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Anatomical, Radiographical and Magnetic Resonance Imaging features of normal Temporomandibular Joint (TMJ) in camels (*Camelus dromedarius*): A special reference to TMJ surgical approach

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Abstract

Temporomandibular joint (TMJ) is a true synovial articulation between the zygomatic process of the temporal bone and the condylar process of the mandible. Limited scientific literature has demonstrated the morphological characteristics of normal TMJ in dromedary camels using different imaging modalities. To the authors' knowledge, no previous study has reported a surgical procedure to approach the TMJ of camels until recently. The purpose of the current study was to investigate the morphological features of normal TMJ in adult dromedary camels. Furthermore, to illustrate, for the first time, a surgical approach to the camel TMJ. The morphological investigation of the TMJ was performed on eight healthy mature dromedary camel cadaver heads by use of sagittal and transverse gross anatomical sections, latero-lateral TMJ radiograph and sagittal and sagittal spiral magnetic resonance images (MRI). An additional camel head was utilized to illustrate the surgical approach to the TMJ. The gross anatomical features of normal camel TMJ correlated with the corresponding structures identified on radiography and MRI. A caudodorsal lateral surgical approach to the camel TMJ has been found to be an easy, applicable surgical procedure that could be beneficial for future treatment of some diseases affecting TMJ in camels.

Keywords: Anatomical, Radiographical, MRI, Surgical Approach, Camel TMJ

Introduction

Mammalian temporomandibular joint (TMJ) is considered a true synovial articulation between the zygomatic process of the temporal bone and the condylar process of the mandible (Herring *et al*., 2002; Patil and Bindra, 2012). The main components of the TMJ include the articular surface of the condylar process, the two non communicating dorsal and ventral synovial pouches, the fibrocartilaginous articular disc, the rostral and caudal TMJ ligaments and joint capsule (Herring *et al*., 2002; Nickel *et al*., 2004). A great deal of interest has been focused on characterization of the TMJ of horses and dogs anatomically, as well as by use of different imaging modalities, such as radiography, computed tomography (CT) and magnetic resonance imaging (MRI) (Piermattei and Johnson, 2004; Auer and Stick, 2006; Rodriguez *et al*., 2008; Rodriguez *et al*., 2010). However, to the author's knowledge, limited publications have previously investigated the normal TMJ in camels anatomically along with using different imaging modalities (Arencibia *et al*., 2012; Alsafy *et al*., 2014). Nevertheless, the TMJ of the dromedary camel remains poorly understood, and further investigation is therefore warranted. Furthermore, no previous study has been performed in an attempt to demonstrate an applicable surgical approach to the TMJ of camels until recently. These were the impetus of the study reported here. Therefore, the objective of the present study is to comprehensively investigate the most characteristic features associated with normal TMJ of dromedary camels using gross anatomy, radiography and MRI. We also aim to illustrate, for the first time, a surgical procedure to approach the camel TMJ in an attempt to facilitate the development of future surgical interventions that can be used to manage the possible affections associated with this joint. We hypothesized that normal gross anatomical features of camel TMJ would correlate with the corresponding radiographic and MRI findings, as well as with the surgical approach reported in the present study.

Materials and Methods

Animals: The current study was conducted on eight healthy, mature dromedary camel cadaver heads from both sexes. The camel heads were obtained from a slaughterhouse located in Cairo, and transferred to the Faculty of veterinary Medicine, Cairo University, Egypt. All heads were sectioned at the level of atlantoaxial joints and imaged within 24 hours to minimize the possible postmortem changes, and then frozen at −20 °C. All enrolled heads had no skin lesions or any other apparent abnormalities that could influence the results of the study reported here. Six camel heads were dissected and transected (sagittally and transversely) for gross anatomical demonstration of the temporomandibular joints (TMJs) and associated soft tissue structures (i.e. ligaments, joint capsule, and muscles). Two fresh camel heads were obtained for radiographic and magnetic resonance imaging (MRI) of the TMJ and associated structures. One of these two heads was utilized for skull preparation using the boiling maceration technique previously described by Simoens *et al*. (1994). The other fresh head was utilized for MRI examination, in which sagittal and sagittal spiral images were acquired to be compared with the relatively similar sections obtained for gross anatomical examination. Finally, an additional healthy camel head was obtained to investigate, for the first time, the surgical approach of TMJ in camels. All TMJ anatomical structures and associated components were identified and labelled according to previous scientific literature (Arencibia *et al*., 2005; Arencibia *et al*., 2012; Alsafy *et al*., 2014; Blanco *et al*., 2015). The nomenclature was adapted to the Nomina Anatomica Veterinaria (NAV, 2012).

