Manual Therapy 19 (2014) 235–241

Contents lists available at ScienceDirect

Manual Therapy

journal homepage: www.elsevier.com/math

Original article

Quantitative investigation of ligament strains during physical tests for sacroiliac joint pain using finite element analysis

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ARTICLE INFO

Article history:
Received 8 May 2013
Received in revised form
3 November 2013
Accepted 11 November 2013

Keywords:
Sacroiliac joint pain
Physical test
Finite element analysis
Biomechanics

ABSTRACT

It may be assumed that the stability is affected when some ligaments are injured or loosened, and this joint instability causes sacroiliac joint pain. Several physical examinations have been used to diagnose sacroiliac pain and to isolate the source of the pain. However, more quantitative and objective information may be necessary to identify unstable or injured ligaments during these tests due to the lack of understanding of the quantitative relationship between the physical tests and the biomechanical parameters that may be related to pains in the sacroiliac joint and the surrounding ligaments. In this study, a three-dimensional finite element model of the sacroiliac joint was developed and the biomechanical conditions for six typical physical tests such as the compression test, distraction test, sacral apex pressure test, thigh thrust test, Patrick's test, and Gaenslen's test were modelled. The sacroiliac joint contact pressure and ligament strain were investigated for each test. The values of contact pressure and the combination of most highly strained ligaments differed markedly among the tests. Therefore, these findings in combination with the physical tests would be helpful to identify the pain source and to understand the pain mechanism. Moreover, the technology provided in this study might be a useful tool to evaluate the physical tests, to improve the present test protocols, or to develop a new physical test protocol.

1. Introduction

The sacroiliac joint is a firm joint that lies at the junction of the spine and the pelvis and transfers the load of the upper body to the lower body. The stability of the sacroiliac joint is maintained mainly through the combination of its bony structure with very strong intrinsic and extrinsic ligaments. Thus, it may be assumed that the stability is affected when some ligaments are injured or loosened, and this joint instability causes sacroiliac joint pain, though the instability is resulted from a trauma incident by high energetic impact, and inflammation is one reason for the pain (Ozgocmen et al., 2008). In addition, it has been reported that sacroiliac joint pain was a source of low back pain with a prevalence that varied from 0.4% (Cyriax, 1978) to 35% (Schwarzer et al, 1995).

The diagnosis of sacroiliac joint pain has usually been based on intra-articular anaesthetic blocks and physical examinations which may include physical tests, a medical history, and imaging. There are various physical tests, such as the compression test, distraction test, sacral apex pressure test, thigh thrust test, Patrick's test, and Gaenslen's test, that can help to isolate the source of pain during the physical examination, as the sacroiliac joint can be moved or compressed by physicians while the hips and legs are placed in certain positions. The validity and reliability of these physical tests for the diagnosis of sacroiliac joint pain have been shown in previous clinical studies (van der Wurff et al., 2000a, 2000b; Laslett et al., 2003; Robinson et al., 2007; Laslett, 2008; Ozgocmen et al., 2008; Arab et al., 2009).

The physical tests may stress ligaments in the sacroiliac joint differently, and the ligaments stretched during each test were qualitatively reported (Levin et al., 1998; Cattley et al., 2002; Laslett et al., 2003; Robinson et al., 2007; Magee, 2008). However, there is no research that quantitatively demonstrates which ligaments are stressed by which tests. In addition, information regarding the relationship between the physical tests and the biomechanical parameters such as intra-articular contact pressure as well as ligament stress and strain that may be related to pains in the sacroiliac joint and the surrounding ligaments is insufficient. In this study, a three-dimensional (3D) finite element (FE) model of the sacroiliac joint was developed and the biomechanical conditions for six typical physical tests were modelled. The sacroiliac joint contact pressure and ligament strain were investigated for each test.

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1356-689X/$ – see front matter
http://dx.doi.org/10.1016/j.math.2013.11.003

2. Materials and methods

A 3D FE model of the sacroiliac joint was developed (Fig. 1). First, 3D CAD models of the fourth lumbar vertebra (L4), the fifth lumbar vertebra (L5), the sacrum, and the ilium were reconstructed from computed tomography (CT) images of a male subject (25 years old, 175 cm of height, and 66 kg of weight) using the 3D-DOCTOR (Able Software, MA, USA) and the Rapidform® 2004™ (INUS Technology, Inc., Seoul, Korea), where the cortical and cancellous regions of the bones were distinguished. Two intervertebral discs between L4 and L5 and between L5 and the sacrum were also modelled based on the CT images. The FE models of the bones and discs were developed from the CAD models using the FEMAP (MSC.Software Co., Santa Ana, CA, USA). The cartilages in the sacroiliac joint were developed with a uniform thickness, where the regions of the articular surfaces were chosen from CT images, and the thicknesses of the cartilages were obtained from the literature. The sacral and iliac cartilages had 2 mm and 1 mm of thicknesses, respectively. The bone end-plate thicknesses of the sacral and iliac parts of the cartilage were 0.23 mm and 0.36 mm, respectively. The gap between two cartilages was assumed to be 0.3 mm (McLauchlan and Gardner, 2002). The material properties drawn from previous studies (Oonishi et al., 1983; Dalstra et al., 1995; Kim et al., 2010) were summarized in Table 1.

