Computers in Biology and Medicine 60 (2015) 100–106

Contents lists available at ScienceDirect

Computers in Biology and Medicine

journal homepage: www.elsevier.com/locate/cbm

Theoretical distribution of load in the radius and ulna carpal joint

Kalenia Márquez-Florez [a,b], Enrique Vergara-Amador [c], Estevam Barbosa de Las Casas [d], Diego A. Garzón-Alvarado [a,b,*]

[a] Departament of Mechanical and Mechatronics Engineering, Numerical Methods and Modeling Group Research (GNUM), Universidad Nacional de Colombia, Bogotá, Colombia
[b] Biomimetics Laboratory, Instituto de Biotecnología, Universidad Nacional de Colombia, Bogotá, Colombia
[c] Department of Orthopedic Surgery, School of Medicine, Universidad Nacional de Colombia, Bogotá, Colombia
[d] Department of Structural Engineering, Universidade Federal do Minas Gerais, Belo Horizonte, Brazil

ARTICLE INFO

Article history:
Received 20 August 2014
Accepted 25 February 2015

Keywords:
Biomechanics of the wrist
Load transmission
Radius
Ulna
Joint analysis
Carpal mechanics

ABSTRACT

Purpose: The purpose of this study is to validate a model for the analysis of the load distribution through the wrist joint, subjected to forces on the axes of the metacarpals from distal to proximal for two different mesh densities.
Method: To this end, the Rigid Body Spring Model (RBSM) method was used on a three-dimensional model of the wrist joint, simulating the conditions when making a grip handle. The cartilage and ligaments were simulated as springs acting under compression and tension, respectively, while the bones were considered as rigid bodies. At the proximal end of the ulna the movement was completely restricted, and the radius was allowed to move only in the lateral/medial direction.
Results: With these models, we found the load distributions on each carpal articular surface of radius. Additionally, the results show that the percentage of the applied load transmitted through the radius was about 86% for one mesh and 88% for the coarser one; for the ulna it was 21% for one mesh and 18% for the coarser.
Conclusions: The obtained results are comparable with previous outcomes reported in prior studies. The latter allows concluding that, in theory, the methodology can be used to describe the changes in load distribution in the wrist.

1. Introduction

The wrist is the joint between the forearm and the hand, formed by the interaction of 15 bones [1] stabilized by the ligaments that interconnect them [2]. When there are conditions of high load concentration on the wrist, the cartilage that covers the bone can become impaired, causing pain, malfunction and progressive degeneration [2–6], affecting functionality of the upper extremity [7]. Various surgical treatments [2] have been proposed to treat these kind of diseases, which can be categorized into those that remove only part of the affected bone [2,8,9], the complete bone [2], or a total or partial arthrodesis (artificial ossification between two or more bones of a joint through surgery) [2,10,11].

Due to the variety of choices in treatments, it is necessary to identify the most appropriate one in the reduction and redistribution of loads. To do so, it is mandatory to compare load distribution in a healthy joint with a pathological after surgical treatment [12]. When trying to address this problem, experimental and computational methods have been used [13]. The most used methods range from ex-vivo techniques for measuring pressures.The most common computational method is the Finite Element (FEM) [14], which has proven effectiveness with simple geometric joints such as the hip [15,16] and knee [17,18], but not in complex joints like the ankle and wrist [14].

Based on the above mentioned limitations, and searching for a cost-effective modeling strategy, this paper presents a three-dimensional study of load distribution on the wrist, using the Rigid Body Spring Model –RBSM [19]. With this method, the distribution of forces in a joint can be analyzed where the bones are considered as rigid bodies, the cartilage and ligaments are modeled as compression-only and tension-only springs, respectively [20], and the system in static equilibrium [12]. Additionally, the RBSM method is able to predict the distribution of loads on joints with a low computational cost, regardless of its geometry or large deformations [21].

The RBSM has been previously applied in the analysis of the load distribution in the wrist joint in two dimensions under static equilibrium conditions, initially by Horii *et al.* [22], who developed a model that was then used to examine procedures for treating Kienböck's

* Corresponding author at: Cra 30 N° 45-03, Departament of Mechanical and Mechatronics Engineering, Numerical Methods and Modeling Group Research (GNUM), Universidad Nacional de Colombia, Bogotá, Colombia.
Tel.: +57 1 3165320; fax: +57 1 3165333.
E-mail address: dagarzona@unal.edu.co (D.A. Garzón-Alvarado).

http://dx.doi.org/10.1016/j.compbiomed.2015.02.016
0010-4825/

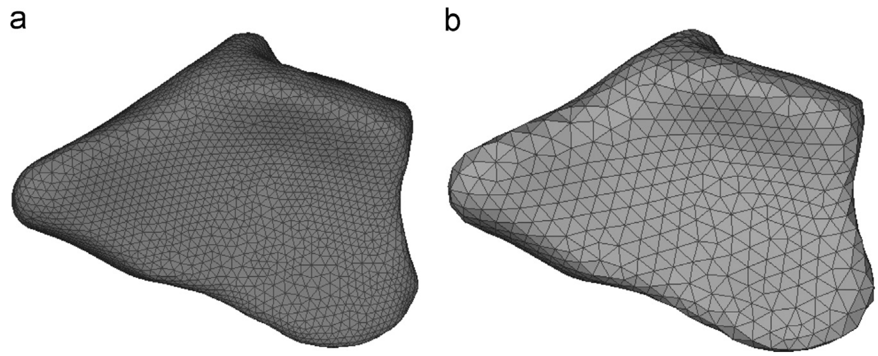

Fig. 1. Comparison of used meshes of all bones. (a) Elements with an average area of 0.18 mm^2 and (b) elements with an average area of 0.73 mm^2.

