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The influence of unilateral disc displacement on stress in the contralateral joint with a normally positioned disc in a human temporomandibular joint: An analytic approach using the finite element method

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ABSTRACT

Objectives: To investigate the influence of unilateral disc displacement (DD) in the temporomandibular joint (TMJ) on the stress in the contralateral joint, with a normally-positioned disc, during clenching.
Study design: A finite element model of the TMJ was constructed based on MRI and 3D-CT of a single patient with a unilateral DD. A second model with bilateral normally-positioned discs served as a reference. The differences in stress distribution in various TMJ components during clenching were predicted with these models.
Results: In the unaffected joint of the unilateral DD model, the largest von Mises stress at the start of clenching was predicted in the inferior surface of the disc and increased by 30% during clenching. In the connective tissue the largest stress (1.16 MPa) did not reduce during clenching, in contrast to the (unaffected) joints of the reference model. In the affected joint, the largest stress was predicted in the temporal cartilage throughout clenching. In the surrounding connective tissue, the largest stress (1.42 MPa) hardly changed during clenching indicating no, or negligible, stress relaxation.
Conclusions: This suggested that a unilateral DD could affect the stresses in the unaffected (contralateral) joint during clenching, where it may lead to weakening of the tissues that keep the disc on the top of the condyle. The results may be helpful in counseling worried patients, since they give insight into possible future developments of the disorder.

1. Introduction

The temporomandibular joint (TMJ) is considered as load bearing during mastication. The loads are distributed over the articular surfaces by an intra-articular disc and cartilage (Tanaka and van Eijden, 2003; Kuroda et al., 2009). The loading condition of the joint has a large influence on the development and maintenance of the normal structure and function of its components (Tanaka et al., 2008; Koolstra and Tanaka, 2009). When this is disturbed, it may lead to internal derangement of the TMJ (TMJ-ID). The consecutive stages of internal derangement have been described by several authors. In the initial stage, reciprocal clicking of the TMJ, indicative of a temporary displaced articular disc, is the dominant clinical sign (de Leeuw et al., 1994). When this situation becomes more chronic, the disc becomes more deformed, resulting in an intermittent locking (de Leeuw et al., 1994, 1995). Eventually, the disc may become permanently displaced. This may interfere with condylar translation, and is frequently accompanied by pain (de Leeuw et al., 1994, 1995). Ultimately, this may result in joint degeneration.

Generally, a joint with a displaced disc remains a relatively harmless condition (Naeije et al., 2013). However, it may lead to asymmetries in masticatory performance and it could affect the

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loading of the healthy (contralateral) joint. The characteristics of such altered loading are presently unknown. Since these alterations might also render this healthy joint vulnerable to disorders, the purpose of this paper was to investigate the influence of a unilateral disc displacement on the stresses in the disc of the contralateral joint. Increased equivalent (von Mises) stress in the disc itself could indicate that it may be squeezed out from between the articular surfaces towards an abnormal position. Increased equivalent stress in the retrodiscal tissue, which can be considered to prevent the disc from moving anteriorly too much, could indicate potential damage leading to weakening. To help predict these stresses a biomechanical model of the human masticatory system (del Palomar and Doblaré, 2006; Tanaka et al., 2007; Koolstra and Tanaka, 2009; Mori et al., 2010; Koolstra, 2012) was applied, incorporating one healthy TMJ and one affected with an anteriorly displaced disc. This model was derived from a patient suffering from a unilateral TMJ disorder. Using finite element (FE) modeling the stress distribution in the TMJ components was predicted during clenching. This was compared with predictions obtained with a similar model containing unaffected joints with a normally-positioned disc in each. It was hypothesized that the altered loading due to a displaced disc could lead to increased stresses in the contralateral joint in such a way that it also becomes vulnerable to a disorder.

2. Material and methods

2.1. Construction of the TMJ finite element models

A symptomatic female subject (42 years old) with an anteriorly displaced disc in one of her joints was selected. 3-D CT (3DX Multi-image CT, Morita Co., Kyoto, Japan) and MRI (1.5-Tesla system, Signa, General Electric, Fairfield, CT, USA) (Fig. 1) reconstructions of the masticatory system were obtained for diagnosis. The latter applied a tube voltage of 85 kV and a current of 2 mA for a slice thickness of 1.0 mm with a resolution of 0.25 mm (Tanaka et al., 2002). The contours of the temporal bone and the mandibular condyle were obtained from the 3-D CT scans, while soft tissue contours were constructed based on the MR images. This work was approved by the Ethical Committee of the Tokushima University Hospital.

