Computed tomographic findings in dogs and cats with temporomandibular joint disorders: 58 cases (2006–2011)

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Objective—To describe CT findings in dogs and cats with temporomandibular joint (TMJ) disorders.

Design—Retrospective case series.

Animals—41 dogs and 17 cats.

Procedures—Medical records and CT images of the skull were reviewed for dogs and cats that were examined at a dentistry and oral surgery specialty practice between 2006 and 2011.

Results—Of 142 dogs and 42 cats evaluated, 41 dogs and 17 cats had CT findings consistent with a TMJ disorder. In dogs, the most common TMJ disorder was osteoarthritis; however, in most cases, there were other TMJ disorders present in addition to osteoarthritis. Osteoarthritis was more frequently identified at the medial aspect rather than the lateral aspect of the TMJ, whereas the frequency of osteoarthritic involvement of the dorsal and ventral compartments did not differ significantly. In cats, fractures were the most common TMJ disorder, followed by osteoarthritis. Clinical signs were observed in all dogs and cats with TMJ fractures, dysplasia, ankylosis, luxation, and tumors; however, only 4 of 15 dogs and 2 of 4 cats with osteoarthritis alone had clinical signs.

Conclusions and Clinical Relevance—Results indicated that TMJ disorders were frequently present in combination. Osteoarthritis was the most common TMJ disorder in dogs and the second most common TMJ disorder in cats. Computed tomography should be considered as a tool for the diagnosis of TMJ disorders in dogs and cats with suspected orofacial disorders and signs of pain. (*J Am Vet Med Assoc* 2013;242:69–75)

The TMJ is a synovial joint in which the condylar process of the mandible articulates with the mandibular fossa on the squamous portion of the temporal bone, and both the condylar process of the mandible and the mandibular fossa of the temporal bone are covered with a unique fibrocartilaginous layer.[1,2] A fibrocartilaginous articular disk separates the TMJ cavity into dorsal and ventral compartments.[2] The disk extends medially from the articular surface of the condylar process of the mandible to the temporal bone via a ligamentous extension; thus, the disk fills the void between the condylar process and the mandibular fossa, which promotes the congruity of the joint.[1,3] The TMJ joint capsule attaches to the articular disk circumferentially, and the lateral aspect of the joint capsule is additionally strengthened by a lateral ligament.[2] Relative to the cranium, the mandibular fossa remains stationary; it is only the mandible that moves via the TMJ joint.[1] The TMJ is primarily responsible for the hinge movement necessary for opening and closing the mouth, although in dogs, it also allows for a slight laterotrusion movement.[4] In cats, the morphology of the TMJ is more restrictive such that independent movement of the mandible aside from hinge movement is minimal.[4,5]

Abbreviation

TMJ	Temporomandibular joint

Studies of TMJ disorders in dogs and cats are lacking and have been limited to those involving fractures resulting from trauma, dysplasia, and ankylosis.[6–11] Temporomandibular joint disorders are often debilitating and frequently require medical or surgical treatment. In humans with TMJ disorders, the most common pathological change is degenerative joint disease, also known as osteoarthritis or osteoarthrosis, which is generally caused by displacement of the articular disk or some other intra-articular derangement.[12] For patients with advanced degenerative TMJ disease, osteoarthritis can become crippling and result in a variety of morphological and functional abnormalities.[12,13]

For human patients, MRI is currently the standard-of-care diagnostic method for evaluation of the soft tissue and osseous components of TMJ disease.[14] In

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veterinary patients, the role of the soft tissues in the TMJ (ie, the articular disk and its attachments) in the development of TMJ disorders is unknown, and CT remains an important diagnostic tool for the evaluation of the TMJ. Computed tomography is valuable for evaluation of osseous lesions as well as the spatial position of the TMJ bones,[15] and CT images with 3-D reconstruction may improve understanding of the pathogenesis of TMJ lesions for selected patients.[6] Moreover, results of 1 study[16] suggest that CT is superior to conventional radiography of the skull for identification of anatomic structures and lesions in the maxillofacial regions of dogs and cats. The aim of the study reported here was to describe CT findings, including incidental findings, associated with the TMJ in a case series of dogs and cats.

Materials and Methods

Case selection—Medical records and CT images of the skull were reviewed for dogs and cats that were examined by the Dentistry and Oral Surgery Service at the University of California-Davis William R. Pritchard Veterinary Medical Teaching Hospital between January 2006 and December 2011. The patients were evaluated because of oral masses, trauma, signs of pain, and difficulty opening or closing the mouth, among other reasons, or for preoperative evaluation prior to an oral surgical procedure. Patients were included in the study if they had CT findings consistent with any type of TMJ disorder.

Medical records review—For each patient enrolled in the study, information obtained from the medical record included age, sex, breed, skull configuration (eg, brachycephalic, mesaticephalic, or dolichocephalic), body weight, history, and clinical signs. Computed tomographic images were reviewed and scored.

