Wrist function in malunion: Is the distal radius designed to retain function in the face of fracture?

CE Uzoigwe, N Johnson

University Hospitals of Leicester NHS Trust, Leicester, UK

ABSTRACT

INTRODUCTION Fractures of the distal radius are the most common fracture in humans and are the sempiternal hazard of 3.5 million years of bipedalism. Despite the antiquity of the injury, one of the most controversial topics in current orthopaedics is the management of distal radius fractures. It has been suggested that radiographic appearances rarely correlate with functional outcomes. As the success of the human species is predicated almost exclusively on its dexterity and intelligence, it is conceivable that the distal radius has evolved to preserve function even in the face of injury. We therefore hypothesise that the distal radius is designed to accommodate the possibility of fracture.

METHODS We conducted a review of studies comparing fracture pattern and form with function. We also explore the paleoanthropological evidence and comparative studies with other primates.

FINDINGS The evidence points to the human distal radius being highly tolerant of post-fracture deformity in terms of preservation of function. In addition, the distal radius appears to have apparently anatomically 'redundant' features that confer this capability. We believe these phenomena to be an evolved trait that developed with bipedalism, increasing the chances of survival for a species whose success depends upon its dexterity.

KEYWORDS

Intelligence – Radius fractures – Wrist fractures

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CORRESPONDENCE TO

Chika Uzoigwe, E: chika@doctors.org.uk

The Laetoli footprints, dated at 3.5 million years old, were discovered in Tanzania in 1978.¹ They belonged to human ancestor *Australopithecus*, of whom Lucy is the most famous.² The footprints are the earliest direct evidence of exclusive bipedalism. Bipedalism liberated hands for dexterous activity, which was germane to human success. With this locomotor advantage came the hazard of falling and injuring this valuable commodity. Unsurprisingly, distal radial fractures are the most common fracture in humans.³ In 1814, the Irish surgeon Abraham Colles described his eponymous fracture: "The limb will at some remote period again enjoy perfect freedom in all of its motions and be completely exempt from pain: the deformity, however, will remain undiminished through life."⁴

In other words, Colles noted 200 years ago that the distal radius was resilient to the effects of fractures, with little disability even in the face of significant deformity. Human evolutionary success has been exclusively dependent upon intelligence and dexterity. It is therefore conceivable that the distal radius has evolved to accommodate the possibility of fracture by preserving function in the event of injury.

Anatomy, pathomechanics and adaptations

Distal radius fractures occur following a fall onto an outstretched hand.⁵ This produces the classical deformity,

characterised by reduction of volar tilt and radial height. The distal radius appears to have developed a distinctive anatomical profile to counteract the deformities resulting from this fracture pattern.⁶ It is inclined 11° (range 4–22°) to the volar (palmar) surface. Its surface is also 22° inclined medially to the ulna. The radial height is the distance between two parallel lines, one co-linear with the scaphoid radial articular surface and the second tangential to the tip of the radial styloid. This measures 11.6mm. The distal radial articular surface sits 0.6mm (range –2mm to 2mm) proud of the ulna.

Biomechanical and in vivo studies

Pogue et al showed in cadaveric studies that 20° of dorsal or palmar angulation was required before pathological radiocarpal pressures developed.⁷ Patterson and Viegas observed that cadaveric wrists could tolerate changes in radial inclination, volar inclination and radial shortening of up to 20°, 38° and 6mm, respectively, before pathological biomechanics resulted.⁸ Thus, the dimensions of the wrist appear to possess 20° of 'redundant' radial inclination, 38° of 'redundant' volar inclination and 6mm of 'redundant' length, which may compensate for fracture deformity.

