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Cell Type and Distribution in the Porcine Temporomandibular Joint Disc

Michael S. Detamore, PhD^{*}, Jay N. Hegde, BS[†], Rohan R. Wagle, BA[‡], Alejandro J. Almarza, PhD[§], Dina Montufar-Solis, BS^{||}, P. Jackie Duke, PhD[¶], and Kyriacos A. Athanasiou, PhD, PE[#]

^{*}Assistant Professor, Department of Chemical and Petroleum Engineering, University of Kansas, Lawrence, KS

[†]Medical Student, University of Texas Southwestern Medical School, Dallas, TX

[‡]Medical Student, Baylor College of Medicine, Houston, TX

[§]Postdoctoral Fellow, Musculoskeletal Research Center, Department of Bioengineering, University of Pittsburgh, Pittsburgh, PA

^{||}Senior Research Associate, Department of Diagnostic Sciences, University of Texas Health Science Center Dental School, Houston, TX

[¶]Professor, Department of Orthodontics, University of Texas Health Science Center Dental School, Houston, TX

[#]Professor, Department of Bioengineering, Rice University, Houston, TX; and Adjunct Professor, Department of Oral & Maxillofacial Surgery, University of Texas Health Science Center Dental School, Houston, TX

Abstract

Purpose—Surprisingly little is known about the cellular composition of the temporomandibular joint (TMJ) disc, which is a crucial piece of the puzzle in tissue engineering efforts. Toward this end, cell types were identified and quantified regionally in the TMJ disc.

Materials and Methods—Porcine TMJ discs were examined by histology, electron microscopy, and immunohistochemistry. Histology consisted of hematoxylin and eosin staining to identify regional variation of cell type and cell numbers. Transmission electron microscopy was used to elucidate differences in organelle content and pericellular matrix between TMJ disc cells and chondrocytes from hyaline cartilage. Immunohistochemistry was used to assess the presence of smooth and skeletal muscle character in the TMJ disc.

Results—The overall ratio of fibroblasts to chondrocyte-like cells in the TMJ disc was approximately 2.35 to 1, with the highest relative number of chondrocyte-like cells in the intermediate zone. Electron microscopy revealed distinct differences between TMJ disc chondrocyte-like cells and chondrocytes from hyaline cartilage with respect to organelles and the

pericellular region. Immunostaining identified smooth muscle in the form of vessels, which were most prominent in the anterior band. Skeletal muscle was not observed.

Conclusion—The cells of the TMJ disc are distinctly different from cells of hyaline cartilage, and consequently should not be referred to as chondrocytes. TMJ disc cells are comprised of heterogeneously distributed subpopulations, with fibroblasts predominating over fibrochondrocytes.

Approximately 3% to 4% of the population seek treatment for temporomandibular joint (TMJ) disorders,¹ and roughly 70% of these patients suffer from disc displacement.² Tissue engineering is a potential solution to assist in the healing of this poorly studied structure.³ While pioneering tissue engineering studies exist for the TMJ disc,⁴⁻⁷ it is critical that the detailed standards of native disc properties are determined to advance our tissue engineering efforts.⁸

An early study in TMJ anatomy reported that the majority of the cells of the human TMJ disc were fibrocytes with occasional groups of rounder cells.⁹ In addition, a study of the bovine TMJ disc indicated that these cells possessed characteristics of both fibroblasts and chondrocytes.¹⁰ In contrast, primate TMJ disc cells have been reported to be primarily chondrocyte-like round cells surrounded by lacunae.¹¹ In a detailed study of the cells of the TMJ disc, rats and marmosets were analyzed at varying ages.¹² In addition, the possibility of the existence of muscle character in the TMJ disc was mentioned. Evidence thus far would suggest that the TMJ disc possesses both chondrocyte-like cells and fibroblasts. However, information on the relative distribution of these cell types in the TMJ disc is currently unavailable.

A porcine model has been recommended for characterization and tissue engineering studies of the TMJ disc.³ This recommendation is based on several studies that suggest the porcine model is the preferred animal model for the human TMJ over cats, cows, dogs, goats, rabbits, rats, and sheep,¹³⁻¹⁶ juxtaposed with a tissue engineering study where no differences were observed between results from porcine and human cells.⁷ In this study, the objective was to first identify regional cell type distribution of the porcine TMJ disc in 3 dimensions, then to identify and classify the ultrastructure of the chondrocyte-like cells of the disc in comparison to chondrocytes from hyaline cartilage. In addition, this study aimed to identify the presence of smooth and skeletal muscle in the TMJ disc.

