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Morphometric analysis of temporomandibular joint elements

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A B S T R A C T

Purpose: To study the morphology of temporomandibular joint (TMJ) elements and examine the feasibility of a novel biofidelic articular disc casting technique.
Methods: 18 formalin-fixed cadavers (77.8% female, 22.2% male) with mean (SD) death age of 71.9 (13.7) years were used for this study. In each specimen the masseter muscle, mandibular ramus, and articular disc were dissected bilaterally and measured for length, width, and thickness. All anatomic measurements were made using a digital slide caliper (Hawk Inc., Cleveland, OH). Further, a novel method for the creation of biofidelic articular disc models was established through trial and error. Models were measured for accuracy against their biological counterparts.
Results: Left articular disc length and thickness were inversely correlated ($r = -0.58$, $p < 0.049$). Direct correlations existed between right disc and ramus thickness ($r = 0.56$, $p < 0.039$), masseter length and thickness ($r = 0.59$, $p < 0.009$), and masseter width and thickness ($r = 0.66$, $p < 0.003$). Comparison of the model measurements with their biological counterparts found no significant differences.
Discussion: These observed correlations between elements of the TMJ hold relevance for oral-maxillofacial surgeons and researchers examining disorders of the TMJ. Additionally, our casting technique proved accurate in modeling human articular discs.

1. Introduction

Temporomandibular disorder (TMD) describes an assortment of temporomandibular joint (TMJ) disorders that in total, affect roughly 25% of the population (Murphy et al., 2013). Internal derangement of the TMJ (TMJ ID), characterized by a progressively dysfunctional association between the condyle and articular disc (TMJ disc), accounts for up to 70% of TMD cases (Costa et al., 2008; Hagandora and Almarza, 2012; Murphy et al., 2013). Treatment of TMJ ID via articular disc discectomy, which involves the replacement of defective tissue with allogeneic materials (fascia, dura, and cartilage), has yielded mixed surgical results (Ingawale and Goswami, 2009; Hagandora and Almarza, 2012). Alloplastic disc replacements also represent a non-ideal solution, with prosthesis breakdown driving adverse reactions and further degradation of the TMJ, in extreme cases necessitating a full TMJ replacement

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(Wolford and Mehra, 2000; Mercuri, 2007; Ingawale and Goswami, 2009; Westermark et al., 2011). Despite surgical correction, these cases often fail to achieve positive long-term surgical outcomes. Therefore, creation of a safe, anatomically correct articular disc prosthesis is key in the treatment of TMD.

The fabrication of prosthetic articular discs is a multi-faceted process, involving the consideration of tissue engineering techniques, biomechanical properties, disc integrity, and disc morphology (Stankovic et al., 2013). Placing aside the challenges surrounding tissue engineering, the creation of accurate, individually specific scaffolds requires accurate disc morphology data. Image-guided, three-dimensional (3D) models have shown promise in anatomical investigations, surgical planning, and prosthesis development (Tanaka et al., 2001, 2004; Ingawale and Goswami, 2009; Zizelmann et al., 2010; Matsumoto et al., 2014; Legemate et al., 2016). However, these data are subject to inherent imaging limitations.

Across the various imaging modalities, including MRI, CT, and cone-beam CT (CBCT), there exist limitations and variability in accuracy—a product of device and parameter differences (Westesson et al., 1987a,b; Hilgers et al., 2005; Lewis et al., 2008; Nackaerts et al., 2011). A further limitation arises from the inability of dissected organic material to be recognized by a 3D scanner. In light of these limits, a novel casting method is required to facilitate 3D scanning of dissected articular discs.

The purpose of this study was to obtain human articular disc morphometric data and statistically analyze the interrelations of the discs and surrounding structures. In addition, we sought to create a novel casting method for biofidelic 3D plastic articular disc models. The study was performed using formalin-fixed cadavers and a novel disc dissection method to ensure the integrity of the disc was established.

2. Materials and methods

2.1. Morphometric analysis of TMJ elements

Temporomandibular joint discs were dissected from 18 formalin-fixed adult human cadavers (14 female, 4 male) with a mean (SD) age at death of 71.9 (13.7) years (Table 1). Exclusion criteria included signs of gross disc deformity, disc degradation, evidence of previous TMJ surgery, and absence of a disc resulting in 34 TMJ discs (16 left, 18 right).