Gross anatomy: Two out of 6 camel heads were dissected from both sides to demonstrate the morphological structures the TMJ. The remaining 4 heads were transected sagittally and transversely at the level of the corresponding TMJs. The lengths of the TMJ capsular ligaments were measured by use of a Vernier caliper.

Radiographic technique: A latero-lateral radiograph of the camel TMJ was obtained by use of a digital radiography machine (Shimadzu, Kyoto, Japan) with standard exposure factors of 40 kV and 100 mAs and a film focal distance of 80 cm. A grid was used to reduce the scattering radiation and enhance the resolution of the film. The radiographic anatomic structures of interest were delineated, numbered, and nominated on the lateral projection of the caudo-dorsal region of the camel head. The radiographic anatomy of the TMJ and surrounding bony structures were outlined and compared to the corresponding components illustrated on the macerated camel skull.

Magnetic resonance imaging (MRI) technique

Specimen preparation and MRI scanning procedure: The fresh head cadaver has been washed with water and taped in plastic bag before scanning. The head was then positioned ventrally throughout scanning and MR images were acquired in sagittal and sagittal spiral planes with fast spin-echo (FSE) sequences. MRI scanning of the TMJ was performed at a filed strength of 1.5 Telsa (Philips - Achieva 1.5 Tesla, Closed High Field MRI, Japan) with a permanent magnet being used for the study. A Torso coil 16 channel (phased array coil) was used to obtain the images. The study protocol and sequence parameters are summarized in *table* 1. The sagittal and sagittal spiral planes of MR images were compared to the same gross anatomical sections to identify the normal MRIanatomy of the TMJ in dromedary camels (Arencibia *et al*., 2005; Arencibia *et al*., 2012; Alsafy *et al*., 2014; Blanco *et al*., 2015).

Surgical approach to TMJ: A caudodorsal lateral surgical approach to the TMJ has been described and illustrated in figure 1A-D. The TMJ was localized at the caudodorsal region of the camel head and the surrounding area was prepared (clipped) for the surgical procedure. An 8-cm curvilinear skin incision (centered on the caudodorsal aspect of the TMJ) was made along the dorsal margin of the zygomatic process of temporal bone and extended caudoventrally to cross the TMJ. The subcutaneous tissue was transected along the line of skin incision. An incision was made along the origin of the masseter muscle on the ventral border of zygomatic arch. The masseter muscle was then retracted rostroventrally. The rostral borders of parotid lymph node and salivary gland were dissected and retracted caudally to expose the tendinous portion of the masseter muscle. A transverse incision through the tendinous portion of the masseter muscle was made to expose the TMJ capsule. The joint capsule was then transected horizontally to expose the articular surfaces of the TMJ and associated structures. A 3-cm vertical incision was made to the periosteum on the mandibular condyle and the periosteum was elevated both rostrally and caudally by use of a periosteal elevator for the purpose of performing mandibular condylectomy, whenever indicated. The joint capsule and tendinous portion of the masseter muscle were closed routinely, and the masseter muscle was sutured to the fascia of the temporalis muscle along the dorsal edge of the zygomatic arch. The subcutaneous tissue was then sutured followed by routine closure of the skin incision.

Results

Animals: All enrolled camel cadaver heads had no gross, radiographic, or MRI evidence of TMJ diseases or other head abnormalities. Among the 9 normal camel heads, six heads were obtained from male, and three were from female, mature dromedary camels (age range, 4-7 years & body weight range, 550-650 Kg).

Gross anatomical features

The TMJ: The sagittal and transverse anatomical sections of the camel head at the level of the TMJ are shown in figure 2A&B. As demonstrated, the camel TMJ is formed by the articular surface of the mandibular condyle ventrally and the glenoid cavity of the temporal bone dorsally. Thus, the articular surfaces of the TMJ involve mandibular and temporal components. The mandibular component involves the condylar process of the mandible ventrally; whereas, the temporal component includes the articular tubercle, mandibular fossa and retroarticular process of the squamous part of the temporal bone dorsally. The two articular surfaces of the TMJ are separated by an articular disc which is attached circumferentially with a synovial fibroelastic joint capsule. The TMJ is supported by rostrolateral, caudolateral, and caudomedial ligaments (Fig. 2C&D). The skeletal muscles acting on the TMJ include temporalis, masseter, occipito-mandibularis, digastricus, and lateral and medial pterygoid muscles.