Materials and Methods

TISSUE HARVEST

Hog heads (P.I.C. Genetic Breed, provided by Fisher Ham and Meat Co, Spring, TX) from females of approximately 6 months of age and weighing 70 to 80 kg (150 to 180 lbs) were obtained from a local slaughterhouse. TMJ discs from both sides were extracted and separated from peripheral attachment tissue within 4 hours of death. All discs were assessed grossly, and no signs of degeneration were observed. Discs for histologic and electron microscopy analyses proceeded directly to processing without freezing, whereas discs for immunohistochemistry were frozen at -20°C until further use.

HISTOLOGY

On dissection from hogs, TMJ discs were divided into 9 regions (Fig 1A).

Anteroposteriorly, the disc was cut into 3 regions: anterior band, intermediate zone, and posterior band. Mediolaterally, these 3 regions were further cut into 3 regions each: medial, central, and lateral. These 9 regions were then dehydrated in graded ethanol, paraffin-embedded, and sectioned at a thickness of 4 μm at 3 layers along the superoinferior axis: near the superior surface, middle, and near the inferior surface (Fig 1B). These 27 sections from each disc were stained with hematoxylin and eosin; cells were classified either as fibroblasts (spindle-shaped, no discernible cell boundary) or chondrocyte-like (polygonal, in lacunae). Two TMJ discs were used for a total of 54 sections. The number of each cell type was counted in 10 random windows in every section at $400\times$ magnification (window area, 0.051 mm^2), resulting in 20 observations from each of the 27 regions of interest.

Occasionally, a random window would include regions appearing vascular in nature. In these instances, the window was shifted slightly to exclude the apparently vascular regions. This observation prompted the immunohistochemical investigation of smooth muscle character described below. The cell count data were modeled with a Poisson regression, and post-hoc differences between treatment levels were tested with linear contrast.¹⁷

TRANSMISSION ELECTRON MICROSCOPY

Two additional TMJ discs from different hogs were harvested and specimens were taken from the anterior band, intermediate zone, and posterior band. In addition, porcine ankle hyaline cartilage was tested as a positive control for chondrocytes. Specimens were fixed in 2% glutaraldehyde and postfixed for 1 hour in 0.5% osmium tetroxide, dehydrated in graded ethanol, and embedded. Approximately 80 ultrathin sections ($\sim 90\text{ nm}$) were prepared, stained with lead citrate and uranyl acetate, and examined in a JEOL 100CXII electron microscope (JEOL-USA, Inc, Peabody, MA).

IMMUNOHISTOCHEMICAL INVESTIGATION OF MUSCLE CHARACTER

An additional 2 TMJ discs from different hogs were harvested and divided into 9 regions as described above for histology (Fig 1A). These 9 regions were sectioned in a cryotome at -20°C , and 3 sections were taken as described above (Fig 1B). Smooth muscle was identified with an anti- α -smooth muscle actin primary antibody (Sigma-Aldrich, St Louis, MO) and skeletal muscle was identified with an anti-sarcomeric actin primary antibody (Sigma-Aldrich). Sections were then incubated with a secondary antibody and avidin-biotin complex (Vector Laboratories; Burlingame, CA), visualized with 3,3'-diaminobenzidine, and counterstained with hematoxylin. Porcine masseter served as positive control for smooth and skeletal muscle. Negative controls were produced by exclusion of the primary antibody.

Results

TOTAL CELL NUMBERS

Histologic assessment yielded an overall density of $681 \pm 197\text{ cells/mm}^2$, of which 70% $\pm$ 11% were fibroblasts (mean $\pm$ standard deviation). Regional variations in total cell number and percent fibroblasts along the mediolateral and anteroposterior axes are depicted in

Figure 2. Along the 3 axes, statistically significant differences in total cell numbers were observed only along the mediolateral and anteroposterior axes, with no statistical difference between layers along the superoinferior axis. The lateral and medial regions had 9.9% and 10.1% more cells than the center of the disc ($P < .002$), respectively, although there was no significant difference between lateral and medial regions. The anterior band had 11.0% fewer cells than the intermediate zone ($P < .0001$) and 8.3% fewer than the posterior band ($P < .005$), with no significant difference between the intermediate zone and posterior band.

