of the distal radius. Prior to its publication, the critical factors which determined successful long term management of intra-articular distal radius fractures in young patients had not been determined. The finding with the greatest impact on treatment algorithms was that accurate articular restoration was the most critical factor in preventing long term arthritis in young patients with intra-articular distal radius fractures. However, twenty-one years of advancements in orthopaedic surgery and technology has exposed the study's methodological flaws. Analysis of radiographs incorrectly interpreted fracture lines and the study failed to use intra- and inter-observer validation in its analysis. The study also was conducted before the advent of computerized tomography and the popularization of wrist arthroscopy. Still, despite these shortcomings, an updated critical analysis reveals that its conclusions are still germane in today's treatment of distal radius fractures in the young adult.

DISCUSSION

"Intra-articular Fractures of the Distal End of the Radius in Young Adults"[1] is cited in three hundred and thirty research and scholarly articles, making it among the most cited manuscripts in the orthopaedic surgery literature. Today, its conclusions not only direct the treatment of distal radius fractures, but also continue to generate hypotheses for outcome studies. Given the study's impact on the standard of care and orthopaedic research, it is appropriate to critically review its methodology to determine whether the study's findings remain relevant today.

Intra-articular fractures of the distal radius in the young adult are a distinct group of fractures which can lead to accelerated post-traumatic arthritis. Prior to the study's publication in 1986, there was an incomplete understanding of the radiographic parameters that were most predictive in determining whether a patient developed post-traumatic arthritis. Distal radius fractures were managed with the primary goal of extra-articular reduction, with restoration of radial length and maintenance of dorsal tilt.[2,3,4,5,6,7] Knirk and Jupiter conducted the study after observing many young patients who developed persistent pain and early advanced degenerative arthritis, despite having distal radius fractures which healed with restored radial length and dorsal tilt. They recognized that the same group of patients sustained distal radius fractures with radiocarpal incongruity. The primary goal of the study was to determine which radiographic parameters – radiocarpal incongruity, radial length or dorsal tilt – were the most critical in the managing distal radius fractures and predicting the development of post-traumatic arthritis.

"Intra-articular Fractures of the Distal End of the Radius in Young Adults" was a retrospective study that reviewed the long-term outcomes of 43 patients with a mean age of 27.6 years, and whose complex intra-articular fractures were managed with varied treatment methods. The radiographic parameters of dorsal tilt, radial length and radiocarpal incongruity were quantified on initial injury radiographs using traditional methods. Patient outcomes were subsequently assessed by comparing subjective and objective clinical variables with an arthritis grading scale that measured the presence and extent of post-traumatic arthritis on follow-up radiographs. Radiographic evidence of arthritis developed in all patients whose fractures healed with an articular step-off of 2mm or greater; in contrast, only eleven percent of patients whose fractures healed with a congruous articular surface eventually developed arthritis. The study determined accurate intra-articular restoration to be the most critical factor in achieving a successful clinical result, but restoration and maintenance (extra-articular reduction) of the dorsal tilt and radial length did not prove to be critical factors.

Notwithstanding the study's conclusive findings, a comprehensive review of its methodology using today's more rigorous standards shows that they are scientifically flawed (Table 1). One conspicuous weakness of the study is that it was uncontrolled and lacked any assessment of inter- or intra-observer agreement. The radiographic parameters of radial length, dorsal tilt, and articular step-off used to analyze outcomes were analyzed by a single reviewer without any controls or way of eliminating chance or other confounding variables.

Brian M. Haus, MD, PGY-5 Resident, Harvard Combined Orthopaedic Residency Program

Jesse B. Jupiter, MD, Hansjorg Wyss AO Professor of Orthopaedic Surgery, Chief Hand and Upper Extremity Service, Professor of Orthopaedic Surgery, Massachusetts General Hospital

Address Correspondence to:

Department of Orthopaedic Surgery
Massachusetts General Hospital
18 Fruit Street
Boston, MA 02114

Methodologic flaws of "Intra-articular Fractures of the Distal End of the Radius"

