International Journal of Veterinary Sciences and Animal Husbandry

**ISSN:** 2456-2912
VET 2018; 3(1): 03-09

www.veterinarypaper.com
Received: 02-11-2017
Accepted: 03-12-2017

**Allouch GM**
Department of Veterinary Medicine, Faculty of Agriculture and Veterinary Medicine, Qassim University, Saudi Arabia

**Correspondence**
**Allouch GM**
Department of Veterinary Medicine, Faculty of Agriculture and Veterinary Medicine, Qassim University, Saudi Arabia

# Functional anatomy of the masticatory mechanism: A comparative study of physical characteristics of jaw-closing and jaw- opening muscles in sheep

## Allouch GM

### Abstract
The functional anatomy study of the mammalian muscles is very important for understanding the mastication mechanism during eating. It is also important for their health and breeding performance. Fifteen heads of sheep (Mean ± SD age: 18 ± 4 month) and of both sexes were included in this study.
A comparative gross anatomical study and linear measurements of the two types of masticatory muscles were conducted on slaughtered sheep heads. The physiological cross- sectional area (PCSA), maximal isometric force, torque and kinetic energy were calculated. were calculated. The study showed that the sheep jaw-closing muscles were the masseter and temporal muscles whereas the digastricus was a jaw-opening muscle. The physiological cross- sectional area (PCSA) was 3.1, 2, 3.1 cm² for the masseter, temporal and the digastric muscle, respectively. The maximal isometric force for those muscles was 6.2, 4, 6.2 cm², respectively. The force of those muscles was 0.49, 0.098, 0.196 N, respectively. The torque of those muscles was 0.49, 0.098, 0.196 Nm, respectively. While the kinetic energy of the jaw-closing group was 90 Joule, that of the jaw-opening group was 30 Joule. The values of the PCSA, force, maximum isometric force, torque and kinetic energy of the jaw-closing group were higher than those of the jaw- opening. This is suggested to be due to the increased activity of the jaw-closing muscles.

**Keyword:** Functional, anatomy, masticatory muscles, sheep

### Introduction
The functional anatomical study of the masticatory muscles in sheep is very important to understand the mastication mechanism during eating. They are also important for the animal health and breeding success. There is very rare literature about the physical properties of the masticatory muscles that explain masticatory mechanism in sheep.
The anatomy of the masticatory muscles was previously studied in ruminants and described carefully in details (Getty, 1976 and Dyce *et al*., 2010). Moreover; the function of the masticatory muscles correlates with resemblance generally skull shape and food natural of the deer reported by (Janis, 1990) [14]. However, no detailed description of masticatory mechanics is available in sheep. The oro-facial system including stomatognathic system, maxilla-mandibular apparatus and masticatory system was a functional unit (Patial and Bindra, 2012), while the masticatory system was completed by including a jaw opener digastric muscle using the origin and insertion sites (Weijs *et al*., 1987) [24]. The involvement actions of masticatory muscles in a variety of mammals in which feeding behavior and the configuration of the masticatory apparatus were different was reported by (Gans, 1978; Gorniak, 1985) [10]. The mechanism of jaw opening and closing is complex (Herring, 1992; Hiiemae, 2000) [12]. The mechanical advantage of the superficial layer of the masseter muscle was promoted by elevation of the jaw joint and expansion of the mandibular angle (Popowics and Herring, 2006) [17]. The present work which aimed to investigate the functional anatomy of the different masticatory muscles in the sheep could be considered as supporting The present study was aimed to present the research concerning the comparison of the masticatory functional biomechanics of the closing and opening movements of the masticatory muscles in sheep in addition to understand the dynamics of masticatory muscles of adult's sheep.

## Materials and Methods

### Materials

Fifteen heads of sheep of both sexes and different ages (12-24 months) were collected from Buraidah slaughterhouse, Qassim Region, KSA were used in this study. Ten heads were dissected using standard instruments to investigate the anatomical features including weight and measurements of masticatory muscles. In addition, five heads of a live sheep were used for taking the time expended by the jaw opening and jaw closing muscle during mastication mechanism.

### Methods

An incision was made in the masticatory muscles along its length bell to reveal the muscle fibers. Linear measurements (cm) concerning the muscles longitudinal axis were taken. The muscle volume was determined using water displacement technique.