Blunt and sharp dissections were carried out to gain access to the TMJ and ultimately the disc inside the joint. Superficial dissection of the TMJ consisted of removal of the skin and superficial fascia to expose the musculature. Next, the masseter muscle was carefully dissected and its length, width, and thickness measured. Removal of the masseter muscle included performing a horizontal transection through the muscle belly at the middle aspect of the mandibular ramus. The mandibular ramus was horizontally transected and the thickness was measured at the anterior (thin) and posterior (thick) aspects of the bone. In addition, the zygomatic process was transected and removed to expose the joint capsule of the TMJ.

Further dissection of the TMJ included the use of a probe to carefully scrape the superior aspect of the disc from the inferior end of the temporal bone. This same technique was then used to create space between the head of the mandibular ramus and the inferior aspect of the disc. Lastly, blunt scissors were used to cut the anterior attachments of the lateral pterygoid muscle and posterior fascia attachments. The TMJ disc was removed and its length, width, and thickness were measured at the apex of its convexity. All anatomical measurements were made using a digital slide caliper (Hawk Inc., Cleveland, OH).

To ensure high inter-rater reliability throughout the study, measurements recorded by two researchers were then re-measured by the principal investigator (PI). All anatomical variations and TMJ relationships were recorded.

Data were statistically analyzed using SPSS Version 20.0 (IBM, Armonk, NY). A p-value of less than 0.05 was considered significant.

2.2. Bioengineering of TMJ disc model

The biofidelic 3D plastic model was fabricated using Alja-Safe® and Smooth-Cast 300 liquid plastic compound materials. 300 ml of 80 °F water was mixed with 500 ml of Alja-Safe® silica for 3 min. The mixture was poured into a styrofoam cup, filling it halfway. The dissected disc was placed into the cup, and additional silicone mixture was poured over the top and allowed to cure for 8 min. The styrofoam was removed and a perpendicular cut was made into the silicone mold, close to the location of the disc. The silicone was then carefully peeled off to allow for removal of the disc. Two ounces of part A (diphenylmethane diisocyanate) and two ounces of part B (4,4′ methylene bis(phenylisocyanate)) Smooth-Cast 300 liquid plastic (LP) compound were mixed together for 3 min at 62 °F. The 4 oz part A and B mixture was poured into mold to ensure an overflowing effect. Lastly, forceps were used to carefully remove the plastic disc from the silicone mold.

Once the biofidelic discs were created thickness measurements were performed on each. For each TMJ cadaveric disc that was selected, at least three plastic models were fabricated to perform measurement analysis. Each plastic and cadaveric model was measured at five different points on the TMJ disc. The thickness measurements consisted of three posterior points: posterior lateral, central dense apex, and posterior medial. The other measurements consisted of two anterior medial and lateral points on the disc. This

Table 1
Cadaver sample demographics ($n = 18$).

Characteristics	All cadavers No. (%)
Age group, years[a]	
<55	3 (16.7)
55–64	2 (11.1)
65–74	4 (22.2)
≥75	9 (50.0)
Sex	
Female	14 (77.8)
Male	4 (22.2)

[a] Mean age (range), 72 (42–88).

Table 2
Analysis of laterality of temporomandibular joint elements.

	Right side	Left side	Both sides	p-Value between sides
	Mean (SD)	Mean (SD)	Mean (SD)	
Articular disc				
Thickness[a]	2.08 (0.88)	2.14 (0.73)	2.14 (0.69)	0.572
Length	17.14 (1.81)	15.98 (1.49)	16.85 (1.66)	0.068
Width	20.29 (2.34)	20.90 (1.78)	20.41 (1.68)	0.718
Mandibular ramus				
Thick segment	10.32 (2.26)	9.37 (1.88)	9.87 (1.77)	0.066
Thin segment	4.82 (0.96)	4.65 (1.01)	4.71 (0.84)	0.162
Masseter muscle				
Thickness	6.01 (1.4)	5.90 (1.26)	6.09 (1.22)	0.533
Length	56.66 (5.38)	56.01 (7.51)	56.77 (5.88)	0.701
Width	29.27 (4.05)	30.53 (2.88)	30.35 (3.41)	0.383

Note: All measurements are in mm.
[a] Measured at the apex of its convexity.