CT procedure and review—Each patient was anesthetized, and 1 of 2 CT scanners[a,b] was used to obtain high-quality contiguous transverse collimated images of the skull. For dogs, the transverse collimated images were obtained at a thickness of ≤ 1.25 mm (n = 22 dogs), 2 to 3 mm (16 dogs), or 5 mm (3 large-breed dogs). For cats, the transverse collimated images were obtained at a thickness of ≤ 1 mm (n = 12 cats), 2 mm (4 cats), or 3 mm (1 cat). Evaluation of osseous structures was performed with a window width of 2,500 Hounsfield units and window level of 480 Hounsfield units, and evaluation of soft tissue structures was performed with a window width of 750 Hounsfield units and window level of 200 Hounsfield units. All digital CT images were evaluated on a medical-grade flat-screen monitor with com-

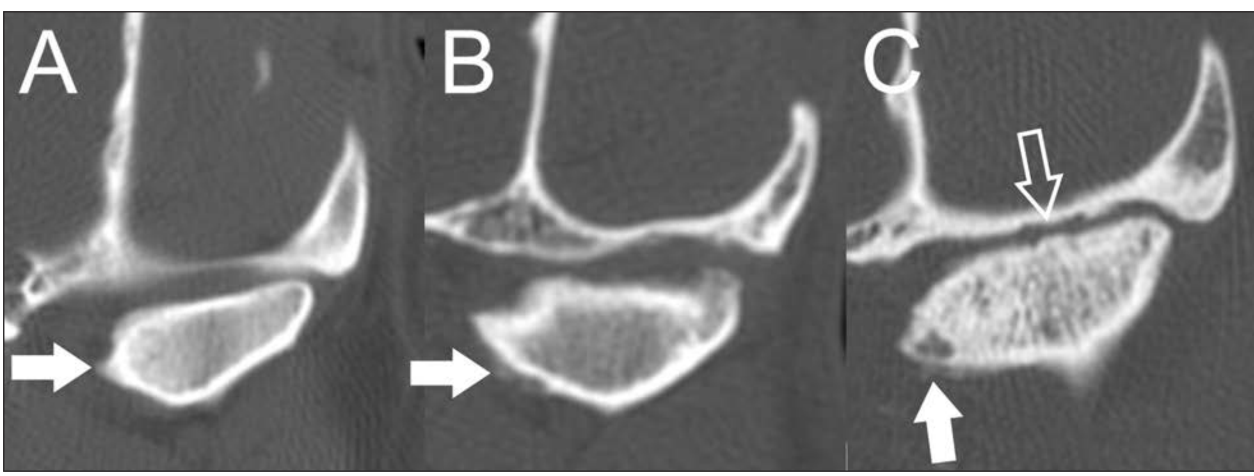

Figure 1—Computed tomographic images of the TMJs of 3 dogs with mild (semiquantitative score, 1; A), moderate (semiquantitative score, 2; B), or marked (semiquantitative score, 3; C) osteoarthritis. Notice the periarticular new bone formation at the medial aspect of the condylar process of the mandible (solid white arrows) in all 3 panels. Additionally, in panel B, notice the narrowing of the medial portion of the TMJ space, and in panel C, notice the biaxial, symmetric narrowing of the TMJ space, lysis of the subchondral bone of the mandibular fossa of the temporal bone (open arrow), and diffuse sclerosis of the condylar process of the mandible.

Table 1—Frequency distribution of TMJ disorders identified on CT images for 41 dogs evaluated at a dentistry and oral surgery specialty practice between 2006 and 2011.

Disorder	Osteoarthritis	Fracture	Dysplasia	Ankylosis	Luxation	Tumor or cyst	MMM
Osteoarthritis	15	1	7	4	3	2	2
Fracture	1	7	0	2	3	0	0
Dysplasia	7	0	0	0	1	0	0
Ankylosis	4	2	0	0	1	0	0
Luxation	3	3	1	1	0	0	0
Tumor or cyst	2	0	0	0	0	1	0
MMM	2	0	0	0	0	0	0

MMM = Masticatory muscle myositis.

