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ScienceDirect

Medical Engineering & Physics 31 (2009) 182–187

Medical Engineering & Physics

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Biomechanical analysis of distal radius fractures using intramedullary Kirschner wires

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Received 23 September 2007; received in revised form 17 August 2008; accepted 20 August 2008

Abstract

Colles's fracture is the most common type of distal radius fracture. Surgically, it remains a challenge to restore radial height and volar tilt in order to regain optimal wrist function. Ulson's procedure provides a dynamic effect on fixing fractured fragments and restoring joint function using two wires. However, the biomechanical influences of bone and wire remain critical issues for fracture reduction and bone union in Ulson's procedure. Based on elastic beam and foundation theory, this study formulated a closed-form mathematical model to investigate the effects of bone and wire parameters on wire deflection and bony reaction. The wire deflection and bony reaction were chosen as the indices of wrist stability and reduction within the post-operative period.

The predicted results showed that greater bone strength, higher wire stiffness, and longer wire contact length provide a more stable wire–bone construct, thus facilitating fracture reduction and bone union. The wire stiffness had a much more significant effect on the construct stability compared with bone quality and contact length. In terms of entry point and insertion angle, surgical planning for the contact length was more important than bony quality for stabilizing the whole wire–bone construct.

Keywords: Distal radius fracture; Kirschner wire; Ulson's procedure; Mathematical model

1. Introduction

The comminuted distal radius fracture (AO classification: A2.2 and A3.2), particularly in osteoporotic bone, has been a difficult management problem in terms of restoring wrist anatomy and function, and currently remains a surgical challenge [1,2]. Both external fixators and internal fixation using plates and screws have been popular treatment methods for this type of fracture [3–5]. In comparison with plating fixation, intramedullary fixation with percutaneous wires allows a shorter operation time, excellent cosmetic outcomes, minimal invasiveness and minimal soft-tissue dissection, ease of hardware removal, and early motion after removal. The Kapandji technique (Fig. 1A), initially designed to treat distal radius fractures in children, is capable of avoiding damage to the epiphyseal growth area by way of intrafocal invasion [6–8]. The modified Kapandji technique (Ulson's procedure) which uses Kirschner wires via intrafocal invasion for intramedullary insertion has been proposed as a method of achieving excellent results with few complications (Fig. 1B). For Ulson's procedure, the Kirschner wires are placed into the dorsal styloid in order to restore radial height and volar tilt [1,6].

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doi:10.1016/j.medengphy.2008.08.007

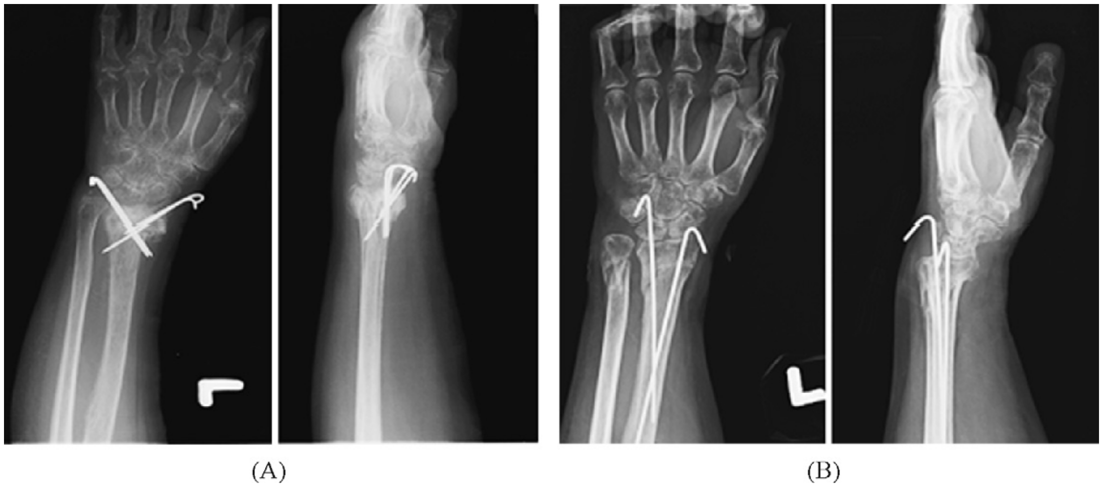

Fig. 1. Two views showing the traditional treatments for distal radius fractures. (A) Kapandji procedure. (B) As an alternative, an intramedullary wire was inserted into the radial medullary canal in the current study.