Taking the density of muscle by Mass/Volume. The physiological cross-sectional area (PCSA) was determined using the following equations: PCSA= (mass /density) / fiber length (Anapol and Barry 1996) [1], maximum isometric force generation capacity of muscle =2 x PCSA (Woledge *et al*., 1985) [26]. Force =Mass x Gravity (g x 9.8). The muscle torque (T) = F. d = F. r. Sin θ: Where F (force) r (The vertical distance of the center of force for the axis of rotation. Sin θ a numerical value for the rotation angle of each masticatory muscle. The muscular Kinetic energy =KE= ½. m. $v^2$: where M (mass of muscle) V (speed of muscle).

The muscle weight was estimated by (g), volume ($cm^3$), Density (g /$cm^3$), force (N), PCSA ($cm^3$), the torque (Nm), Kinetic energy (Joule).

## Results

The sheep masticatory system is a complete functional unit including muscles, mandible bone and other tissues comprise ligaments, tendons, arteries and nerves. The masticatory muscle was divided into three groups: the closing, the opening and the unilateral (medially and laterally).

In the present study we focus on the anatomical, physiological and physical characteristics of masticatory muscles closing, and opening muscles was performed. They were presented as follow as the masseter, temporal and digastricus muscles. The closing muscles include both masseter and temporal muscles.

**The masseter muscle** (Figs. 1, 2, 3, 4) is the largest masticatory muscle. It occupies most of the lateral surface of the cheeks, representing about 83% of weight of closing muscle mass, and represents 10% of the volume of this muscle and 41% of the total volume of these muscles. The masseter mass weight is about 40-60 g. This muscle subdivides by two tendinous laminae forming three distinguished separate layers namely; superficial, middle and deep masseter muscle. The average length of the masseter mass is 12±2 cm cranio-caudally, 6±8 upper- lower and about 1 cm lateromedially. Length of the muscle fiber is about 8±2 cm which are oriented in different directions according to the layer of masseter muscle.

The superficial masseter muscle fibers are oriented cranioventrally in the superior part in an angle about 30° degree to the horizontal line. The fibers of the superficial muscle are oriented almost cranio-ventrally pulling the mandible anteriorly, when is elevated the mandible to close the mouth as well as this part of the muscle aid to rotate to the medial side of the mandible. While the fibers of the intermediate layer of the masseter muscle are oriented ventrally according to the vertical line and due to these fibers orientation, this part is responsible for elevation the mandible to close the mouth. The fibers of the deep masseter muscle are oriented ventrally in a vertical direction and overlapped with the fibers of the temporal muscle. Because of this ventral orientation, it contributes to elevate the mandible and retracts the mandible posteriorly.

The physical characteristics of the masseter muscle indicates the volume of the masseter muscle was 50 $cm^3$, density of the muscle is 1.612 g/ $cm^3$. Moreover, the physiological cross-sectional area (PCSA) is the area of the cross section of the muscle perpendicular to its fibers. It is typically used to describe the contraction properties of pennate muscles: PCSA = 50/1.612) / 10 = 3.1$cm^2$. Furthermore, the maximum isometric force generation capacity of muscle is representing PCSA. 3.1 x 2= 6.2 N$cm^2$.

Regarding the estimated force that of the masseter muscle, it is 0.49 N. The torque is the measurement of the turning force on muscle. The torque is estimated about 0, 49 Nm due to the fibers direction which increases the torque of the movement by closing the lower jaw. The kinetic energy moves the masseter muscle of the mouth either it is vertically or horizontally, is about 75 Joule. It depends on the movement speed of the muscle. It represents the work needed to moves muscle mass from rest state to limited distance to the new position.

The same used kinetic energy of work is done by the muscle to return from its new position to a rest state. The main function of the masseter muscle is to stabilize the tempo-mandibular joint elevating the mandible and aides in the simple rotating movement.

**The temporal muscle** (Figs. 5, 6, 7) is smaller than the masseter muscle. It locates in the temporal fossa of the temporal bone, presenting about 17% of weight of closing muscle mass, and represents 12% of the volume of this muscle. The temporal mass weight is about 8-14 g.

This muscle has thick spherical shape and have a broader aponeurotic extension almost the length of the muscle. The average length of the temporal mass is 8±2 cm cranio-caudally, 2±4 upper- lower and about 1-1.5 cm lateromedially. The length of the muscle fiber is about 8±2 cm which oriented caudo-ventrally to the horizontal line.

The fibers of the temporal muscle oriented caudo-ventrally to pull the lower jaw caudally, they are considered responsible for elevation of the lower jaw to close the mouth and pulling it caudally.