Dogs with > 2 concurrent TMJ disorders are represented multiple times within a column or row (eg, a dog that had osteoarthritis, fracture, and luxation would be represented in the osteoarthritis and fracture categories as well as the osteoarthritis and luxation categories).

mercially available software[c] and scored by 2 investigators (BA and DDC), one of whom was a board-certified veterinary radiologist (DDC) who was unaware of the patient's diagnosis. When necessary, 3-D reconstructive images were generated to assess the spatial relationship of the bones of the TMJ (eg, to diagnose luxations or subluxations). For each patient, the right and left TMJ were evaluated independently. Images were evaluated for the presence and location of fractures, joint space narrowing, ankylosis, periarticular new bone formation, and subchondral bone sclerosis or lysis. The severity of osteoarthritis in each TMJ was scored by the use of a 4-point semiquantitative system as follows: 0 = no osteoarthritis detected, 1 = mild (early signs of periarticular new bone formation with minimal or no joint space narrowing or subchondral bone change), 2 = moderate (moderate periarticular new bone formation, joint space narrowing, or subchondral bone sclerosis), or 3 = marked (severe periarticular new bone formation, joint space narrowing, or subchondral bone sclerosis or lysis; **Figure 1**).[17]

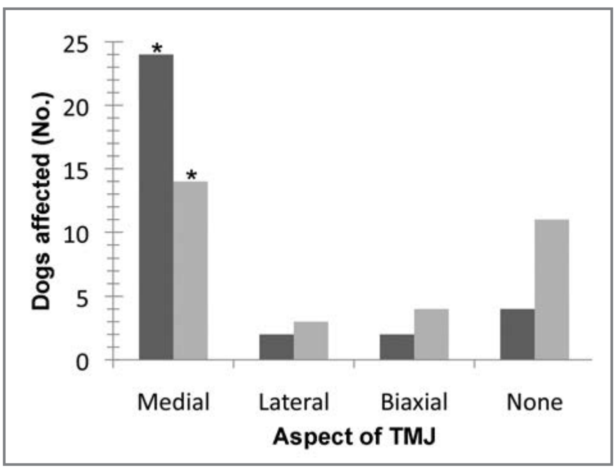

Figure 2—Location of osteophytes in the right (dark gray) and left (light gray) TMJs of 41 dogs with TMJ disorders as determined via evaluation of CT images. All dogs are represented twice (once for the right TMJ and once for the left TMJ). *Within a TMJ (ie, right or left), value differs significantly ($P < 0.001$) from that for lateral and biaxial aspects of the TMJ.

Statistical analysis—Computer software[d] was used to perform all statistical analyses. A χ^2 test for independence was used to evaluate the distribution of TMJ fracture locations and the respective associations between osteoarthritis and each of the following: age, sex, skull conformation, and body weight. A χ^2 goodness-of-fit test was used to evaluate the distributions of osteophytosis and narrowing of the TMJ space. Binomial 95% confidence intervals were calculated for the presence of signs of pain and osteoarthritis only. For all analyses, values of $P < 0.05$ were considered significant.

Results

Between January 2006 and December 2011, 142 dogs and 42 cats underwent a CT examination of the skull, of which 43 (30%) dogs and 18 (43%) cats had CT findings consistent with TMJ disorders. However, 2 dogs and 1 cat with TMJ disorders were excluded from the analyses because the CT image quality was insufficient to evaluate all of the TMJ abnormalities examined in the study; thus, data from only 41 dogs and 17 cats are presented.

Dogs—The distribution of TMJ disorders in dogs was summarized (**Table 1**). Of the 41 dogs with TMJ disorders, 32 had osteoarthritis, 11 had fracture, 7 had dysplasia, 4 had ankylosis, 4 had luxation, 2 had a tumor, 1 had a cyst, and 2 had masticatory muscle myositis; some dogs had ≥ 2 TMJ disorders. Twenty-six of 32 (81.3%) dogs had evidence of osteoarthritis in both TMJs, whereas 6 dogs had evidence of osteoarthritis in only 1 TMJ. Osteoarthritis was observed as the only TMJ abnormality in 15 of the 41 (36.6%) dogs; the other 17 dogs with osteoarthritis also had at least 1 additional TMJ disorder. For dogs with osteoarthritis of the TMJ, osteophytes were more frequently detected at the medial aspect of the joint rather than at the lateral aspect of the joint or biaxially ($P < 0.001$; **Figure 2**). Most dogs with osteoarthritis of the TMJ had narrowing of the joint space biaxially, but for those dogs without biaxial narrowing of the joint space, the joint space was more frequently narrowed at the medial rather than at the lateral aspect of the joint ($P < 0.001$; **Figures 3 and 4**). Age, sex, and body weight were not associated with the presence

Figure 3—Computed tomographic images of the TMJs of 3 dogs with concurrent osteoarthritis and narrowing of the medial (A), lateral (B), or biaxial (C) aspects of the TMJ. For all panels, medial is to the left.