The TMJ disc (articular disc): The TMJ disc is a large, oval, biconcave fibrocartilaginous plate composed of rostrodorsal and caudoventral bands with a thin intermediate zone (Fig. 2C). The articular disc separates the TMJ cavity into deep dorsal and shallow ventral synovial pouches. The examined articular disc measured 37 mm in its rostrocaudal length (i.e. in a sagittal plane) and 42 mm in its lateromedial width (i.e. in a transverse plane).

The TMJ capsule (Fig. 2 B&C): The TMJ capsule consists of two layers, outer thick fibrous and inner thin serous. The outer layer passes rostrolaterally to attach with the free borders of the lateral aspect of the corresponding articular surfaces until it terminates on the lateral surface of the mandibular notch and the caudolateral surface of the coronoid process of the mandible forming the rostrolateral ligament. It then curves caudally below the caudal border of the zygomatic process of the temporal bone to cover the medial aspect of the mandibular condyle dorsally where it increases in its thickness to constitute the caudal, lateral, and medial ligaments of the TMJ. Thus, the joint capsule is oriented rostrally by a rostrolateral ligament and caudally by caudolateral and caudomedial ligaments.

The TMJ ligaments: The ligaments of the TMJ include rostrolateral, caudolateral, and caudomedial ligaments (Fig. 2 A-D). The rostrolateral ligament is a small, thin structure measuring approximately 16 mm long and 14 mm wide. It originates from the outer fibrous layer of the joint capsule and extends from the rostrolateral aspect of the mandibular condyle to completely cover the lateral side of the mandibular notch. The caudolateral ligament is a large, thick ligament measuring approximately 22 mm long and 17 mm wide. It originates from the caudolateral wall of the joint capsule and passes caudoventrally to cover the retroarticular process of the temporal bone. The caudomedial ligament is a long, thin ligament measuring approximately 24 mm long 15 mm wide. It originates from the caudomedial aspect of the TMJ capsule and directs rostromedially around the lateral pterygoid muscle until it reaches the lateral wall of the upper third of the soft palate.

Radiographic features: The radiographic anatomy of TMJ and associated structures outlined on the lateral head projection have correlated with the corresponding components identified on the camel skull (Fig. 3A&B).

Magnetic resonance imaging (MRI) features: The MRI features of the TMJ and associated structures identified on the sagittal and sagittal spiral planes are illustrated in figure 4 A&B. The structures of the TMJ and associated components were characterized based on the signal intensity of different tissues. The bony components of TMJ showed heterogeneous (granular) intermediate signal intensity on FSE T1-weighting sagittal and sagittal spiral MRI images. This appearance may be related to the hypo-intensity and lack of signal intensity (dark to black signal intensity) of the associated trabecular, cortical and subchondral bones and hyperintensity (bright signal intensity) of the corresponding fat infiltration. The muscles associated with TMJ (temporal, masseter, and lateral pterygoid muscles), articular fibrocartilage disc, and joint capsule showed intermediate to high signal intensity which appeared grey to bright in color, respectively. The anatomical MRI features of the TMJ and associated structures relatively correlated with the corresponding components identified on the gross sagittal and transverse anatomic sections made through the investigated camel head at the level of the TMJ.

Surgical approach to TMJ: In the study reported here the caudodorsal lateral approach of the camel TMJ provided a good exposure to the articular surfaces of the joint, as well as the TMJ disc (articular disc) and associated rostrolateral and caudomedial ligaments (Fig. 1D). The two exposed articular surfaces of the TMJ involved the articular cartilage of the mandibular condyle ventrally and the articular/mandibular fossa of the zygomatic process of the temporal bone dorsally. A better exposure to the TMJ and corresponding mandibular condyle has been achieved to facilitate the process of possible future mandibular condylectomy by use of an osteotome (Fig. 1D). Interestingly, there were no major vessels or nerves identified in the region of the surgical approach.

Table 1. The plus sequence protocol used for imaging the temporomandibular joint (TMJ) of camel in high-field magnetic resonance image (MRI) system.