Forward et al examined patients with distal radius malunion, with a mean and maximum age of 25 years and <40

years, respectively.⁹ After a mean follow-up of 38 years, the average radial dorsal tilt was 11°. This represents a deviation of 22° (range 18°–25°) from the uninjured contralateral wrist. The cohort also had a mean loss of radial length of 3.5mm and loss of radial inclination of 8°. The researchers found that functional scores were normal, with no clinically significant difference in objective or subjective function between injured and uninjured wrists, as measured by the Disability of the Shoulder, Arm and Hand (DASH) and Patient Evaluation Measure, respectively. They conclude: “We have not been able to identify any thresholds of malunion beyond which function was clearly worse as measured by the Patient Evaluation Measure and DASH scores”.

Brogren examined the effect of malunion-union on wrist function 1 year after wrist fracture, which showed that AO fracture type had no bearing on function.¹⁰ In further work, Brogren showed that only those with both dorsal tilt >10° and ulnar variance >2mm had some loss of function at 2 years’ follow-up. There was no difference between those with no malunion and those with one of either dorsal tilt >10° or ulnar variance >2mm.¹¹

Gliatis examined the outcomes of 169 patients with distal radius fracture who had a mean age of 35 years at the time of injury and a mean follow-up of 4.9 years.¹² Neither radial height nor radial inclination influenced outcome, despite a variance in radial height of 19mm to -11mm and in radial inclination of 31° to -24°. Those with dorsal tilt of beyond 10° did, however, suffer inferior outcomes, which included dorsal tilt angles of 10°–31°.

Intra-articular distal radius fractures

Knirk and Jupiter laid down the orthopaedic dogma that restoration of “articular congruity was the most critical factor in achieving a successful result” following wrist fracture.¹³ However, the paper has been challenged on methodological grounds.¹⁴ Catalano et al examined 26 fractures in patients aged under 46 years with mean follow-up of 7 years using computerised tomography and two observers.¹⁵ They concluded: “The functional status...did not correlate with the magnitude of the residual step and gap displacement at the time of fracture-healing. All patients had a good or excellent functional outcome irrespective of radiographic evidence of osteoarthritis of the radiocarpal or the distal radio-ulnar joint or non-union of the ulnar styloid process.” Similar results were reported by Leung.¹⁶

Gliatis et al noted that intra-articular steps reduced very fine dexterity but did not affect strength, work or daily activity, and did not predict pain.¹² His cohort also involved the young (mean age 35 years) who were followed-up for an average of 5 years. Tellingly, the size of the intra-articular step could not determine the outcome. In addition, articular surface gaps had no bearing on strength, dexterity or the degree of interference with work/daily activities. They concluded that intra-articular fractures were slightly more injurious than extra-articular fractures, but not considerably so.

Forward et al found the distal radius to be resistant to developing osteoarthritis.⁹ In their study of 106 patients aged under 40 years, distal radius malunion was defined as radial

inclination <20°, radial shortening >2mm and loss of volar tilt. At a minimum follow-up of 33 years, 67% of those with an extra-articular fracture had osteoarthritis that was no worse than that on the uninjured side. In those who suffered intra-articular fractures, this figure was 40%. The findings are significant given that, in antiquity, humans may not have survived long enough to develop function-limiting osteoarthritis.

Affects of wrist osteoarthritis

Knirk and Jupiter noted that, even in the presence of radiocarpal osteoarthritis, there was no reduction in grip strength.¹³ Similar findings have been reproduced by other authors.^{17–19} Giannoudis et al performed a meta-analysis of evidence regarding the effect of traumatic articular steps on functional and radiographic outcome in a number of joints.²⁰ The evidence showed that the distal radius was highly tolerant of articular steps and osteoarthritis. Although steps >2mm tended to cause osteoarthritis and inferior early outcomes, long term outcomes tended to be very good or excellent. The authors concluded: “Surprisingly, high levels of function are achieved despite radiographic evidence of deterioration of the radiocarpal joint.”