The indication of the physical characteristics of the temporal muscle are the volume of the temporal muscle was 12 $cm^3$. The density of muscle is 0.83 g/$cm^3$. Moreover, the physiological cross-sectional area (PCSA) is typically used to describe the contraction properties of pennate muscles: PCSA = 10/0.83)/6 = 2 cm. Furthermore, the maximum isometric force generation capacity of muscle is representing PCSA. 2 x 2= 4 N$cm^2$.

According to the estimated force of the temporal muscle. It is 0,098 N. The torque is a measure of the turning force on muscle. The estimated torque is about 0, 49 Nm due to the direction which to increment the torque of the movement by closing the mandible

The kinetic energy of the temporal muscle which causes its moving whether it is vertical or horizontal is about 15 Joule. It represents the work needed to move a muscle from opining movement to closing movement. The same used kinetic energy of work is done by the muscle to return from the opening state to a closing state of the lower jaw.

The main function of the temporal is to stabilize the temporo-mandibular joint, elevation the mandible. The vertical movements of the lower jaw apparently are produced by action of the three parts of masseter and temporal muscles.

The opening muscles include one muscle which is digastric muscle (Fig. 8). It occupies most of the medial surface of the mandible. The digastric muscle has a different shape from the other masticatory muscles. The digastricus muscle mass weight is about 18-22 g, representing 100% of weight of opening muscle mass, and represents 41% of the volume of this muscle. This muscle has two bellies between them a short tendinous junction namely; cranial, caudal belly. The average length of the digastric mass is 14±2 cm cranio-caudally, 3±1upper- lower and about 1 cm lateromedially. The length of the muscle fiber of each belly is about 8±2 cm which are oriented in two directions. The fibers are oriented cranio-ventrally in the caudal belly and oriented cranially in the cranial belly due to these fibers orientation the muscle is responsible for pulling down the mandible and acts reduction the mandible.

The physical characteristics of theof digastric muscle indicates the volume of the of digastric muscle was 10 $cm^3$, density of the muscle is 0.64 g/ $cm^3$. Moreover, the physiological cross-sectional area (PCSA) = (mass/density)/fiber length, PCSA = 20/0.64)/ 10 = 3.1 $cm^2$.

Furthermore, the maximum isometric force generation capacity of muscle is representing PCSA. 3.1 x 2= 6.2 $Ncm^2$.

Regarding the estimated force that of the digastric muscle. It is 0.196 N due to the fibers orientation and arrangement had a role on a muscle's ability to produce movement and to generate force.

The torque is the force applied to the distance between the center of the axis of force and the axis of rotation. It is rotational force as a linear force is a push or a pull and it is a measure of the turning force on muscle. The estimated torque is about 0.196 Nm due to the fibers direction which increases the torque of the movement by closing the lower jaw.

The estimated the kinetic energy involved in moving the digastricus muscle of the mouth whether it is vertical or horizontal movement is about 30 Joule. The kinetic energy is needed to move a muscle mass from closing to opening position.

The main function of the digastricus muscle is to open the mouth. Finally, the closing and opening movements apparently are produced by action of the masseter, temporal and digastric muscles.

Finally, the closing and opening pattern for moving the lower jaw vertically or horizontal depends a force both masseter, temporal and digastric muscles on both sides of the mandible, generally.

**Table 1:** The physical functional characterizes of the masticatory muscles (jaw closing -opening) comparative the total masticatory mass.

| Muscle | Weight (g) | Weight (%) | Volume ($cm^2$) | Volume % | | Weight (%) | Volume (%) | KE (J) |
|---|---|---|---|---|---|---|---|---|
| Masseter. M | 50 | 62.5% | 10 | 41.5% | **Closing** | 75% | 58.5% | 90 |
| Temporal. M | 10 | 12.5% | 4 | 17% | | | | |
| Digastric. M | 20 | 25% | 10 | 41.5% | **Opening** | 25% | 41.5% | 30 |

**Table 2:** The calculation of the physical characterizes of the masticatory muscle.

| Muscles | Fiber Length (cm) | Mass (g) | Density ($cm^3$) | PCSA ($cm^2$) | Force (N) | maximum isometric force ($Ncm^2$) | Torque (N. m) | KE (J) | KE of each group (J) |
|---|---|---|---|---|---|---|---|---|---|
| Masseter. M | 10 | 50 | 1.61 | 3.1 | 0.49 | 6.2 | 0,49 | 75 | 90 (J) |
| Temporal. M | 6 | 10 | 0.83 | 2 | 0.098 | 4 | 0,098 | 15 | |
| Digastric. M | 10 | 20 | 0.64 | 3.1 | 0.196 | 6.2 | 0,196 | 30 | 30 (J) |