Items	T1-weighted sagittal (14/30)	T1-weighted sagittal spiral (17/35)
Field of view (FOV) mm	140	140
Slice thickness (S. Th.) mm	3	3
Distance factor (Gap) %	0	0
Matrix	256 X 256	256 X 256
Repetition time (TR) ms	530	2600
Echo time (TE) ms	15	30
Averages(Av)	8	6
Flip angle (^{o})	90	90
Fat suppression	1.5	1.5
Turbo factor	4	15

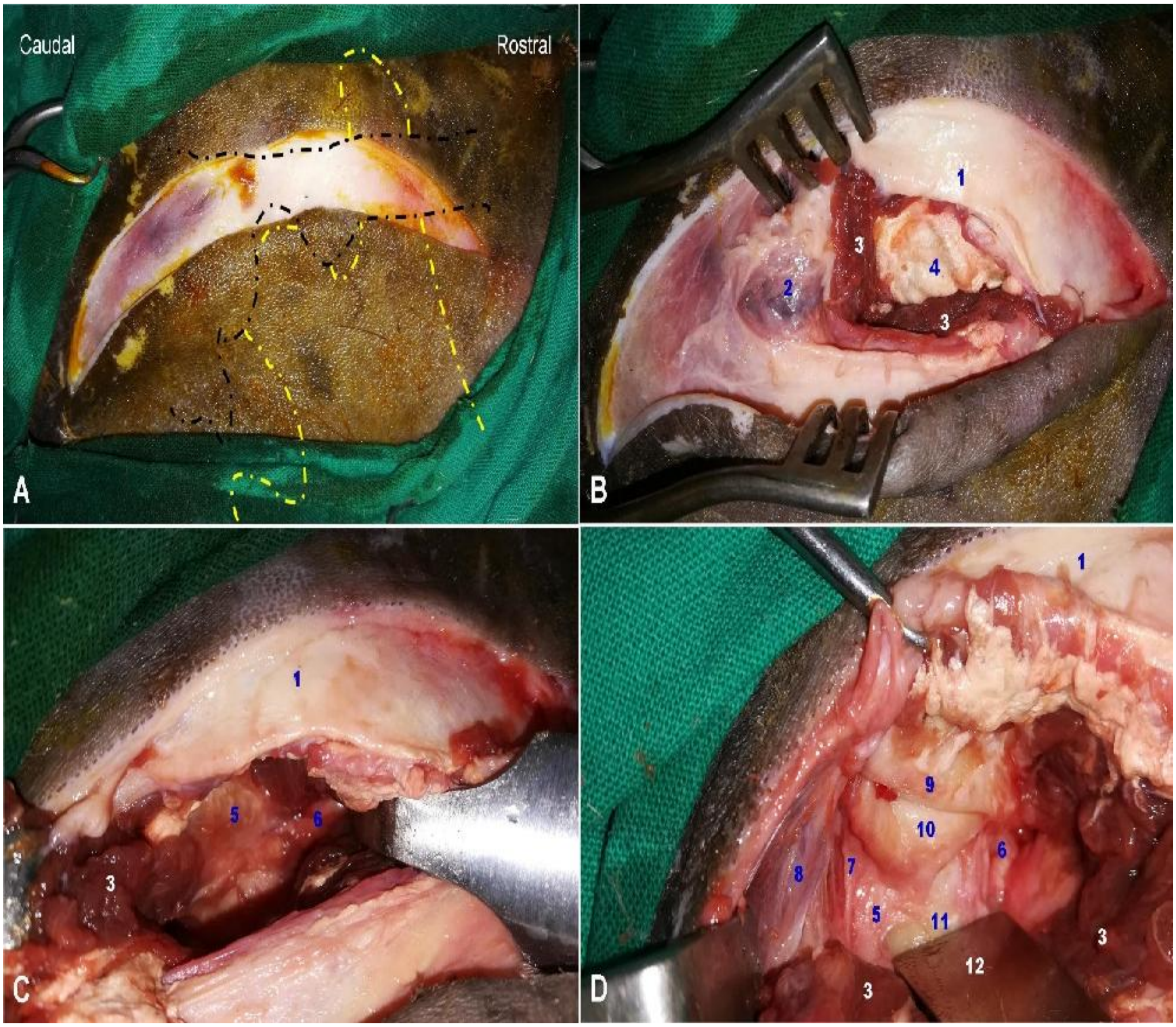

Fig. 1: Caudodorsal lateral surgical approach to the TMJ of an adult camel (A-D). 1, Zygomatic arch; 2, Parotid lymph node; 3, Masseter muscle; 4, Tendinous portion of masseter muscle; 5, Articular capsule; 6, Rostrolateral ligament; 7, Caudomedial ligament; 8, Parotid salivary gland; 9, Dorsal articular portion of the TMJ; 10, Articular disc; 11, Mandibular condyle; 12, Osteotome.