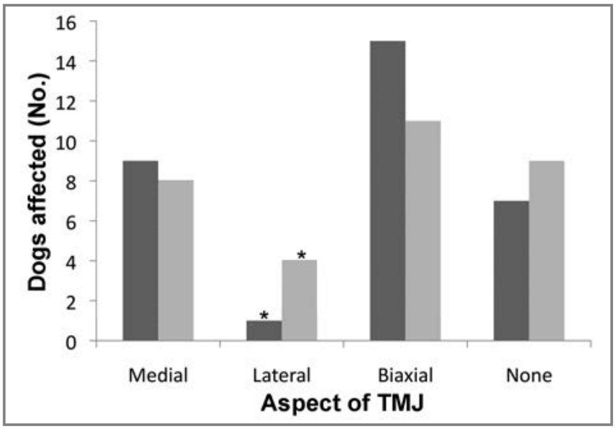

Figure 4—Location of joint space narrowing in the right (dark gray) and left (light gray) TMJs of 41 dogs with TMJ disorders as determined via evaluation of CT images. All dogs are represented twice (once for the right TMJ and once for the left TMJ). *Excluding biaxial TMJ narrowing, within a TMJ (ie, right or left), value differs significantly ($P < 0.001$) from that for the medial aspect of the TMJ.

or severity of osteoarthritis in affected dogs. Osteoarthritis of the TMJ was more frequently detected in dogs with a mesaticephalic skull conformation than in dogs with either a brachycephalic or dolichocephalic skull conformation ($P < 0.001$). Of the 15 dogs in which the only TMJ disorder detected was osteoarthritis, only 4 had clinical signs of pain during opening and closing of the mouth (n = 2) or decreased range of motion (2) in the joint. During physical and oral examinations, all 7 dogs with concurrent TMJ osteoarthritis and dysplasia had decreased range of motion in the joint and signs of pain during opening and closing of the mouth. Subchondral sclerosis of the temporal bone and the condylar process of the mandible was detected with similar frequency in both the left and right TMJs; however, subchondral sclerosis of both bones was more frequently detected in the right TMJ ($P < 0.05$; **Figure 5**). One dog had a multilobular tumor of the bone and 1 dog had an osteosarcoma. Another dog had a well-defined, non–contrast-enhancing, fluid-filled structure at the medial aspect of the joint, which was presumed to be

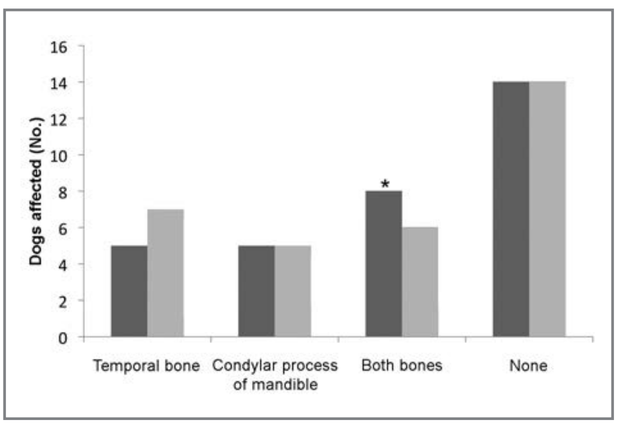

Figure 5—Location of subchondral bone sclerosis in the right (dark gray) and left (light gray) TMJs of 41 dogs with TMJ disorders as determined via evaluation of CT images. All dogs are represented twice (once for the right TMJ and once for the left TMJ). *Between TMJs (ie, right or left), value differs significantly ($P < 0.05$).

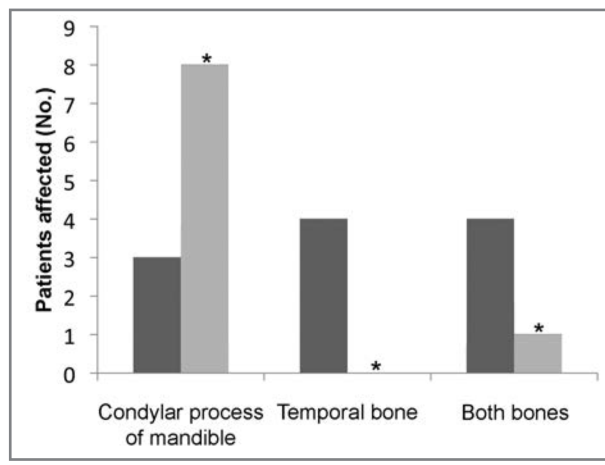

Figure 7—Location of fractures in the bones of the TMJs of dogs (n = 11; dark gray) and cats (9; light gray). *Within a location, value differs significantly ($P < 0.05$) from that for dogs.

Figure 6—Computed tomographic images of the TMJs of 3 dogs with a comminuted fracture of the condylar process of the mandible (A), simple fracture of the mandibular fossa of the temporal bone (B), or comminuted fracture of the mandibular fossa of the temporal bone and a simple displaced fracture of the medial aspect of the condylar process of the mandible (C). For all panels, medial is to the left.

Table 2—Frequency distribution of TMJ disorders identified on CT images for 17 cats evaluated at a dentistry and oral surgery specialty practice between 2006 and 2011.