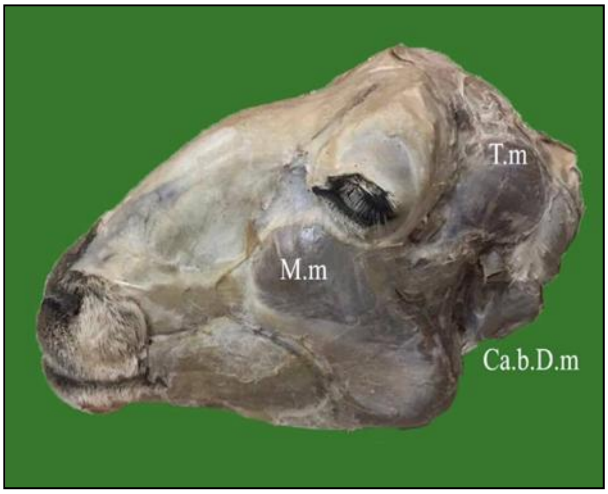


**Fig 1:** A photograph shows the masticatory muscles. Opening and closing muscles group. Masseter muscle (M.m), Temporal muscle (T.m) and caudal belly of digastric muscle (Ca.b.D.m).

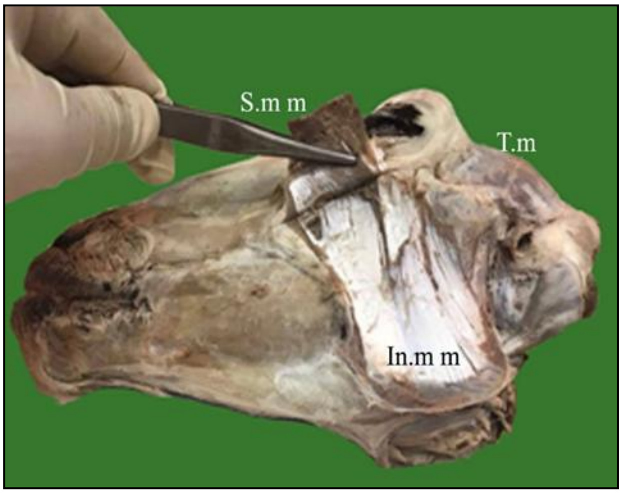


**Fig 2:** A photograph shows the two layers of masseter muscle, superficial masseter layer (S.m.m) and Intermediate masseter layer (In. m.m)

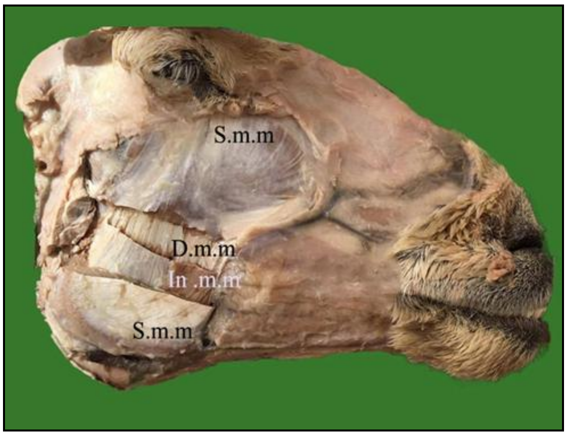


**Fig 3:** A photograph shows three layers of masseter muscle; superficial masseter layer (S.m.m), Intermediate masseter layer (In.m.m) and Deep masseter layer (D.m.m)

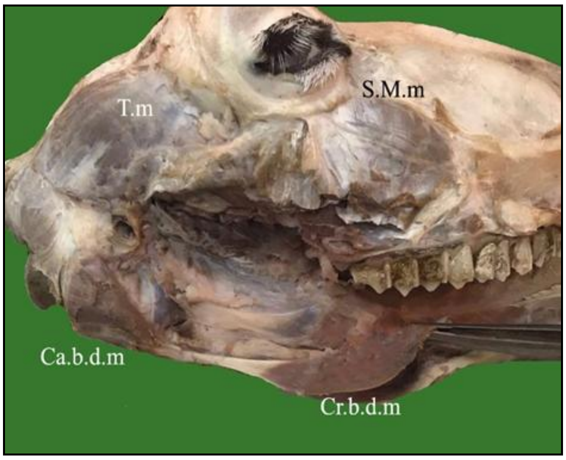


**Fig 4:** A photograph shows bellies od digastric muscle. Cranial belly of digastric muscle (Cr.b.d.m), caudal belly of digastric muscle (Ca.b.d.m). Superficial masseter layer (S.m.m), Temporal m (T.m).