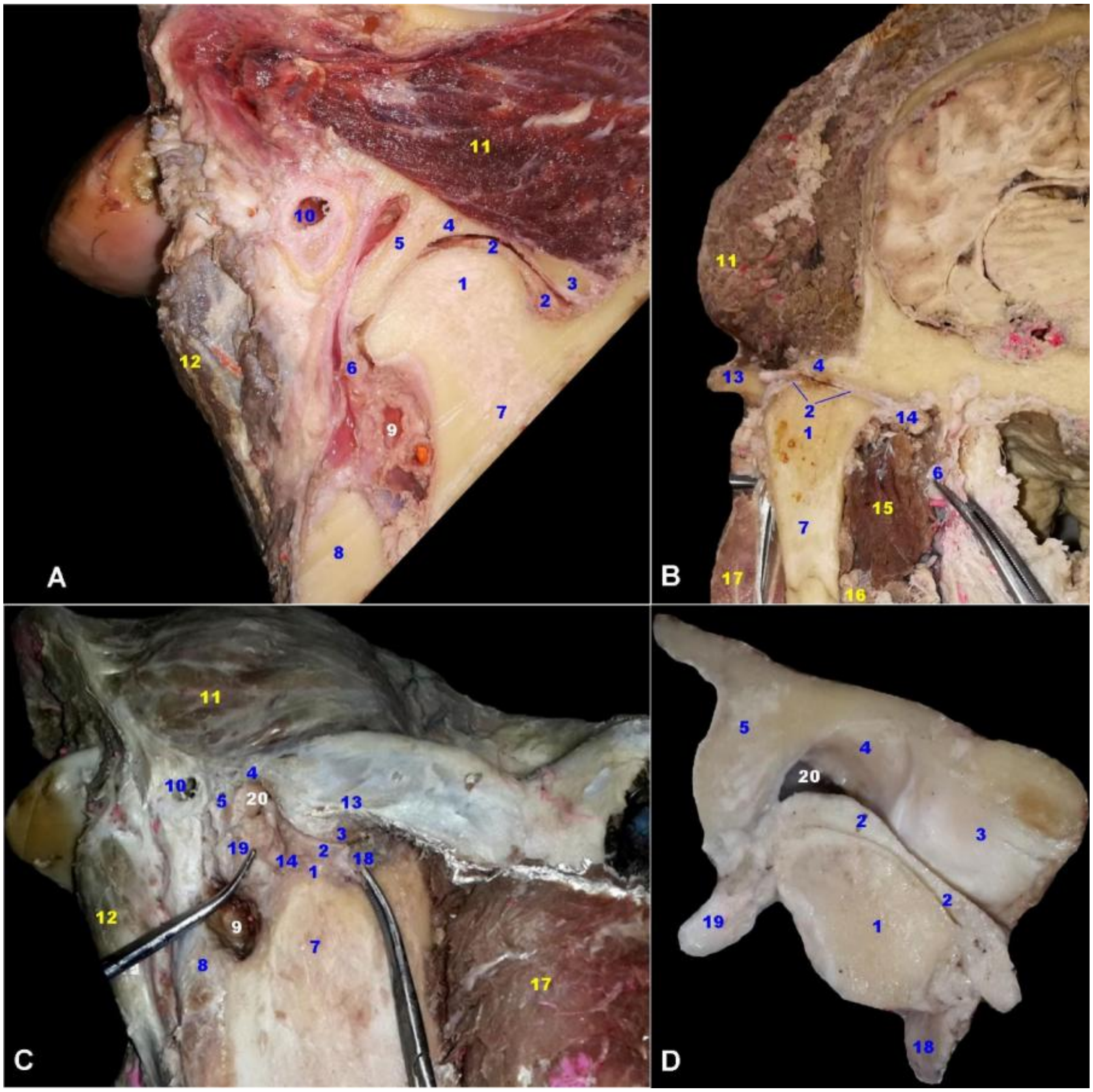

Fig. 2: Gross anatomical features of the TMJ and associated structures of an adult camel. A, Sagittal anatomical section; B, Transverse anatomical section; C, Lateral view of TMJ after reflection of the masseter muscle; D, Sagittal section of a dissected TMJ. 1, Mandibular condyle; 2, Articular disc; 3, Articular tubercle; 4, Mandibular fossa; 5, Retroarticular process; 6, Caudomedial ligament; 7, Ramus of the mandible; 8, Angular process of the mandible; 9, Superficial temporal vessels; 10, External acoustic meatus; 11, Temporalis muscle; 12, Occipito-mandibularis muscle; 13, Zygomatic arch; 14, Articular capsule; 15, lateral pterygoid muscle; 16, Medial pterygoid muscle; 17, Masseter muscle; 18, Rostrolateral ligament; 19, Caudolateral ligament; 20, Articular cavity.