The 3-D modeling of the bone components from the DICOM data of the 3DX-CT was performed using ZedView (LEXI, Tokyo, Japan). This application performs as a semi-automatic segmentation tool for rapid processing of 3-D data (Mori et al., 2010; Abe et al., 2013). It extracts boundaries from each cross sectional image and combines them into a surface model composed of 3-D polygons. From the contiguous axial slices the contours of the mandibular condyle and temporal bone (glenoid fossa) were traced semi-automatically. They were combined to represent the 3-D geometry of each TMJ component. For shape refinement of the lateral and medial portions, the sagittal and coronal views were used.

The deformable parts of the joint, the articular disc and the ligaments, were manually created. The disc position was determined from the MRI data. The upper and lower boundaries of the disc were shaped according to the respective articular surfaces. Both these surfaces were lined with a uniform-thickness layer (0.2 mm) mimicking the temporal and mandibular condylar cartilage, respectively. The disc was able to deform and move along the articular surfaces. Because of the limited resolution of the MRI, the

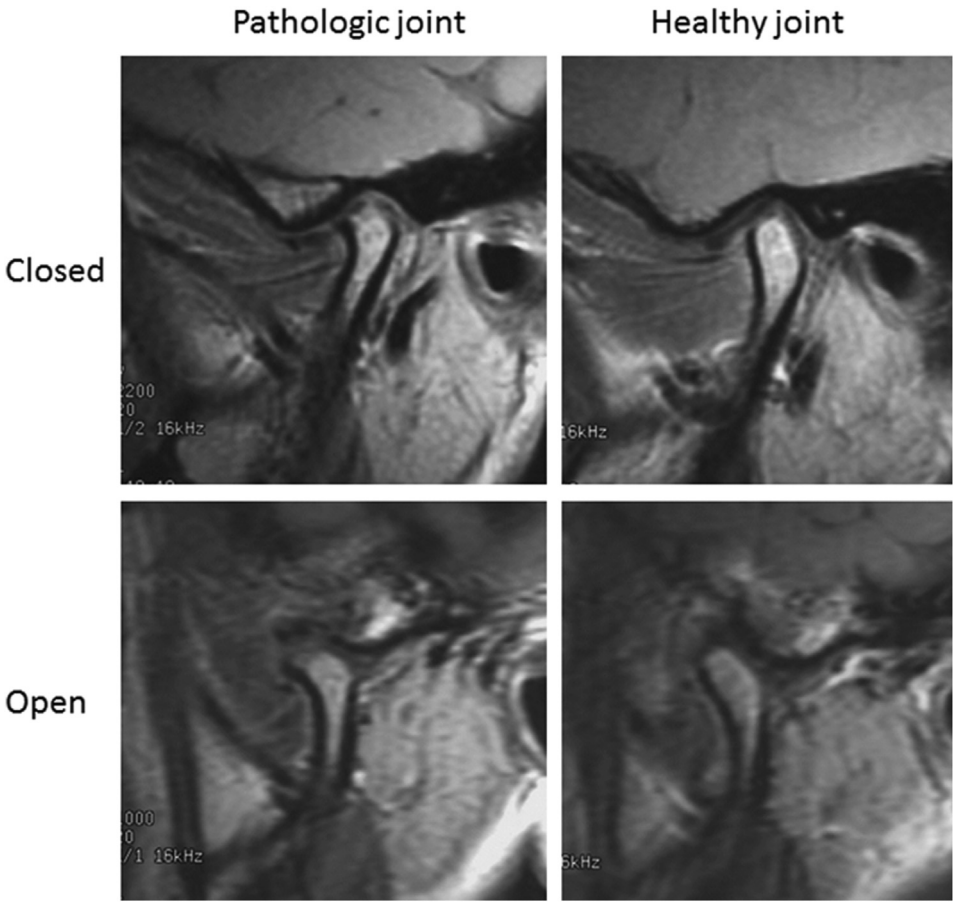

Fig. 1. Clinical MR images of a patient TMJ with unilateral anterior disc displacement sectioned in the direction perpendicular to the condylar axis.