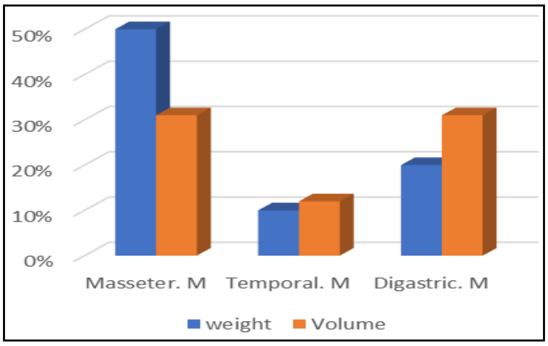


**Fig 5:** A diagram showing the relationship between the weight and volume of the masticatory muscle (closing and opening).

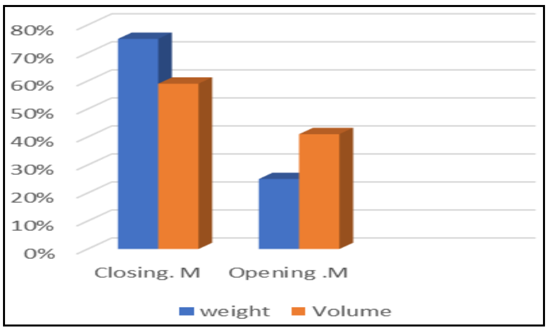


**Fig 6:** A diagram showing the relationship as a percentage between the weight and volume of the closing and opening groups of the masticatory muscle.

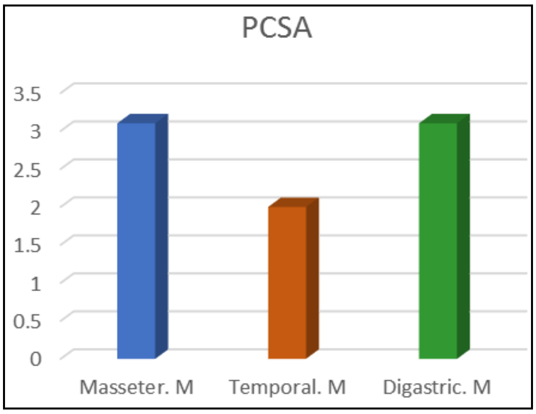


**Fig 7:** A diagram showing PCSA of the closing and opening groups of the masticatory muscle.

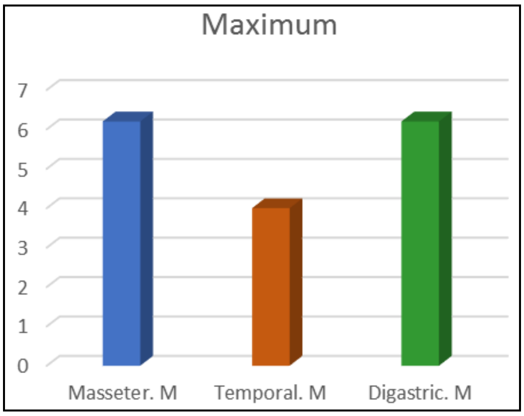


**Fig 8:** A diagram showing Maximum isometric force of each muscle of the closing and opening of the masticatory muscle.