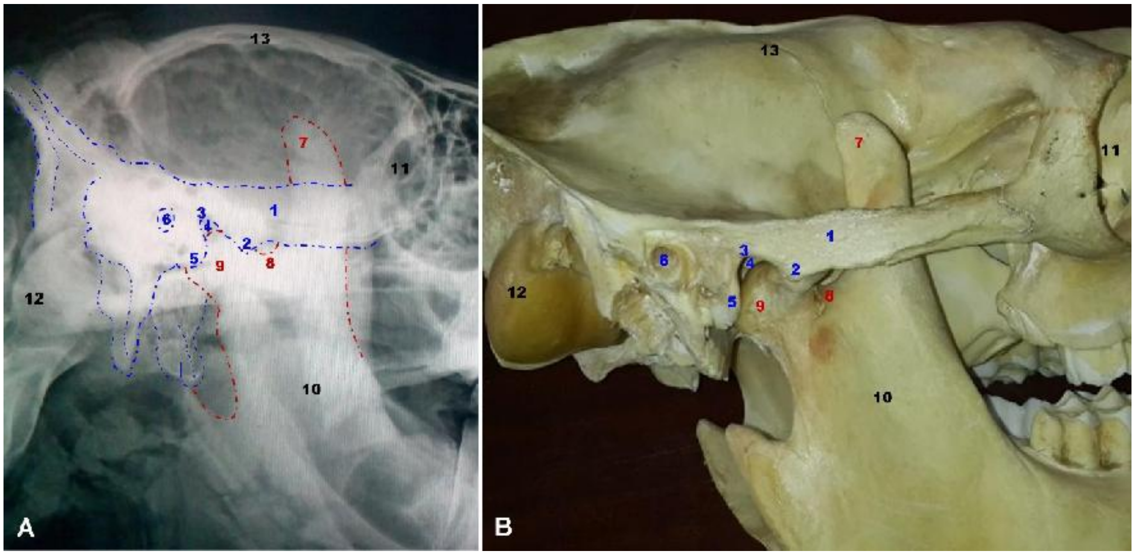

Fig. 3: Latero-lateral radiograph of the TMJ (A) and corresponding bony components on a macerated skull of an adult camel. 1, Zygomatic arch; 2, Articular tubercle; 3, Mandibular fossa; 4, Articular cavity; 5, Retroarticular process; 6, External acoustic meatus; 7, Coronoid process of the mandible; 8, Mandibular notch; 9, Condylar process of the mandible; 10, Ramus of the mandible; 11, Orbit; 12, Occipital condyle; 13, Parietal bone.