DISTRIBUTION OF CELL TYPES

The cell type distribution was also observed to vary throughout the TMJ disc, with significant differences along all 3 axes (Fig 2). Along the anteroposterior axis, the anterior ($P < .05$) and posterior ($P < .002$) bands both had a higher percentage of fibroblasts than the intermediate zone (3.5% and 6.3% larger values, respectively). The anterior and posterior bands were not significantly different. Mediolaterally, the central region had the highest percentage of fibroblasts, 7.6% and 6.2% larger than the medial and lateral regions, respectively ($P < .0005$), while there was no significant difference between the medial and lateral regions. Along the superoinferior axis, the superior and middle layers, while not significantly different from each other, had higher relative numbers of fibroblasts than the inferior surface ($P < .0001$). The superior and central layers had $72\% \pm 10\%$ and $72\% \pm 11\%$ fibroblasts, respectively, compared with $66\% \pm 12\%$ (mean $\pm$ standard deviation) in the inferior layer.

ULTRASTRUCTURAL CHARACTERISTICS

There were no noticeable ultrastructural differences between regions in the TMJ disc. Fibroblasts in general appeared to have fairly large nuclei with very few organelles (Fig 3A). The rough endoplasmic reticulum was minimal in these cells, and the smooth endoplasmic reticulum was present to an even lesser extent. Moreover, a well defined Golgi apparatus and mitochondria were rarely observed in the fibroblasts. While ribosomes were typically sparse in these cells, occasional fibroblasts did contain relatively large amounts of ribosomes.

The chondrocyte-like cells of the TMJ disc normally did not exhibit a well defined pericellular electron lucent zone (Fig 3B), although there were a few exceptions where a small discernible zone was observed. A small amount of rough endoplasmic reticulum presence was apparent in the chondrocyte-like cells of the TMJ disc, while smooth endoplasmic reticulum was sporadically present. In addition, very few of these cells had a readily identifiable Golgi apparatus. However, the chondrocyte-like cells of the TMJ disc appeared to often have several mitochondria and a relatively large nucleus. A moderate number of ribosomes were observed compared with the fibroblasts of the TMJ disc and chondrocytes.

Over 40 TMJ disc cells and 25 chondrocytes were observed. Chondrocytes (Fig 3C) appeared distinctly different from TMJ disc chondrocyte-like cells. While chondrocytes typically had a well defined electron lucent zone, labeled as pericellular matrix, a pericellular capsule was not evident. The chondrocytes typically had a very well-organized

endoplasmic reticulum, both rough and smooth. Moreover, the Golgi apparatus was frequently observed in chondrocytes, as were numerous ribosomes. Interestingly, there were fewer mitochondria observed in chondrocytes than in TMJ disc chondrocyte-like cells. A recurrent presence of distinct pseudopodia was observed along the periphery of the chondrocytes, whereas the TMJ disc cells appeared much smoother around the periphery.

MUSCLE CHARACTER

No staining was detected for sarcomeric actin in any of the regions of the TMJ disc, which were indistinguishable from the negative control. In comparison, the positive control masseter tissue stained intensely for sarcomeric actin. In contrast to sarcomeric actin staining, α -smooth muscle actin staining was observed in both the TMJ disc (Figs 4A,B) and the masseter (Fig 4C). In both the TMJ disc and the masseter, the α -smooth muscle actin stain was observed in clearly discernible circular or sometimes cylindrical patterns. No staining for α -smooth muscle actin was observed in the negative control (Fig 4D). In the TMJ disc, the number of locations that stained for α -smooth muscle actin appeared to be greatest in the anterior band. There did not appear to be any differing trends along the mediolateral or superoinferior axes in the frequency of the regions containing α -smooth muscle actin.

Discussion

Previous studies have qualitatively determined that cells were more numerous in or near the anterior and posterior bands compared with the intermediate zone in rabbit and primate TMJ discs.^{18,19} In contrast, the current findings indicate quantitatively in a porcine model that the anterior band has fewer cells than the intermediate zone and posterior band.