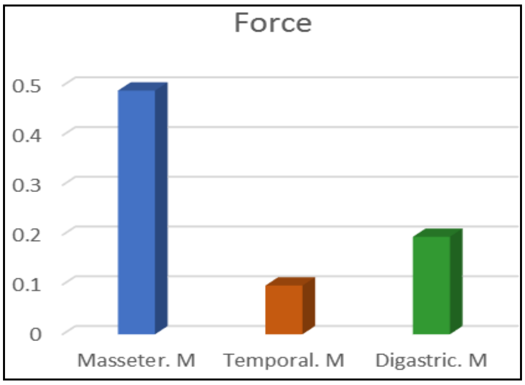


**Fig 9:** A diagram showing the force of the closing and opening of the masticatory muscle,

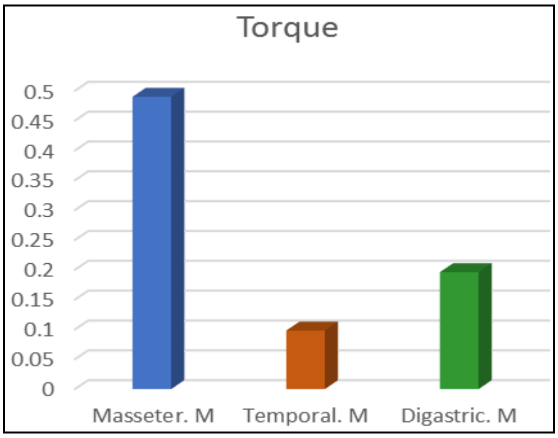


**Fig 10:** A diagram showing the torque of each muscle, opening and closing group.

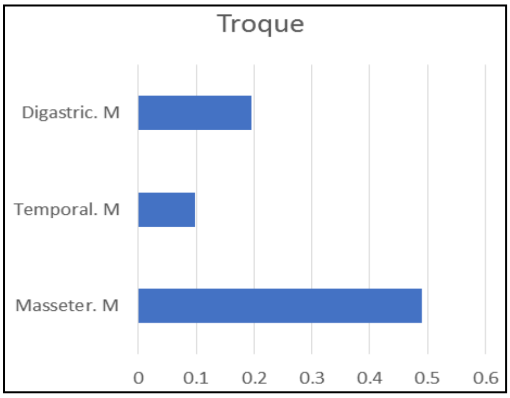


**Fig 11:** A diagram showing the torque of each muscle, opening and closing group.

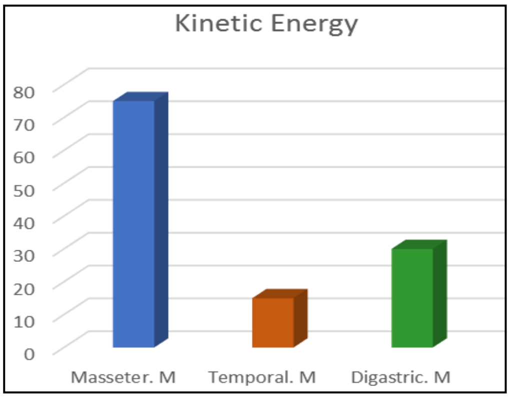


**Fig 12:** A diagram showing kinetic energy of each muscle, opening and closed group

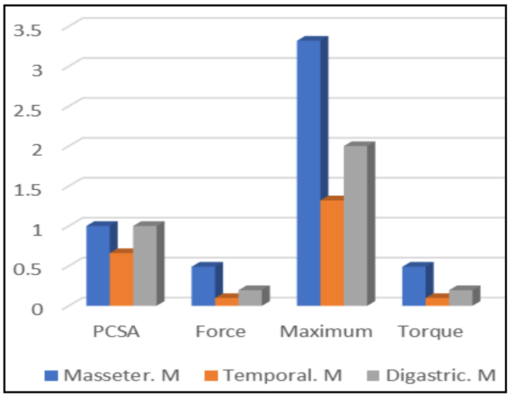


**Fig 13:** A diagram showing the physical properties of PCSA, Force, Maximum isometric force generation capacity, torque and Kinetic energy of each muscle of the closing and opening of masticatory muscle.

## Discussion

This study has investigated the gross anatomy and the functional anatomy of the masticatory muscles through studying physical characteristics of closing and opening muscles including: (Fibers orientation, PCSA, force, maximum force, torque and kinetic energy) in sheep.

The masseter muscle is polygona, which is covered by a thick tendinous aponeurosis. It is larger than temporal muscle which has a thick spherical shape and covered by a different thick aponeurosis. The present results are in agreement with Budras and Habel (2009) in bovine, Smut *et al*., (1980) in camel and Budras *et al*., (2013) [4] in horse. On the other hand, the current work demonstrated three layers of masseter muscle, superficial, intermediate and deep. The current results were similar to those of Parker (1983) [16] in contrast to two layers, superficial and deep in cattle (Budras and Habel 2009), camel (Smut *et al*., 1987) [20] and horse (Budras *et al*., 2013) [4]. On the other hand, the camel has a large temporalis muscle is not unexpected (Maynard Smith & Savage, 1959).