Fracture in children and possible adaptive features

Noonan and Price concluded in their review that children could tolerate 100% displacement of the distal radius, with up to 20° of angulation, and still remodel to normal anatomy if the child had at least 2 years of growth remaining.²¹ In children, the distal radius does not adopt the adult appearance until physal fusion. Although the remodelling potential is lost once fusion occurs, it is possible that the adult volar tilt, radial height and radial inclination mitigate against the effects of subsequent fracture.

Comparison with primates

There are three modes of primate locomotion: bipedalism, knuckle-walking and brachiation (branch swinging). The distal radius of knuckle-walkers is characterised by a dorsal projection with a concavity in which the proximal carpal bones nestle.²² This is thought to allow the wrist locking to resist extension and facilitate knuckle-walking. The wrist of brachiators is deeply concave, adopting a ball (carpus) and socket (distal radius) morphology.²³ While this profile permits tool manufacture, use and projection, it has not been adopted with the bipedal *Homo* and ancestor. It is posited that, while this configuration is functionally useful given the range of movement it allows, the wrist would be incapacitated following fracture. Falling onto an outstretched wrist would lead to a die-punch injury in which the carpals impact into the distal radius socket, causing it to explode, with numerous intra-articular fragments. For brachiators, a fall will be broken by branches, and there would therefore be no selective pressure to produce anatomical variants that could accommodate the possibility of distal radius fracture.

The evolution and origin of distal radius anatomy: Dexterity in antiquity

Anatomically, modern *Homo sapiens* appeared in Africa 250,000 years ago.²⁴ *Australopithecus*, living 1–4 million years ago, is ancestor to the Homo species. It was exclusively bipedal but also spent significant periods in an arboreal milieu. The profile of the species' distal radius is, however, similar to that of *Homo sapiens*.²⁵ The same is true of *Ardipithecus*, a putative *Australopithecus* ancestor and earliest Homo ancestor, which inhabited Africa around 4.4 million years ago.^{25,26} It is thought to have been a facultative biped, walking erect but also scaling trees. The distal radius of *Homo sapiens* and our bipedal ancestors appears to have developed along an evolutionary stream distinct from that of the brachiator and knuckle-walker.²⁷ Both the brachiator and knuckle-walker profiles predated that of the biped, but the Homo genus and ancestors do not retain them. This is in spite of the ball and socket profile allowing skilled activity.²⁴ Hence, the Homo species distal radius profile appears linked to bipedalism.

Fracture would have expressed a strong selective pressure. Archaeological finds show that it was very a common injury amongst early *Homo sapiens* and *Homo neanderthalensis*. Every complete adult Neanderthal skeleton aged 25 years or older shows fractures and fracture healing.²⁸ Ortner et al reported that, after arthritis, fracture was the most common pathological finding in the skeletons of archaic humans.²⁹ A fracture rate of 7.1% has been recorded in the radii recovered from populations living in North America around 3,500 years ago.³⁰ Lovejoy and colleagues examined a similar population and observed that Colles type distal radius fracture was one of the most common injuries.³¹

Treatment of distal radius fractures

The oldest reported treated fractures date from 130,000 years ago in Croatia, when only Neanderthals inhabited Europe.³² However, there is, even today, no consensus on the optimum management of wrist fractures.⁶ The 2009 American Academy of Orthopaedic Surgeons (AAOS) guidelines recommend operative fixation post-manipulation if the fracture has >10° of dorsal angulation, >3mm of radial shortening or an articular step >2mm. However, the AAOS could not recommend any one fixation technique over another.³³ Moreover, a Cochrane review found no difference in functional outcome between operative methods.³⁴

The uncertainty regarding the optimum mode of fixation of distal radius fractures largely revolves around there being little correlation between the radiographic appearance functional performance.³⁵ This remains a consistent finding,^{35–39} thus supporting the hypothesis that the distal radius has evolved to be tolerant of wrist fracture.