Disorder	Fracture	Osteoarthritis	Luxation	Ankylosis	Tumor
Fracture	5	2	2	0	0
Osteoarthritis	2	4	2	1	0
Luxation	2	1	1	1	0
Ankylosis	0	2	1	0	0
Tumor	0	0	0	0	1

Cats with > 2 concurrent TMJ disorders are represented multiple times within a column or row (eg, a cat that had fracture, osteoarthritis, and luxation would be represented in the fracture and osteoarthritis categories as well as the fracture and luxation categories).

a synovial cyst. Of those 3 dogs, the cyst appeared to be an incidental finding because only the 2 dogs with a TMJ tumor had clinical signs of pain and discomfort. The 2 dogs with masticatory muscle myositis had concurrent osteoarthritis. Of the 11 dogs with TMJ fractures, the frequency with which the mandibular fossa of the temporal bone (n = 4), condylar process of the mandible (3), or both bones (4) were fractured was similar **(Figures 6 and 7)**.

Cats—The distribution of TMJ disorders in cats was summarized **(Table 2)**. Of the 17 cats with TMJ disorders, 9 had fracture, 8 had osteoarthritis, 4 had luxation, 2 had ankylosis, and 1 had a tumor; some cats had ≥ 2 concurrent TMJ disorders. The condylar process of the mandible was fractured in all 9 cats that had a TMJ fracture, and 1 of those cats also had a concurrent fracture of the temporal bone. All cats with a TMJ fracture had signs of pain while resting and additional fractures of bones in the maxillofacial region and soft tissue trauma. The distribution of TMJ fractures differed significantly ($P < 0.024$) between dogs and cats. All 8 cats with osteoarthritis of the TMJ were affected bilaterally, and osteoarthritis was the only TMJ disorder detected in 4 cats. Age, sex, and body weight were not associated with the presence or severity of osteoarthritis in affected cats. Osteoarthritis of the TMJ was more frequently detected in cats with a mesaticephalic skull conformation than in cats with either a brachycephalic or dolichocephalic skull conformation ($P < 0.001$). Of the 4 cats in which the only TMJ disorder detected was osteoarthritis, only 2 had decreased range of motion in the joint.

Discussion

To our knowledge, the present study was the first to describe several cardinal features of TMJ disorders in dogs and cats. Temporomandibular joint disorders were generally detected in combination. Osteoarthritis was the most common TMJ disorder in dogs and the second most common TMJ disorder in cats. Disorders more commonly affected the medial rather than the lateral aspect of the TMJ. Finally, the distribution of bones involved in TMJ fractures differed significantly between dogs and cats.

The finding that dogs and cats with TMJ disorders generally have multiple joint abnormalities was intriguing. Many studies[6,8–11] involving TMJ disorders in dogs and cats have been individual case reports or focused only on the clinical signs of affected patients. In the present study, we retrospectively evaluated CT images obtained from all patients that underwent CT evaluation of the skull during the study period, which allowed us to identify TMJ abnormalities even in patients that did not have clinical signs of disease.

Investigators of human and animal studies[16,18] concluded that advanced imaging such as MRI and CT was critical for the assessment of the underlying etiology and pathological mechanisms of TMJ disorders. Furthermore, during evaluation of a TMJ disorder, an attempt should be made to identify all of the components of the disease rather than focusing only on the obvious abnormality. For example, patients with or without clinical signs of TMJ disorders such as subluxation or dysplasia that subsequently develop osteoarthritis of the TMJ may have an unfavorable long-term prognosis.[12,19,20]

Osteoarthritis of the TMJ is an arthritic condition characterized by minimal inflammation that is either primary or secondary to trauma, abnormal morphology, or other acute or chronic overload situations.[12,21] The pathogenesis of osteoarthritis of the TMJ is characterized by erosion, deterioration, and abrasion of the articular fibrocartilage as well as localized thickening and remodeling of the subchondral bone and development of marginal osteophytes.[12,13,22]

We were surprised to find that osteoarthritis was the most common TMJ disorder in dogs because osteoarthritis of the TMJ of dogs has been reported by investigators of only 1 other study.[15] The prevalence of osteoarthritis in the TMJ of dogs in the present study was similar to that for human patients.[23] Moreover, CT findings for human patients with osteoarthritis of the TMJ suggest that affected patients have a high rate of bony changes (condylar process involvement, 61%; temporal bone involvement, 47%),[23] although the etiology of osteoarthritis in human patients likely differs from that in dogs because osteoarthritis of the TMJ in human patients is commonly associated with TMJ disk displacement (ie, internal derangement).[12,24] Also, in human patients, osteoarthritis of the TMJ develops more frequently in women,[12,22] whereas in the present study, we did not find an association between sex and the presence of osteoarthritis in the TMJ. In a study[25] in which human autopsy results were reviewed, macroscopic or microscopic evidence of osteoarthritis or articular remodeling was detected in the TMJ of 57 of 102 (56%) middle-aged and older individuals.