The digastric muscle or jaw- opening muscle had two bellies of spindle shape separated by an intermediate tendon which penetrates the tendon of the stylohyoideus. Our finding is compatible with (Kushkhov, 1991) [15] in sheep and (Budras and Habel, 2009) in bovine, (Smut *et al*., 1980) in camel and (Budras *et al*., 2013) [4] in horse.

The dominance of the masseter musculature is in contrast to the emphasis of the temporalis musculature in carnivores (Turnbull, 1970) [22].

The relative mass of the closed and opening muscles group was functionally consistent. The closed and opening muscles group proportions were 60%. They were presented of masseter 50%, temporal 10%, the opening group were 20%; presented by digastric 2%.They were similar to white-tailed deer; masseter 46.1%, temporalis 29.3% among the mammals investigated by (Turnbull, 1970) [22] and that is agree with (Janis, 1990) [14] who recorded that the function of the masticatory muscles correlates with similarities generally skull shape and food natural of the deer.

The present study revealed that the function of muscles was estimated through measuring the length and the orientation of muscle fibers. The length of muscular fibers of masticatory closed group was about 10 cm of masseter muscle, 6 cm of the temporal. However; the superficial masseter fibers directed cranioventrally, the intermediate masseter layer was ventrally direction while the deep masseter layer was ventrally and caudoventrally direction. While the length muscular fiber of opening group was about 5 cm of each belly and cranioventrally directed. These results were in accordance with those of Gorniak (1985) [10] who recorded that the horizontal movements are generated by muscles having fibers arranged in marked anteroposterior direction, whereas vertical movements are generated by muscles having more or less vertically arranged fibers.

In ruminants, Suzuki (1977) [21] recorded that the masseter fibers of the ruminant differed from those of the other species in histochemical properties. Budras and Habel (2009) mentioned that a superficial layer with almost horizontal muscle fibers, and a deep layer with caudoventral fiber direction in bovine and added the digastric muscle the two parts have different fiber directions. On the contrary, Budraset *et al*., (2013) [4] recorded that the superficial fibers in horse run obliquely caudoventrally but deeper ones run nearly vertically. These fiber direction are responsible for the lateral and rotational chewing movement.

Furthermore, the results showed that the physiological cross-sectional area (PCSA) of the closed masticatory group in sheep was 5.1 cm². They were represented by 3.1 cm² of the masseter, 2 cm² of the temporal muscle. While (PCSA) was 3.1 cm² of the opening masticatory group. These results explain the PCSA of the closed mastication is larger than the PCSA of the opening mastication muscle about double value due to mass, density, length of fiber of the muscle and function of the muscle. (Watson *et al*., 2017) [23] recorded that in the rabbits, the PCSA was 5.3 cm² of the closing group represented by 4.7 cm² of the masseter, 1.5 cm² of the temporal muscles. They don't remember PCSA of digastric muscle. This result was in harmony with those of Watson *et al*., (2017) [23] as value of PCSA to closed and opening mastication group. On the other hand; our result Emphasizes Eijden *et al* (1995) [6] who recorded that the Muscle force is proportional to the physiological cross-sectional area (PCSA).

The differences in PCSA measurements can be attributed to variations in the muscle mass and the type of the comparative studied animals (Fukunaga *et al*., 1990).

Also, the present study revealed the force of the closed muscle group presented about 6 N collected by 4.9 from the masseter muscle and 0.9 from the temporal muscle. This force was necessary for closing operation of the mouth. It was produced due a large mass of the masseter muscle, whereas the increasing of masseter muscles size serves both the moving the mandible vertically.

The force of the opening muscle presented was about 2 N from the digastric muscle. This force was necessary for the opening of the mouth. Also, this force was produced due to the mass, the extending of the digastric muscle serves both the moving the mandible vertically but distally.

This explains why the force of the closed was equal to threefold of the opening force and force of the opening equal $1/_3$ of the closed force its due to the gravity which need more force to occlusion. This agree with (Watson *et al*., 2017) [23] mentioned that the closed force was almost completely attributed to a vertical component (97.4% of resultant), with only minor contributions from the anterior and medial components (20.6% and 9.8% of resultant, respectively.