Conclusions

The concept of supra-normal adaptation with the development of physiological parameters in excess of that required to survive is not new: adults can lose up to 15% of blood volume before tachycardia develops,⁴⁰ while 70% of the small

bowel can be removed before 'short bowel syndrome' results. *Homo sapiens* display a distinct distal radius anatomy that retains function in the face of deformity. The evolution of this anatomical configuration is possibly a skeletal example of supra-normal evolution.

References

1. Agnew N, Demas M, Leakey MD. The Laetoli footprints.[letter]. *Science* 1996;271(5256):1,651–1,652.
2. Kimbel WH, Delezenne LK. "Lucy" redux: a review of research on *Australopithecus afarensis*. *Am J Phys Anthropol* 2009; **140 Suppl 49**: 2–48.
3. Court-Brown CM, Caesar B. Epidemiology of adult fractures: A review. *Injury* 2006; **37**: 691–697.
4. Colles A. On the fracture of the carpal extremity of the radius. *Edinburgh Med Surg J* 1814; **10**: 182–186.
5. Owen RA, Melton LJ, Johnson KA et al. Incidence of Colles' fracture in a North American community. *Am J Public Health* 1982; **72**: 605–607.
6. Nijs S, Broos PL. Fractures of the distal radius: a contemporary approach. *Acta Chir Belg* 2004; **104**: 401–412.
7. Pogue DJ, Viegas SF, Patterson RM et al. Effects of distal radius fracture malunion on wrist joint mechanics. *J Hand Surg Am* 1990; **15**: 721–727.
8. Patterson R, Viegas SF. Biomechanics of the wrist. *J Hand Ther* 1995; **8**: 97–105.
9. Forward DP, Davis TR, Sithole JS. Do young patients with malunited fractures of the distal radius inevitably develop symptomatic post-traumatic osteoarthritis. *J Bone Joint Surg Br* 2008; **90**: 629–637.
10. Brogren E, Hofer M, Petranek M et al. Relationship between distal radius fracture malunion and arm-related disability: a prospective population-based cohort study with 1-year follow-up. *BMC Musculoskelet Disord* 2011; **12**: 9.
11. Brogren E, Wagner P, Petranek M et al. Distal radius malunion increases risk of persistent disability 2 years after fracture: a prospective cohort study. *Clin Orthop Relat Res* 2013; **471**: 1,691–1,697.
12. Gliatis JD, Plessas SJ, Davis TR. Outcome of distal radial fractures in young adults. *J Hand Surg Br* 2000; **25**: 535–543.
13. Knirk JL, Jupiter JB. Intra-articular fractures of the distal end of the radius in young adults. *J Bone Joint Surg Am* 1986; **68**: 647–659.
14. Haus BM, Jupiter JB. Intra-articular fractures of the distal end of the radius in young adults: reexamined as evidence-based and outcomes medicine. *J Bone Joint Surg Am* 2009; **91**: 2,984–2,991.
15. Catalano LW, Cole RJ, Gelberman RH et al. Displaced intra-articular fractures of the distal aspect of the radius. Long-term results in young adults after open reduction and internal fixation. *J Bone Joint Surg Am* 1997; **79**: 1,290–1,302.
16. Leung F, Ozkan M, Chow SP. Conservative treatment of intra-articular fractures of the distal radius—factors affecting functional outcome. *Hand Surg* 2000; **5**: 145–153.
17. Goldfarb CA, Rudzki JR, Catalano LW et al. Fifteen-year outcome of displaced intra-articular fractures of the distal radius. *J Hand Surg Am* 2006; **31**: 633–639.
18. Kopylov P, Johnell O, Redlund-Johnell I et al. Fractures of the distal end of the radius in young adults: a 30-year follow-up. *J Hand Surg Br* 1993; **18**: 45–49.
19. Lutz M, Arora R, Krappinger D et al. Arthritis predicting factors in distal intraarticular radius fractures. *Arch Orthop Trauma Surg* 2011; **131**: 1,121–1,126.
20. Giannoudis PV, Tzioupis C, Papathanassopoulos A et al. Articular step-off and risk of post-traumatic osteoarthritis. Evidence today. *Injury* 2010; **41**: 986–995.
21. Noonan KJ, Price CT. Forearm and distal radius fractures in children. *J Am Acad Orthop Surg* 1998; **6**: 146–156.
22. Wolfe SW, Crisco JJ, Orr CM et al. The dart-throwing motion of the wrist: is it unique to humans. *J Hand Surg Am* 2006; **31**: 1,429–1,437.
23. Lewis OJ, Hamshire RJ, Bucknill TM. The anatomy of the wrist joint. *J Anat* 1970; **106**: 539–552.
24. Wood B, Richmond BG. Human evolution: taxonomy and paleobiology. *J Anat* 2000; **197**: 19–60.
25. White TD, Asfaw B, Beyene Y et al. *Ardipithecus ramidus* and the paleobiology of early hominids. *Science* 2009; **326**: 75–86.
26. Lovejoy CO, Simpson SW, White TD et al. Careful climbing in the Miocene: the forelimbs of *Ardipithecus ramidus* and humans are primitive. *Science* 2009; **326**: 70e1–8.