To the best of our knowledge, this is the first time that cell subpopulations have been quantified in the TMJ disc. The observed trends may have important structural and functional implications. The abundance of chondrocyte-like cells in the center of the TMJ disc compared with the periphery corresponds well to the elevated levels of chondroitin sulfate and higher compressive stiffness reported for the center of the disc.²⁰⁻²⁴ Moreover, the higher relative number of chondrocyte-like cells on the inferior surface compared with the superior surface of the disc may shed light on functional differences between the inferior and superior joint spaces of the TMJ. These results may suggest a more mechanically demanding environment in the inferior joint space, which is supported by the observed increased levels of degeneration in the inferior space in cases of TMJ disorders.²⁵⁻²⁷

Fibroblasts, on the other hand, are associated with more tensile tissues such as skin, ligament, and tendon. Previous qualitative studies agreed with the finding that fibroblasts were more predominant at the attachment regions, notably the anterior and posterior attachments.^{11,18} The significantly higher relative number of fibroblasts in the center of both the anterior and posterior bands may be indicative of tensile behavior in these regions, likely corresponding to taut and perhaps pulling attachments in these regions. This explanation would make sense in light of a recent tensile study of the TMJ disc, which found that the disc was stiffest in the center in the anteroposterior direction.²⁸ In addition, collagen fibers were arranged in a circumferential manner around the periphery of the disc and

anteroposteriorly through the middle which, in conjunction with the heightened prevalence of fibroblasts in the center of the anterior and posterior bands observed in the current study, may support the notion that the primary anchors for tensile stress in the TMJ disc are attached at these 2 locations. Physiologically, this is intuitive, because the disc moves anteriorly in a normally functioning TMJ during jaw opening and posteriorly during jaw closing, and these attachments would be most responsible for maintaining proper disc position throughout this range of motion.

At the subcellular level, relatively low amounts (and in some cases a lack) of organelles, especially in fibroblasts, confirmed prior observations in rodent TMJ disc cells.¹² Chondrocytes did not appear to exhibit a distinct pericellular capsule typical of articular chondrocytes.²⁹ This may have been because of the species, location, or maturity of the tissue. Nevertheless, the electron lucent halo of pericellular matrix surrounding these cells was far more common and extensive than with TMJ disc chondrocyte-like cells. This distinct difference set these cell types apart, suggesting that it may not be prudent to refer to the cells of the TMJ disc as “chondrocytes.” Moreover, differences in organelle content between chondrocytes and TMJ disc chondrocyte-like cells likely suggest differences in cellular behavior. For example, the larger amounts of smooth and rough endoplasmic reticulum and Golgi apparatus in chondrocytes likely suggest higher levels of protein synthesis, lipid synthesis, and/or carbohydrate metabolism compared with TMJ disc cells. The greater number of mitochondria in TMJ disc chondrocyte-like cells should correspond to a higher metabolic activity than in chondrocytes.

Investigation into the muscle character of the TMJ disc has 2 major implications. First, the discovery of sporadic blood vessels may suggest that tissue engineering efforts in the future may be tailored to capitalize on this feature. For example, potential strategies may include co-culture of smooth muscle cells, factors supporting microvasculature, and/or bioreactors using a flow regime. Second, the absence of skeletal muscle character suggested by the lack of sarcomeric actin staining might provide supporting evidence for arguments against direct insertion of the lateral pterygoid muscle into the TMJ disc.³⁰⁻³² There are 2 caveats that should be mentioned. One is that this study did not investigate muscle character in peripheral attachments of the disc, but only in the disc itself. Another is that the possibility of a tendinous insertion into the disc cannot be ruled out by immunohistochemical sarcomeric actin staining. Thus, this lack of staining only provides direct evidence for the lack of actual muscle fiber insertion through the boundaries of the TMJ disc.

The TMJ disc contains a nonhomogeneous distribution of cell subpopulations, which are distinct from chondrocytes from hyaline cartilage. Thus, the cells of the TMJ disc should not be referred to as chondrocytes, but perhaps instead should be referred to as a mixed population of fibroblasts and fibrochondrocytes (chondrocyte-like cells). In addition, a relatively small number of endothelial cells, smooth muscle cells, and blood cells must exist within the small number of blood vessels. While the current study endeavors to provide a foundation for in situ cellular characterization of the TMJ disc, work remains to be done. For example, it may be worth-while to investigate the possibility that the different cell types of the TMJ disc are all members of 1 lineage and perhaps differentiate or dedifferentiate between cell types with age.