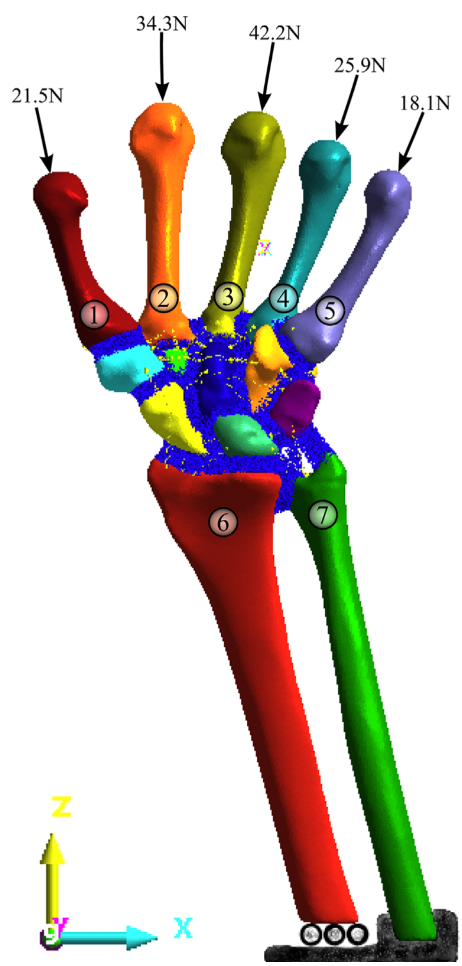

Fig. 2. Diagram of the bone in RecurDyn, palmar view of the wrist with loads shown. The names of bones numbered in figure are: 1-I Metacarpal; 2-II Metacarpal; 3-III Metacarpal; 4-IV Metacarpal; 5- V Metacarpal; 6-Radial; 7-Ulna.

disease. Shuind *et al.* [12] also developed a two-dimensional analysis using RBSM. Iwasaki *et al.* [23] applied the same method to analyze the changes on force distribution across the wrist for different stages of Kienböck's disease. Subsequently models in three-dimensions were developed by Iwasaki *et al.* [24] who determined which intercarpal fusions reduced loads on the lunate the most. Genda and Horii [25] also analyzed the force distribution on the radio-carpal joint with the wrist in neutral and functional position. This last work was continued by Majima *et al.* [19], who analyzed the load distribution on the wrist joint on extended position. Another three-dimensional RBSM of the wrist has been developed, where kinematics was analyzed and the findings were compared with experimental data [26].

Table 1
Rectangular components of loads applied in the metacarpals.

Metacarpal I	(7.412, 3.988, −19.78)
Metacarpal II	(−0.1263, −8.12, −33.311)
Metacarpal III	(−6.545, −6.286, −41.202)
Metacarpal IV	(−7.275, −4.509, −24.429)
Metacarpal V	(−8.662, −1.8641, −15.761)

The main purpose of this work is to test and validate a method for the determination of the forces distribution in the carpal joint of the radius and ulna, with loads of a grip handle in a physiological wrist joint under static equilibrium conditions. The results will be compared with previous studies by other authors. We also determined how a change on mesh density affects the final results, in order to have a notion of how this factor influences the model. This can then be used to compare load distributions on a wrist for various treatments of arthrodesis, pathologies and wrist positions.

2. Materials and methods

The study began with the generation of a three-dimensional model of the wrist joint to which we applied the RBSM method. The bones were considered as rigid bodies connected by springs between their articular surfaces. The cartilage was modeled as springs that support only compressive loads, while the ligaments were considered as tension-only springs. The models were assembled using a multi-body dynamic analysis software RecurDyn (*Multi-Body Dynamics - MBD*), a software based on Computer Aid Engineering tools (CAE) for dynamic analysis –MultiBody Dinamics MBD- by *Functionbay*, Inc. Seoul, Korea, [27]; the same software used in the study by Fischli [26].

2.1. Geometry

Three-dimensional models of the bones were obtained from segmented images from a CT scan (kV: 120; Slice Thickness: 0.5 mm; ma: 60) of a living subject's (adult male with type II lunate) wrist in a neutral pose with no alteration or disease on his joint and who volunteered and gave informed consent, which was subsequently processed in Mimics 10.01 (*Materialize, Belgium*); the study was approved by the University's Ethics Committee. Each solid was meshed in ICEM CFD 14.5 (*ANSYS*, Inc.,) with triangular elements so that the area of these was equivalent. It resulted in two models with a different number of elements on its surface (Fig. 1). These meshes were imported as a stereolithography format file (the extension of this type of file is.STL) in RecurDyn software (*Functionbay, Inc.* Seoul, Korea), where each bone was considered as an independent solid.