27. Kivell TL, Schmitt D. Independent evolution of knuckle-walking in African apes shows that humans did not evolve from a knuckle-walking ancestor. *Proc Natl Acad Sci U S A* 2009; **106**: 14,241–14,246.
28. Papathanasiou A, Spencer Larsen C, Norr L. Bioarchaeological inferences from a Neolithic ossuary from Alepotrypa Cave, Diros, Greece. *Int J Osteoarchaeol* 2000; **10**: 210–228.
29. Ortner DJ, Putschar WGJ. *Identification of pathological conditions in human skeletal remains*. Washington: Smithsonian Institution Press, 1981.
30. Frantz DA. The Investigation and Analysis of Changes in Bone Fracture Frequencies for Selected Prehistoric Populations [dissertation]. Tallahassee: Florida State University; 1989.
31. Lovejoy CO, Heiple KG. The analysis of fractures in skeletal populations with an example from the Libben site, Ottawa County, Ohio. *Am J Phys Anthropol* 1981; **55**: 529–541.
32. Rajković Z, Krklec V. [The oldest treated bone fracture in Croatia–130,000 years ago]. *Acta Med Croatica* 2008; **62**: 89–92.
33. *The Treatment of Distal Radius Fractures. Guideline and Evidence Report*. Rosemont, IL: American Academy of Orthopaedic Surgeons, 2009.
34. Handoll HH, Madhok R. Surgical interventions for treating distal radial fractures in adults. *Cochrane Database Syst Rev* 2003; CD003209.
35. Grewal R, MacDermid JC. The risk of adverse outcomes in extra-articular distal radius fractures is increased with malalignment in patients of all ages but mitigated in older patients. *J Hand Surg Am* 2007; **32**: 962–970.
36. Egol KA, Walsh M, Romo-Cardoso S *et al*. Distal radial fractures in the elderly: operative compared with nonoperative treatment. *J Bone Joint Surg Am* 2010; **92**: 1,851–1,857.
37. Karantana A, Downing ND, Forward DP *et al*. Surgical treatment of distal radial fractures with a volar locking plate versus conventional percutaneous methods: a randomized controlled trial. *J Bone Joint Surg Am* 2013; **95**: 1,737–1,744.
38. Finsen V, Rod O, Rød K *et al*. The relationship between displacement and clinical outcome after distal radius (Colles') fracture. *J Hand Surg Eur Vol* 2013; **38**: 116–126.
39. Lang PO, Bickel KD. Distal radius fractures: percutaneous treatment versus open reduction with internal fixation. *J Hand Surg Am* 2014; **39**: 546–548.
40. MyATLS. ATLS, LLC. <http://www.myatls.com> (cited May 2016).