Lack of inter- and intra-observer agreement	The study was analyzed by a single reviewer, without a clear method for determining the agreement, or disagreement, between reviewers. The radiographic parameters of radial length, dorsal tilt, and articular step-off should have been reviewed by multiple reviewers and the kappa value – a chance-corrected measure of agreement between observers – should have been determined to validate that the results were precise and not due to chance.
Radiographic interpretation of intra-articular incongruity and arthritis	The most significant finding of the study, that radiographic evidence of arthritis developed in all patients whose distal radius fractures had a residual articular displacement of 2mm, could not have been accurately determined using standard posteroanterior and lateral radiographs.
Radiographic interpretation of extra-articular alignment	Standard posteroanterior and lateral radiographs fail to accurately represent radial height and dorsal tilt.
Exclusion of additional radiographic parameters	The study failed to consider other potential radiographic outcome parameters, including the teardrop angle and the anteroposterior distance.
Comparison with two- and three-dimensional computerized tomography	The study pre-dates computerized tomography, which is more sensitive in identifying and quantifying articular incongruities and provides a more accurate quantification of articular angles and anteroposterior and medial-lateral distances.
Exclusion of radiocarpal instability	A retrospective review of the radiographs used in the study demonstrates that many of the patients had substantial carpal instability patterns associated with intercarpal ligament injury.

Table 1. Retrospective review of the methodology used in the study exposes its multiple weaknesses.

Retrospective studies of radiographs are properly analyzed by multiple reviewers, with a clear method for determining the agreement, or disagreement, between reviewers. Accordingly, the specificity of the radiographic parameters in the study should have been tested by determining the kappa value – a chance-corrected measure of agreement between pairs of observers.[7] A kappa value nearing 1.0 would have provided more rigorous scientific proof that articular incongruity is the most important factor in determining improved long-term outcomes of distal radius fracture treatment. Unfortunately, because there was a single reviewer and no kappa value was determined, it is difficult to argue that the study's conclusions are due to clinical significance rather than due to chance alone.

The most significant finding of the study was that radiographic evidence of arthritis developed in all patients whose distal radius fractures had a residual articular displacement of two millimeters or more. The methodology used to analyze the radiographs was flawed, however; it could not have accurately determined the degree of intraarticular incongruity or arthritis, because it inferred radiographic measurements taken from standard two-dimensional radiographs. It has become well recognized that radiographic measurements of the distal radius that use standard posteroanterior and lateral projections can lead to incorrect interpretion of fracture lines.[8] A standard posteroanterior view of a normal volarly tilted articular surface demonstrates a proximal relationship of the volar rim relative to the dorsal rim. In fractures with dorsal angulation visualized in the posteroanterior view, the parallel orientation of the radiographic beam reverses the relationship of the volar and dorsal articular surfaces. Radiographically, the anatomic relationship of fracture fragments and the degree of articular displacement can become distorted and difficult to interpret.

Articular Incongruity Grading

Grade	Step-off
0	0-1 mm
1	1-2 mm
2	2-3 mm
3	> 3mm

Arthritis Grading

Grade	Findings
0	None
1	Slight joint space narrowing
2	Marked joint space narrowing
3	Bone-on-bone, osteophyte/cyst formation

Table 2. The subjective grading systems created to determine the degree of intra-articular incongruity and arthritis in "Intra-articular fractures of the distal end of the radius" using standard posteroanterior and lateral radiographs. The degree of intra-articular incongruity was assigned a grade of zero to 3 depending on the magnitude of the so-called step-off of the articular surface of the radius. The degree of arthritis in the radiocarpal or radio-ulnar joint was graded from zero (normal) to 3 (extensive). Both grading systems were assessed by a single reviewer without any controls or way of eliminating chance or other confounding variables, and lacked any assessment of intra-and inter-observer agreement. In addition, both subjective grading systems were analyzed from standard posteroanterior and lateral radiographs, which incorrectly interpret fracture lines and misrepresent articular borders. Both two-dimensional and three-dimensional computerized tomography images have been shown to be more reliable at assessing the extent and degree of articular step-off in the majority of fractures.

Although the lateral view may assist with correlation, it can also lead to misinterpretation. The lateral view, when compared

with a modified lateral beam angled at ten degrees, offers a less reliable assessment of the fracture lines. The ten-degree lateral projection positions the articular surface in direct visualization, allowing a more direct profile view of the articular offset in the sagittal view and the apical ridges of the volar and dorsal rim. The limitations of the standard lateral and posteroanterior views are particularly germane to the reliability of the findings in "Intra-articular Fractures of the Distal End of the Radius in Young Adults," since they were analyzed to determine both the degree of articular step-off as well as the degree of articular arthritis. Hence, the reliability of both subjective grading scales used in the study's methodology is questionable (Table 2). In particular, one could essentially argue that it is not possible to accurately determine the degree of difference between a 1mm stepoff and a 3mm stepoff using standard radiographs. Such variability brings into scrutiny the study's finding that 2mm is the critical amount of intra-articular incongruity which leads to a high rate of post-traumatic arthritis.