Seven kinds of ligaments, the anterior sacroiliac ligament (ASL), interosseous sacroiliac ligament (ISL), long posterior sacroiliac ligament (LPSL), short posterior sacroiliac ligament (SPSL), sacrospinous ligament (SS), sacrotuberous ligament (ST), and iliolumbar ligament (IL), were modelled as 3D tension-only truss elements. The attachment regions were determined based on the literature (Gray, 2000). The ASL consisted of numerous thin bands connecting the anterior surface of the lateral part of the sacrum to the margin of the auricular surface of the ilium and to the preauricular sulcus. The ISL consisted of a series of short strong fibres connecting the tuberosities of the sacrum and ilium. The LPSL was attached by one extremity to the third transverse tubercle of the back of the sacrum,

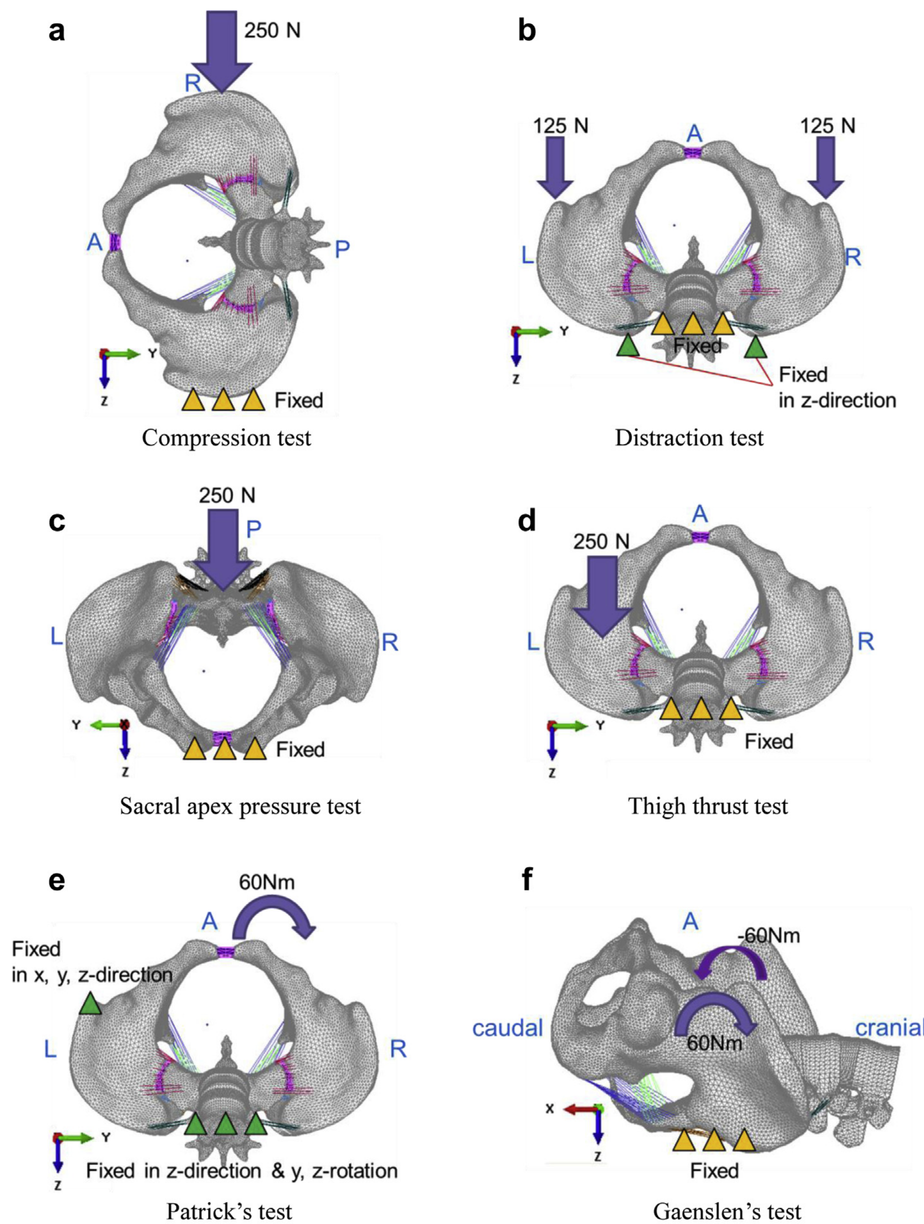

Fig. 1. Loading and boundary conditions for six physical tests.