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References

- Gray, RJM.; Davies, SJ.; Quayle, AA. Temporomandibular Disorders: A Clinical Approach. British Dental Association; London: 1995.
- Farrar WB, McCarty WL Jr. The TMJ dilemma. J Ala Dent Assoc. 1979; 63:19. [PubMed: 297713]
- Detamore MS, Athanasiou KA. Motivation, characterization, and strategy for tissue engineering the temporomandibular joint disc. Tissue Eng. 2003; 9:1065. [PubMed: 14670096]
- Thomas M, Grande D, Haug RH. Development of an in vitro temporomandibular joint cartilage analog. J Oral Maxillofac Surg. 1991; 49:854. [PubMed: 2072197]
- Puelacher WC, Wissner J, Vacanti CA, et al. Temporomandibular joint disc replacement made by tissue-engineered growth of cartilage. J Oral Maxillofac Surg. 1994; 52:1172. [PubMed: 7965312]
- Girdler NM. In vitro synthesis and characterization of a cartilaginous meniscus grown from isolated temporomandibular chondroprogenitor cells. Scand J Rheumatol. 1998; 27:446. [PubMed: 9855216]
- Springer IN, Fleiner B, Jepsen S, et al. Culture of cells gained from temporomandibular joint cartilage on non-absorbable scaffolds. Biomaterials. 2001; 22:2569. [PubMed: 11516090]
- Detamore MS, Athanasiou KA. Structure and function of the temporomandibular joint disc: Implications for tissue engineering. J Oral Maxillofac Surg. 2003; 61:494. [PubMed: 12684970]
- Rees LA. The structure and function of the mandibular joint. Br Dent J. 1954; 96:125.
- Landesberg R, Takeuchi E, Puzas JE. Cellular, biochemical and molecular characterization of the bovine temporomandibular joint disc. Arch Oral Biol. 1996; 41:761. [PubMed: 9022913]
- Milam SB, Klebe RJ, Triplett RG, et al. Characterization of the extracellular matrix of the primate temporomandibular joint. J Oral Maxillofac Surg. 1991; 49:381. [PubMed: 1706426]
- Berkovitz BK, Pacy J. Age changes in the cells of the intra-articular disc of the temporomandibular joints of rats and marmosets. Arch Oral Biol. 2000; 45:987. [PubMed: 11000385]
- Berg R. Contribution to the applied and topographical anatomy of the temporomandibular joint of some domestic mammals with particular reference to the partial resp. total resection of the articular disc. Folia Morphol. 1973; 21:202.
- Bermejo A, Gonzalez O, Gonzalez JM. The pig as an animal model for experimentation on the temporomandibular articular complex. Oral Surg Oral Med Oral Pathol. 1993; 75:18. [PubMed: 8419867]
- Strom D, Holm S, Clemensson E, et al. Gross anatomy of the mandibular joint and masticatory muscles in the domestic pig (*Sus scrofa*). Arch Oral Biol. 1986; 31:763. [PubMed: 3479064]
- May B, Saha S. Animal models for TMJ studies: A review of the literature. TMJ Journal. 2000; 1:20.
- McCullagh, P.; Nelder, JA. Generalized Linear Models. Ed 2. Chapman and Hall; London: 1989.
- Mills DK, Fiandaca DJ, Scapino RP. Morphologic, microscopic, and immunohistochemical investigations into the function of the primate TMJ disc. J Orolfac Pain. 1994; 8:136. [PubMed: 7920350]
- Scapino RP, Canham PB, Finlay HM, et al. The behaviour of collagen fibres in stress relaxation and stress distribution in the jaw-joint disc of rabbits. Arch Oral Biol. 1996; 41:1039. [PubMed: 9068868]
- Kopp S. Topographical distribution of sulphated glycosamino-glycans in human temporomandibular joint disks. A histochemical study of an autopsy material. J Oral Pathol. 1976; 5:265. [PubMed: 62043]