Another important finding of "Intra-articular Fractures of the Distal End of the Radius in Young Adults" was that restoration and maintenance of the dorsal tilt and radial length did not prove to be critical factors in achieving a successful clinical result. However, variation caused by dorsal or volar angulation also contributes to inaccurate measurements of the radiocarpal interval, radial height, and dorsal tilt when measured with a standard anteroposterior and lateral views. Such variability occurs because these parameters are measured from a reference point at the ulnar border of the radius which can anatomically change with angular deformity. As Medoff emphasizes,[8] radiographic parameters of the distal radius are more accurately defined when measured from a central reference point that lies halfway between the volar and dorsal corners as visualized on the posteroanterior view. Measurements of radial inclination, radial height, and ulnar variance can change significantly when applying this alternative reference point. Although the study determined that restoration of these measurements had no effect on the radiographic development of arthritis, because they were not measured properly, the validity of the outcome is questionable. Because the interpretation of these very parameters was the foundation for the study's findings, it is difficult to interpret their true relevance in the management of distal radius fractures.

There are a number of other radiographic parameters that the study did not consider, and which help describe the intra-articular injury pattern and may be as important as the degree of articular step-off in determining patient outcomes. Radiographic parameters such as the teardrop angle and anteroposterior distance are newly characterized and their importance is undefined.[8] The teardrop angle is an important radiographic measurement because it can herald the presence of residual dorsal deformity and articular incongruity when other parameters may erroneously represent the fracture to be stable and adequately aligned. In impacted fractures where there is dissociation of the volar and dorsal surfaces, the volar facet can rotate dorsally into metaphyseal defects, resulting in a severe articular deformity between the dorsal-volar articular surfaces. In such fractures, reduction maneuvers may restore dorsal tilt and radial length, but significant reductions in the teardrop angle may remain. Attention to and measurement of the teardrop angle can accurately demonstrate the unstable nature of the fracture, while limited measurement of radial length and dorsal tilt may ignore such instability.

Similar problems can occur when evaluating another important radiographic parameter, the anteroposterior ("AP") distance. The anteroposterior distance is the distance between the apices of the dorsal and volar rim of the lunate facet. Impaction injuries can cause these apices to splay away from each other, thus increasing their AP distance[8]. Measurement of the AP distance can detect resultant incongruity across the sigmoid notch where measurements of radial length and dorsal tilt may not accurately represent the instability of the fracture pattern. Because "Intra-articular Fractures of the Distal End of the Radius in Young Adults" did not include evaluation of the teardrop angle or the AP distance, an updated understanding of the correlation between its radiographic findings and its clinical correlation is incomplete.

Another significant limitation of the study is that it predates the advent and popularization of advanced imaging modalities. More recent studies show that standard radiographs fail to depict important injury characteristics in the distal radius.[9,10] and that computerized tomography better defines fracture patterns.[11,12,13] Pruitt showed that compared to computerized tomography, radiographs underestimate the extent of comminution and degree of articular step-off in the majority of fractures involving the lunate fossa and in a minority of fractures involving the scaphoid fossa. Two-dimensional computerized tomography is better equipped at characterizing fracture fragment diastasis and depression, especially in the center of the scaphoid and lunate fossae, locations usually not visualized well by radiographs. Overall, radiographs are less sensitive in identifying fractures with intra-articular extension - this discrepancy occurs most often with fractures involving the distal radioulnar joint.[10] Cole showed that computed tomography was more reliable than plain radiography for quantifying articular incongruities.[13] Because the majority of the fractures studied in "Intra-articular Fractures of the Distal End of the Radius in Young Adults" were intra-articular fractures with both distal radioulnar and radiocarpal involvement, the radiographic analysis of these fractures failed to depict important characteristics which may have affected the study's outcomes. This shortcoming is important, because further studies demonstrated that the additional information offered from two-dimensional computed tomography ultimately influenced treatment regimens.[12]

Additional studies analyzing the role of three-dimensional computerized tomography in the characterization of intra-articular fractures further expose the weaknesses of the study. Inferring three-dimensional objects from two-dimensional measurements is inherently limited, because it fails to show the variability in the position of the wrist during X-ray imaging, the quality and

enhancement of the radiographic image, and the accuracy of the individual making the measurements. Three-dimensional CT scans, on the other hand, offer reliable, reproducible views of the articular surface and better definition of the degree of displacement and number of fragments when compared to radiographs.[14] In addition, the imaging modality also offers enhanced understanding of osseous detail, thereby providing more accurate quantification of anteroposterior and medial-lateral distances, articular angles, and areas.[15] Finally, the technology offers superior volumetric and linear accuracy of the carpal bones and distal radius geometric anatomic relationships.[16]