In the present study, no association was found between the presence and severity of osteoarthritis of the TMJ and age or body weight. This finding is contrary to the development of osteoarthritis in appendicular joints, in which both age and body weight are associated with the incidence and severity of osteoarthritis.[17,26,27] The reason for the contrary findings for the effect of age and body weight on the development of osteoarthritis in TMJs versus appendicular joints is unknown, but we suspect that it may be related to the difference in load-bearing forces sustained by the TMJs, compared with those sustained by the appendicular joints.

Results of the present study indicate that periarticular new bone formation and narrowing of the joint space develop more frequently at the medial rather than the lateral aspect of the TMJ of dogs. In humans, the TMJ is considered to be load bearing during masticatory function[12]; therefore, our findings suggest that, in dogs, the medial aspect of the TMJ is subjected to increased load bearing or mechanical stress. These findings contradict the assumption that the obliquity of the TMJ results in excessive movement at the lateral aspect of the condylar process of the mandible.[2,28] In fact, it is possible that the lateral ligament that reinforces the lateral aspect of the TMJ in dogs protects the joint from excessive loading and movement. Alternatively, osteoarthritis of the TMJ of dogs may be caused by articular disk displacement similar to the disease process in human patients, in which the articular disk is typically displaced anteriolaterally.[29,30] If the articular disk of the TMJ is displaced similarly in dogs, it may predispose the medial aspect of the joint to osseous remodeling via altered mechanical forces.

Excessive or sustained physical stress that exceeds the normal adaptive capacity of the articular structures of the TMJ may result in initiation and progression of osteoarthritis in the joint.[12,22,31,32] Similarly, parafunctional hyperactivity of masticatory muscles due to masticatory muscle myositis may result in altered mechanical forces in the TMJ and cause degenerative changes.[33] In the present study, both dogs with masticatory muscle myositis also had concurrent osteoarthritis of the TMJ.

Patients with TMJ disorders commonly have signs of pain and decreased function (ie, decreased range of motion) of the joint.[12] It is likely that the signs of pain develop because the soft tissues around the affected joint and the masticatory muscles undergo a protective reflex spasm in accordance with Hilton's law,[34] which states that the nerves that innervate a joint also innervate the muscles that move that joint. Thus, contraction of the surrounding muscles in response to injury or disease of the TMJ may protect the joint from further damage.[12] Signs of pain may also develop as the result of the arthritic destruction of the subchondral bone of the TMJ.[12] In the present study, only 4 of 15 dogs and 2 of 4 cats in which the only TMJ disorder detected was osteoarthritis had clinical signs of pain. Those findings were similar to findings in human patients, in which arthritic changes were detected in the TMJ of 12 of 34 (35%) patients who had no clinical signs[35] and in 19 of 30 (63%) and 24 of 32 (75%) patients with juvenile idiopathic arthritis, most of whom had no clinical signs at the time of evaluation.[36–38]

Temporomandibular joint fractures and luxations generally result from trauma[4,16,39] and are often detected concurrently with other maxillofacial injuries, especially in cats.[4,16] In the present study, TMJ fractures were the most common TMJ disorder detected in cats and the second most common TMJ disorder detected in dogs. The condylar process of the mandible was fractured in all the study cats with TMJ fractures, whereas in the study dogs with TMJ fractures, the condylar process of the mandible and the temporal bone were affected with similar frequency. It is possible that the difference in the configuration of the skull of cats, compared with the configuration of the skull of dogs, caused the difference in the distribution of TMJ fracture locations between cats and dogs. In human patients, fracture of the condylar process of the mandible can cause a displacement of the articular disk, which removes the physical impediment to transarticular bony fusion and may result in TMJ ankylosis.[40–42] Also, the position of the articular disk in the TMJ was significantly associated with the position of the fractured bone fragments.[40] However, despite the association of articular disk displacement with fractures of the TMJ, post-traumatic TMJ ankylosis is rare in human patients, with an annual incidence rate of approximately 0.4%.[41] Post-traumatic ankylosis of the TMJ was similarly rare in the cats and dogs of the present study; none of the cats and only 2 dogs with TMJ fractures had concurrent ankylosis. The role of displacement of the articular disk following fracture of a bone of the TMJ in cats and dogs remains to be elucidated.

High-quality CT images are essential for accurate diagnosis of TMJ disorders. In the present study, we included 3 dogs in which the TMJ was evaluated via transverse collimated CT images with a slice thickness of 5 mm; however, all 3 dogs were large-breed dogs and the CT images were of sufficient quality that all of the various TMJ characteristics described in the study could be evaluated. For dogs or cats with suspected TMJ disorders, it is recommended that evaluation of the TMJ should be performed with collimated transverse CT images at a slice thickness of ≤ 1 mm whenever possible. Furthermore, it is critical to carefully position the patient's skull within the CT gantry to achieve near-perfect symmetry between the right and left sides of the skull. Evaluation of thicker collimated transverse CT images or failure to position the skull appropriately within the CT gantry will make diagnosis of TMJ disorders more difficult because of the potential introduction of artifacts associated with slice thickness and asymmetry on the images.