In radius fracture management, a satisfactory functional outcome is unlikely unless a good anatomical result is achieved [1,9,10]. For Ulson's procedure, the underlying principle of the Kirschner wires stabilizing the fractured fragments is the reaction force of the deflected wires in the medullary canal. The deflected wire exerts a reaction force directly at the wire–bone interfaces to facilitate bony union and fragment repositioning. From a biomechanical point of view, the reduction of the distal radius fracture is related to the contact length between the inserted wire and the medullary bone, the wire stiffness, the entry point and insertion angle of the wires, and the bone quality [1,11,12]. An unsuitable reaction force could lead to bony non-union or loss of reduction. Hence, it is an important issue to estimate pre-operatively the reaction force induced by the deflected Kirschner wires. However, to the best of the authors' knowledge, the load-transmission mechanics between the inserted wires and the radius fragments have not yet been studied extensively and reported in the literature.

In this study, a closed-form mathematical model based on linearly elastic beam and foundation theory was developed to investigate the influence of bone quality, wire stiffness, and contact length on the wire deflection and bone reaction force. The wire–bone reaction force was hypothesized to be closely related to fracture reduction and bony union using Ulson's procedure. The objective of the current study was to estimate the wire–bone reaction force that could be beneficial for pre-operative planning and post-operative outcome when treating a distal radius fracture with intramedullary Kirschner wires.

2. Methods

2.1. Assumptions of mathematical model

Using the AO classification, the model of a distal radius fracture in this study simulated an A2.2–A3.2 fracture. For reduction of the fractured distal radius, the intramedullary wire is gradually bent while the wire tip makes contact with the medullary bone (Fig. 2A). Consequently, the deflection of the bent wire exerts a reaction force directly on the distal radius fragment, thus providing anatomical reduction, increasing joint stability, and facilitating bony union. In the current study, the potential for fracture reduction and bony union was assumed to be closely related to the reaction force at the wire–bone interfaces. Accordingly, impingement and displacement of fragments, and loss of fixation can be well-controlled with the appropriate reaction force applied at the wire–bone interfaces. The hypothesis of this study was that the reaction force might be affected by some device-, bone-, and surgery-factors, such as bone quality, wire stiffness, and wire–bone contact length.

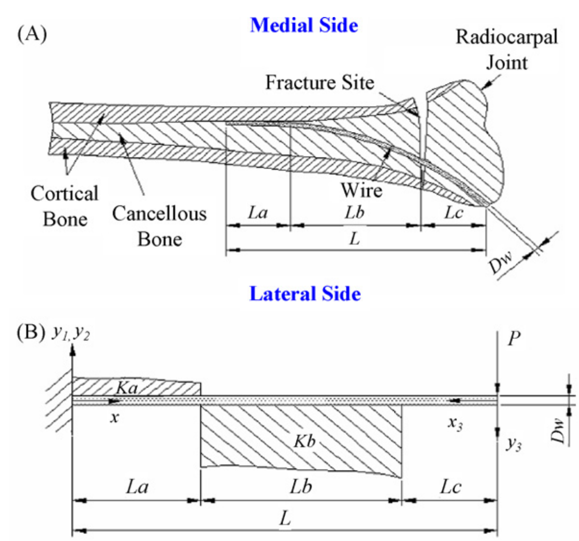

Fig. 2. (A) An intramedullary wire inserted into the radial medullary canal to treat the distal radius fracture (anterior-posterior view). (B) A mathematical model based on linearly elastic beam and foundation theory was developed to simulate the distal radius fracture treated with Kirschner wire. All symbols are defined in the text.