More recent studies investigate whether images based on three-dimensional reconstructions improve fracture characterization or provide more clinically useful information to assist in treatment decisions than those based on two-dimensional images.[17,18] When compared to radiographs and two-dimensional computed tomography, three-dimensional computed tomography improves both the intra- and inter-observer agreement in the analysis of the presence of intra-articular comminution. Three-dimensional computed topography also improves the intraobserver agreement regarding the presence of a central articular fragment and coronal plane fracture lines.[17] The enhanced visualization offered by three-dimensional computerized tomography ultimately influenced treatment recommendations, resulting in a significantly greater number of decisions for an open approach with a combined dorsal and volar exposure.

Just as advances in imaging have improved the analysis of fracture patterns, the popularization of wrist arthroscopy has provided new insights into the relationship between the carpus and the distal radius in distal radius fractures. Since "Intra-Articular Fractures of the Distal End of the Radius in Young Adults," multiple studies have demonstrated that there is a greater degree of associated carpal malalignment with distal radius fractures than previously thought.[19,20,21,22] Hanker first demonstrated the presence of carpal instability when he found tears of the scapholunate ligament in 43%, tears of the radioscapholunate ligament in 90%, and disruption of the dorsal capsule in 60%, of thirty reviewed distal radius fractures.[19]

Similarly, in a series of sixty intra-articular distal radius fractrures, Geissler identified the presence of soft tissue injuries in 68%; 43% had associated triangular fibrocartilage tears and 32% had associated scapholunate tears.[20]

Richards supported these findings and also showed that there was no correlation of two-dimensional radiographs and arthroscopic findings of interosseous ligament injury in distal radius fractures.[21] Radiographs were insensitive at detecting scapholunate tears, as 60% of all scapholunate tears appeared to be normal (scapholunate interval of 2mm or less) on plain radiographs. Conversely, radiographs were nonspecific, as arthroscopic evidence of a scapholunate tear was not detected in half of patients with a radiographic scapholunate interval of 3mm or more.

Wrist arthroscopy ultimately has shown that associated soft tissue injuries in distal radius fractures are the rule, not the exception. A retrospective review of the radiographs analyzed in "Intra-Articular Fractures of the Distal End of the Radius in Young Adults" demonstrates that many of the patients had substantial carpal instability patterns associated with intercarpal ligament injury, which not only could have influenced a less optimal outcome but also may have contributed to the development of arthritis (Figure 1).

Figure 1. Radiographs analyzed in "Intra-articular Fractures of the Distal End of the Radius in Young Adults." The study ignored the scapholunate dissociation and intercarpal ligament injury as factors which not only could have influenced a less optimal outcome, but also may have contributed to the development of arthritis.

CONCLUSION

When Dr. Joseph Buckwalter accepted the Presidency of the American Academy of Orthopaedic Surgery in 2000, he promoted the use of rigorous scientific methodology in orthopaedic surgery research to advance improvements in patient care, emphasizing that progress in medicine relies greatly on "rigorous original basic and clinical research."[23] But Dr. Buckwalter dismissed the views of some in the biomedical community that "improvements in medical practice can occur only as a result of basic research," noting that both the science and the art of medical practice are important in improving patient care.[23] While rigorous basic science research lays the foundation for progress in medicine, "clinical observations…stimulate basic scientific investigations that explain these investigations. If one has the opportunity to make critical observations, develop hypotheses, and evaluate the clinical value of new scientific results, he/she can have a direct and rapid impact on medical practice."[23]

Thus, despite multiple flaws in the scientific methodology underlying "Intra-articular fractures of the Distal End of the Radius in Young Adults," the study remains important for an entirely different reason. It is true that the study lacks inter-and intraobserver validation. It incorrectly interprets fracture lines. It predates newer imaging technologies. But despite its many shortcomings, the study continues to impact the orthopaedic literature and remains clinically relevant for the very reason that Dr. Buckwalter suggests: its hypothesis was generated as a result of a critical clinical observation. Over twenty years

later, the findings in the study have stood the test of time, and continue to transcend the impact of advanced technology and more rigorous research to remain relevant in the management of distal radius fractures.[24,25,26]

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