High-definition CT imaging of the TMJ is an essential part of a diagnostic workup for dogs and cats with trauma to the skull, malocclusion of the jaws, decreased range of motion of the TMJ, or signs of jaw pain during rest or during opening or closing of the mouth.[15] In patients with suspected TMJ disorders, the TMJ should be comprehensively evaluated before treatment because TMJ disorders are characterized by intra-articular positional or structural abnormalities and often involve multiple disease process. Also, on the basis of the results of the present study, osteoarthritis of the TMJ was common alone and in combination with other TMJ disorders and should be included as a differential diagnosis during evaluation of all patients with suspected TMJ disorders. Further research is necessary to determine the role that the soft tissues of the TMJ have in the development of TMJ degenerative changes.

a. HiSpeed Fx/I, GE Healthcare, Little Chalfont, Buckinghamshire, England.
b. LightSpeed 16, GE Healthcare, Milwaukee, Wis.
c. eFilm Workstation 2.1.0, eFilm Medical Inc, Toronto, ON, Canada.
d. StatXact, version 8, Cytel Software Corp, Cambridge, Mass.

References

1. Athanasiou KA, Almarza AA, Datamore MS, et al. The temporomandibular joint. In: Athanasiou KA, Almarza AA, Datamore MS, et al, eds. *Tissue engineering of temporomandibular joint cartilage*. San Rafael, Calif: Morgan and Claypool, 2009;1–25.
2. Lantz GC. Temporomandibular joint dysplasia. In: Verstraete

FJM, Lommer MJ, eds. *Oral and maxillofacial surgery in dogs and cats*. Edinburgh: Saunders, 2012;531–538.