21. Nakano T, Scott PG. Changes in the chemical composition of the bovine temporomandibular joint disc with age. *Arch Oral Biol.* 1996; 41:845. [PubMed: 9022922]
22. Beek M, Aarnts MP, Koolstra JH, et al. Dynamic properties of the human temporomandibular joint disc. *J Dent Res.* 2001; 80:876. [PubMed: 11379888]
23. Nickel JC, McLachlan KR. In vitro measurement of the stress-distribution properties of the pig temporomandibular joint disc. *Arch Oral Biol.* 1994; 39:439. [PubMed: 8060268]
24. Detamore MS, Orfanos JG, Almarza AJ, et al. Quantitative analysis and comparative regional investigation of the extracellular matrix of the porcine temporomandibular joint disc. *Matrix Biol.* 2005; 24:45. [PubMed: 15749001]
25. Kirk WS Jr. Morphologic differences between superior and inferior disc surfaces in chronic internal derangement of the temporomandibular joint. *J Oral Maxillofac Surg.* 1990; 48:455. [PubMed: 2329395]
26. Kondoh T, Westesson PL, Takahashi T, et al. Prevalence of morphological changes in the surfaces of the temporomandibular joint disc associated with internal derangement. *J Oral Maxillofac Surg.* 1998; 56:339. [PubMed: 9496846]
27. Yoshida H, Fujita S, Nishida M, et al. Localization of lymph capillaries and blood capillaries in human temporomandibular joint discs. *J Oral Rehabil.* 1999; 26:600. [PubMed: 10445480]
28. Detamore MS, Athanasiou KA. Tensile properties of the porcine temporomandibular joint disc. *J Biomech Eng.* 2003; 125:558. [PubMed: 12968581]
29. Poole CA, Flint MH, Beaumont BW. Chondrons in cartilage: Ultrastructural analysis of the pericellular microenvironment in adult human articular cartilages. *J Orthop Res.* 1987; 5:509. [PubMed: 3681525]
30. Wilkinson T, Chan EK. The anatomic relationship of the insertion of the superior lateral pterygoid muscle to the articular disc in the temporomandibular joint of human cadavers. *Aust Dent J.* 1989; 34:315. [PubMed: 2775018]
31. Carpentier P, Yung JP, Marguelles-Bonnet R, et al. Insertions of the lateral pterygoid muscle: An anatomic study of the human temporomandibular joint. *J Oral Maxillofac Surg.* 1988; 46:477. [PubMed: 3164053]
32. Piette E. Anatomy of the human temporomandibular joint. An updated comprehensive review. *Acta Stomatol Belg.* 1993; 90:103. [PubMed: 8237635]

FIGURE 1.

Representation of the regions investigated for determining cell type distribution and presence of muscle character. *A*, The TMJ disc was divided mediolaterally and anteroposteriorly into 3 regions each, creating 9 regions. *B*, From each of these 9 regions, sections were taken from 3 layers along the superoinferior axis to produce 27 total sections per disc.

FIGURE 2.

Graphic representation of cell type distribution in the TMJ disc (layers along the superoinferior axis pooled). The upper-right graph depicts the percentage of fibroblasts in each of the 9 regions of the TMJ disc, the balance being chondrocyte-like cells. The lower-right graph illustrates the total cell number per unit area in each region. Error bars represent standard errors, with 60 total observations from 2 discs for each region. Large differences can be seen along both axes for both percent fibroblasts and total cell number.

FIGURE 3.

Transmission electron micrographs comparing TMJ disc cells to a chondrocyte from ankle hyaline cartilage. *A*, Fibroblast from the TMJ disc, aligned in the direction of adjacent collagen fibrils [C]. There is a lack of an electron lucent pericellular matrix, although the presence of rough endoplasmic reticulum [R-ER] is evident. The cell membrane [CM] and nuclear membrane [NM] are identified. *B*, Chondrocyte-like cell from the TMJ disc. Note the abundance of mitochondria [MC] with relatively few other organelles, the large nucleus, a lack of pseudopodia, and lack of a discernible electron lucent pericellular matrix. *C*,

Hyaline chondrocyte, with an extensive organelle network, including rough endoplasmic reticulum [R-ER], smooth endoplasmic reticulum [S-ER], and a small portion of the Golgi apparatus [G]. Pseudopodia are clearly evident, extending out into a well-defined electron lucent pericellular matrix [PM], which is distinguished from the extracellular matrix [ECM].

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FIGURE 4.

Presence of vessel structures in the TMJ disc (magnification $\times 200$). *A,B*, Smooth muscle actin staining in the anterior band of the TMJ disc. *C*, Smooth muscle actin in porcine masseter tissue (positive control). *D*, TMJ disc, primary antibody absent (negative control).