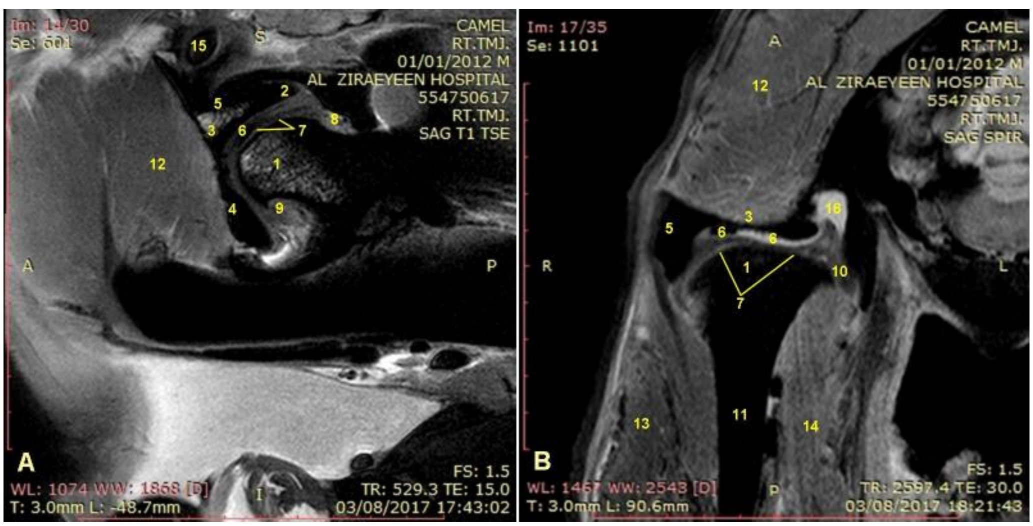

Fig. 4: T1-weighted (14/30) sagittal MR image (A) and T1-weighted sagittal spiral (17/35) MR image (B) at the level of the TMJ in an adult camel. 1, Mandibular condyle; 2, Articular tubercle; 3, Mandibular fossa; 4, Retroarticular process; 5, Zygomatic arch; 6, Articular disc; 7, Articular capsule; 8, Rostrolateral ligament; 9, Caudolateral ligament; 10, Caudomedial ligament; 11, Ramus of the mandible; 12, Temporalis muscle; 13, Masseter muscle; 14, Medial pterygoid muscle; 15, External acoustic meatus; 16, squamous part of the temporal bone.

Discussion

The temporomandibular (TMJ) was described in the present study as a compound true synovial joint with a characteristic hinge like action and sliding movement. It is formed by the condylar process of the mandible ventrally and the articular tubercle, mandibular fossa and retroarticular process of the temporal bone dorsally. These findings are consistent with the results previously reported for most domestic animals, such as camels (Alsafy *et al*., 2014; Arencibia *et al*., 2012), sheep (Patil and Bindra, 2012) and equine (Rodriguez *et al*., 2010; Kuryszko and Mazurkiewicz, 2004). The TMJ disc of our examined camel heads has been found to be a large, thick fibroelastic cartilaginous plate dividing the TMJ cavity into deep dorsal and shallow ventral synovial pouches. Similar anatomic criteria of TMJ disc have been reported in sheep (Patil and Bindra, 2012), equine (Rodriguez *et al*., 2010; Kuryszko and Mazurkiewicz, 2004) and pigs (Herring *et al*., 2002). In the study reported here, the TMJ disc measured approximately 37 mm in its rostrocaudal length and 42 mm in its mediolateral width. The average disc dimension reported for pigs was 14.5 mm in its rostrocaudal length and 26.8 mm in its mediolateral width (Sindelar *et al*., 2002). However, to our knowledge, the dimensions of the TMJ discs have not been documented for other animal species. According to the present study, the TMJ capsule of the camel consisted of two layers; outer thick fibrous and inner thin serous. The outer fibrous layer increased in its thickness forming the ligaments of the TMJ joint. These findings were again in agreement with the results reported for sheep (Patil and Bindra, 2012), equine (Rodriguez *et al*., 2010; Kuryszko and Mazurkiewicz, 2004) and pigs (Herring *et al*., 2002).

The three reported ligaments of the camel TMJ (rostrolateral, caudolateral, and caudomedial) originate from the outer fibrous layer of the corresponding joint capsule. These ligaments simulate those (caudal, lateral and medial capsular ligaments) reported by Rodriguez *et al*. (2010) for equine. In pigs, the TMJ capsular ligaments include an anterior capsular ligament and two collateral capsular ligaments (lateral & medial) (Herring *et al*., 2002). However, the TMJ capsule of sheep is reinforced by a single lateral capsular ligament (Patil and Bindra, 2012). The average length and width of the three capsular ligaments associated with camel TMJ reported here were approximately 20.7 mm and 15.3 mm, respectively. To the authors' knowledge, no previous publications have documented the dimensions of TMJ capsular ligaments for camels or other large domestic animals. In pigs, the dimensions of the corresponding capsular ligaments measured approximately 4-5 mm long and 2 mm wide for the lateral capsular ligament and 4–5 mm long and 4–5 mm wide for the medial ligament (Herring *et al*., 2002).

The use of different diagnostic imaging modalities to demonstrate TMJ and corresponding structures in domestic animals has been reported to be of great value due to the complex anatomical features associated with this joint. These imaging modalities most likely included radiography (Saber, 1990; Shojaei *et al*., 2008), CT (Rodriguez *et al*., 2008), and MRI (Macready *et al*., 2010; Rodriguez, *et al*. 2010). Computed tomography (CT) and magnetic resonance imaging (MRI) were previously utilized to demonstrate the TMJ and associated anatomical structures in camels (Arencibia *et al*., 2012; Alsafy *et al*., 2014). Nevertheless, there remains a relatively limited investigation achieved to characterize the TMJ of camels (Arencibia *et al*., 2012; Alsafy *et al*., 2014). The present study provides a relatively comprehensive overview of the normal anatomy of the TMJ of dromedary camel (*Camelus dromedarius)* using sagittal and transverse gross anatomy, lateral radiographic anatomy, and sagittal and sagittal spiral MRI. In addition, the current study describes a lateral surgical approach to the TMJ of camels for possible future management of TMJ diseases. Ultrasonography has previously been utilized in camels to demonstrate the ultrasonographic structures of the normal phalangeal region in camels (Abu-Seida *et al*., 2012). However, to the author's knowledge, this diagnostic imaging modality (ultrasonography) has not been used yet to investigate the ultrasonographic features of the camel TMJ.