3. Gillbe GV. The function of the disc of the temporomandibular joint. *J Prosthet Dent* 1975;33:196–204.
4. Lantz GC, Verstraete FJM. Fractures and luxations involving the temporomandibular joint. In: Verstraete FJM, Lommer MJ, eds. *Oral and maxillofacial surgery in dogs and cats*. Edinburgh: Saunders, 2012;321–332.
5. Caporn TM. Traumatic temporomandibular joint luxation. *Vet Comp Orthop Traumatol* 1995;8:63–65.
6. Beam RC, Kunz DA, Cook CR, et al. Use of three-dimensional computed tomography for diagnosis and treatment planning for open-mouth jaw locking in a cat. *J Am Vet Med Assoc* 2007;230:59–63.
7. Dickie AM, Schwarz T, Sullivan M. Temporomandibular joint morphology in Cavalier King Charles Spaniels. *Vet Radiol Ultrasound* 2002;43:260–266.
8. Gatineau M, El-Warrak AO, Marretta SM, et al. Locked jaw syndrome in dogs and cats: 37 cases (1998–2005). *J Vet Dent* 2008;25:16–22.
9. Maas CP, Theyse LF. Temporomandibular joint ankylosis in cats and dogs. A report of 10 cases. *Vet Comp Orthop Traumatol* 2007;20:192–197.
10. Meomartino L, Fatone G, Brunetti A, et al. Temporomandibular ankylosis in the cat: a review of seven cases. *J Small Anim Pract* 1999;40:7–10.
11. Roza MR, Silva LA, Januario AL, et al. Cone beam computed tomography in the diagnosis of temporomandibular joint alterations in cats. *J Feline Med Surg* 2011;13:393–398.
12. Tanaka E, Detamore MS, Mercuri LG. Degenerative disorders of the temporomandibular joint: etiology, diagnosis, and treatment. *J Dent Res* 2008;87:296–307.
13. Zarb GA, Carlsson GE. Temporomandibular disorders: osteoarthritis. *J Orofac Pain* 1999;13:295–306.
14. Boeddinghaus R, Whyte A. Current concepts in maxillofacial imaging. *Eur J Radiol* 2008;66:396–418.
15. Schwarz T, Weller R, Dickie AM, et al. Imaging of the canine and feline temporomandibular joint: a review. *Vet Radiol Ultrasound* 2002;43:85–97.
16. Bar-Am Y, Pollard RE, Kass PH, et al. The diagnostic yield of conventional radiographs and computed tomography in dogs and cats with maxillofacial trauma. *Vet Surg* 2008;37:294–299.
17. Arzi B, Wisner ER, Huey DJ, et al. A proposed model of naturally occurring osteoarthritis in the domestic rabbit. *Lab Anim (N Y)* 2012;41:20–25.
18. Bertram S, Moriggl A, Rudisch A, et al. Structural characteristics of bilateral temporomandibular joint disc displacement without reduction and osteoarthrosis are important determinants of horizontal mandibular and vertical ramus deficiency: a magnetic resonance imaging study. *J Oral Maxillofac Surg* 2011;69:1898–1904.
19. Hayes GM, Ramirez J, Langley Hobbs SJ. Does the degree of preoperative subluxation or soft tissue tension affect the incidence of postoperative luxation in dogs after total hip replacement? *Vet Surg* 2011;40:6–13.
20. Wolford LM, Cottrell DA, Henry CH. Temporomandibular joint reconstruction of the complex patient with the Techmedica custom-made total joint prosthesis. *J Oral Maxillofac Surg* 1994;52:2–10.
21. Kristensen KD, Hauge EM, Dalstra M, et al. Association between condylar morphology and changes in bony microstructure and sub-synovial inflammation in experimental temporomandibular joint arthritis. *J Oral Pathol Med* 2011;40:111–120.
22. Machon V, Hirjak D, Lukas J. Therapy of the osteoarthritis of the temporomandibular joint. *J Craniomaxillofac Surg* 2011;39:127–130.
23. Callender KI, Brooks SL. Usefulness of tomography in the evaluation of patients with temporomandibular disorders: a retrospective clinical study. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 1996;81:710–719.
24. Córtes D, Exss E, Marholz C, et al. Association between disk position and degenerative bone changes of the temporomandibular joints: an imaging study in subjects with TMD. *Cranio* 2011;29:117–126.
25. Oberg T, Carlsson GE, Fajers CM. The temporomandibular joint. A morphologic study on a human autopsy material. *Acta Odontol Scand* 1971;29:349–384.
26. Bendele AM, Hulman JF. Effects of body weight restriction on the development and progression of spontaneous osteoarthritis in guinea pigs. *Arthritis Rheum* 1991;34:1180–1184.
27. Hunter DJ, Felson DT. Osteoarthritis. *BMJ* 2006;332:639–642.
28. Robins G, Grandage J. Temporomandibular joint dysplasia and open-mouth jaw locking in the dog. *J Am Vet Med Assoc* 1977;171:1072–1076.
29. Larheim TA, Westesson P, Sano T. Temporomandibular joint disk displacement: comparison in asymptomatic volunteers and patients. *Radiology* 2001;218:428–432.
30. Tasaki MM, Westesson PL, Isberg AM, et al. Classification and prevalence of temporomandibular joint disk displacement in patients and symptom-free volunteers. *Am J Orthod Dentofacial Orthop* 1996;109:249–262.
31. Arnett GW, Milam SB, Gottesman L. Progressive mandibular retrusion—idiopathic condylar resorption. Part I. *Am J Orthod Dentofacial Orthop* 1996;110:8–15.
32. Smartt JM Jr, Low DW, Bartlett SP. The pediatric mandible: I. A primer on growth and development. *Plast Reconstr Surg* 2005;116:14e–23e.
33. Milam SB, Zardeneta G, Schmitz JP. Oxidative stress and degenerative temporomandibular joint disease: a proposed hypothesis. *J Oral Maxillofac Surg* 1998;56:214–223.
34. Hilton J. The classic: on rest and pain: lecture XIV. *Clin Orthop Relat Res* 2009;467:2208–2214.
35. Brooks SL, Westesson PL, Eriksson L, et al. Prevalence of osseous changes in the temporomandibular joint of asymptomatic persons without internal derangement. *Oral Surg Oral Med Oral Pathol* 1992;73:118–122.
36. Muller L, Kellenberger CJ, Cannizzaro E, et al. Early diagnosis of temporomandibular joint involvement in juvenile idiopathic arthritis: a pilot study comparing clinical examination and ultrasound to magnetic resonance imaging. *Rheumatology (Oxford)* 2009;48:680–685.
37. Stoll ML, Good J, Sharpe T, et al. Intra-articular corticosteroid injections to the temporomandibular joints are safe and appear to be effective therapy in children with juvenile idiopathic arthritis. *J Oral Maxillofac Surg* 2012;70:1802–1807.
38. Weiss PF, Arabshahi B, Johnson A, et al. High prevalence of temporomandibular joint arthritis at disease onset in children with juvenile idiopathic arthritis, as detected by magnetic resonance imaging but not by ultrasound. *Arthritis Rheum* 2008;58:1189–1196.
39. Umphlet RC, Johnson AL. Mandibular fractures in the dog. A retrospective study of 157 cases. *Vet Surg* 1990;19:272–275.
40. Duan DH, Zhang Y. A clinical investigation on disc displacement in sagittal fracture of the mandibular condyle and its association with TMJ ankylosis development. *Int J Oral Maxillofac Surg* 2011;40:134–138.
41. Laskin DM. Role of the meniscus in the etiology of posttraumatic temporomandibular joint ankylosis. *Int J Oral Surg* 1978;7:340–345.
42. Long X, Li X, Cheng Y, et al. Preservation of disc for treatment of traumatic temporomandibular joint ankylosis. *J Oral Maxillofac Surg* 2005;63:897–902.