The dorso-ventral radiograph of the camel head was not specific to precisely outline the corresponding TMJ (Saber, 1990; Shojaei B *et al*. 2008). Therefore, the dorso-ventral projection of the TMJ was not provided in the study reported here. Instead, the latero-lateral radiographic projection of the camel TMJ was obtained to outline the bony components associated with such a joint, with respect to the corresponding TMJ structures identified on a camel skull. The radiographic components of the TMJ outlined on the lateral projection correlated with the corresponding structures identified on the skull. A previous study has reported the overall radiographic anatomy of the entire camel head (Shojaei *et al*., 2008). However, as far as the author's knowledge is concerned, the detailed radiographic investigation of the camel TMJ reported in the current study has not been documented previously by scientific literatures.

The use of MRI as a unique diagnostic imaging modality is generally limited in veterinary practice, particularly for large animals such as camels (Arencibia *et al*., 2005; Arencibia *et al*., 2012). This could be related to the high cost of MRI, as well as the lack of its availability and personal clinical expertise in Veterinary Medicine. Nonetheless, we were able in the present study to demonstrate the MRI features of the camel TMJ and associated structures and compare them with the corresponding components identified on the gross sagittal and transverse sections obtained at the level of the TMJ. The TMJ capsule, disc and ligaments as well as bony structures were clarified via different levels of intensity identified on the magnetic resonance image (MRI) sections (T1 sagittal and spiral sagittal). The MRI findings reported in the present study were relatively consistent with the previous publications investigating the MRI characteristics associated with normal TMJ of camels (Arencibia *et al*., 2005; Arencibia *et al*., 2012). Additionally, the anatomical features of TMJ and associated structures investigated on MRI were relatively comparable with the same components identified on the gross sagittal and transverse anatomical sections made through the corresponding TMJ. Our findings are therefore in agreement with previous studies that concluded that MRI could generally provide excellent spatial resolution and better distinction between bone and soft tissue compared with other imaging modalities (Arredondo *et al*., 2013; Aiken *et al*., 2012, Bag *et al*., 2014; Ikeda and Ikeda, 2016).

A great deal of interest has focused on diagnosis and treatment of TMJ affections in dogs and horses (Moll and May, 2002; Piermattei *et al*., 2006; Auer and Stick, 2006). These affections commonly included TMJ subluxation or luxation, fractures, and ankylosis following severe trauma, as well as aseptic or septic TMJ arthritis or osteoarthropathy (Hurtig *et al*., 1984; Moll and May, 2002; Piermattei *et al*., 2006). Surgical approach of the TMJ has previously been demonstrated in dogs and horses to achieve open reduction and fixation of TMJ luxation or fracture, or to perform mandibular condylectomy (Piermattei and Johnson, 2004; Auer and Stick, 2006; Piermattei *et al*., 2006). However, to the authors knowledge, no previous studies have developed a surgical procedure to approach TMJ in camels. Therefore, the present study provides the first evidence of illustrating a caudodorsal lateral approach to the TMJ of camels. Interestingly, our reported surgical procedure has been found to be easily performed without the risk of damaging major vessels or nerves, as no such critical structures were identified in the region of the surgical approach. The reported surgical procedure is therefore expected to be utilized in the future to surgically reduce and stabilize TMJ luxation and fracture, as well as to perform mandibular condylectomy in cases with non-amenable TMJ fractures, severe osteoarthritis, or ankylosis. However, a future survey study is still warranted to document the common surgical affections of TMJ in *Camelus dromedarius*, and to evaluate the incidence of occurrence of each affection and its proper management.

Conclusion

The gross anatomical structures associated with normal TMJ of camels correlated with the corresponding structures identified in the radiographic and MRI examinations. The caudodorsal lateral approach to the camel TMJ reported here has been found to be an applicable and easy surgical procedure that could be useful for future management of some possible diseases affecting TMJ in camels.

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