In the present study, it was clear that the strength of the chewing was limited by the maximum force of muscle, Maximum isometric force generation capacity of muscle was estimated by multiplying muscle PCSA A maximum muscle force was assigned to each mandible closed and opening muscle. They were 10.2 of the closed muscles, they were represented by 6.2 of within masseter muscle and 4 within the temporal muscle as well as it was 6.2 of within opening muscle represented by the digastric muscle. It had maximal effect on the closed force due to the large size of the muscle, while a maximum force within the temporal. It had minimal effect on the closed force due to the small size of the muscle. On the other hand; A maximum force within digastric muscle for the opening group. It had like maximal effect on the masseter muscle of the closed force due to large size and due to extension of the digastric muscle on the distance in the mandible. Watson *et al*., (2017) [23] reported that the rabbit has the highest maximum force of all the masticatory muscles (60.9 N) and the muscle vary significantly in their orientation due to its pennate structure.

The current study revealed that the torque was estimated by 0.49 Nm of masseter muscle and 0.098 Nm of the temporal muscle due to the direction, which to increment the torque of the movement by rotation the mandible. While the torque of the digastric muscle had 0.196 Nm. The torque value of the closed group is higher than the torque value of the opening group due to area increased attached the muscle on the bone and the activity of the masseter and temporal muscle the in comparing with the activity of the digastric muscle.

We find that when the area of muscular attachment to the bones was large, the torque values decreased as well as the torque was rotational force as a axial force to push or a pull and it was a measurement of the turning force on muscle. These results agree with Serway and Jewett (2003) [19].

Herring (2007) [11] recorded that the torques asymmetrical muscle usage sets up torques on the skull and combines with occlusal loads to produce bony deformations not only in the tooth-bearing jaw bones. On the other hand; Other biomechanical forces generated during mastication, such as joint torques (Widmer *et al*., 2002) [25].

Regarding the kinetic energy, it was about 90 Joule of the closed muscles group. They were represented by 75 Joule of masseter muscle and 15 Joule of the temporal muscle. In the closed group; the kinetic energy value of the masseter muscle higher than the value of the temporal muscle due to the size and the activity increasing of the masseter in comparing of the temporal muscle.

While the kinetic energy of the opening muscle group represented by the digastric muscle was 30 Joule. So the kinetic energy value of the closed group about threefold (90: 30) the opening group because the gravity needed more KG to end the closing operation. Thus, these muscles need kinetic energy to move the muscle from its condition to another condition. These results were in parallel line with those of Sasaki and Neptune (2006) [18] who mentioned that the kinetic energy have the potential to be stored as elastic energy in compliant connective tissue and tendinous structures, and subsequently released to do positive work at a later point.

## Conclusion

Finally, this study explained the cause of the functional differences which are responsible for the closing and opening muscles of the mandible. It explained these differences by representing the physical characteristics such as the PCSA, force Maximum isometric force, torque and kinetic energy as well as the differences in the pattern of mandible movements.

**Competing Interest**: The research was not founded officially.

## References


1. Anapol F, Barry K. Fiber architecture of the extensors of the handlimb in semterrestrial and arboreal guenons. Am. J. Phs. Anthropol. 1996; 99:429-447.
2. BECHT C. Comparative biologic-anatomical researches on mastication in some mammals. I and 11. Proceedings Koninklijke Nederlandse Akademie van Welenschappen Amsterdam, Series C. 1953; 56:508-5 I 7, 5:18-527.
3. Budras KD, Habel RE. Bovine Anatomy, An Illustrated Text, First Edition, Schlütersche Verlagsgesellschaft. Hans-Böckler-Allee 7, 30173 Hannover, Germany, 2011.
4. Budras KD, Sack WO, Röck S. Anatomy of the Horse. Fifth, Revised, Edition. Schlütersche Verlagsges ellschaft. Hans-Böckler-Alle. 2013; 7:30173 Hannover.
5. Dyce KM, Sack WO, Wensing CJG. Textbook of Veterinary Anatomy, 3rd edition (WB Saunders Company) Philadelphia, 2002.
6. Eijden TM, Koolstra JH, Brugman P. Architecture of the human pterygoid muscles. J Dent Res. 1995; 74(8):1489-95.
7. Fukunaga T, Roy TRR, Shellock SFG, Hodgson TJA, Day MK, Lee IPL, *et al*. Cross- Sectional Area of Human Leg Muscles Based on Magnetic Resonance Imaging, J Thopaedic Res, Raven Press, Ltd, New York, 1992.
8. Gans C, Vree FD, Gorniak GC. Analysis of mammalian masticatory mechanisms: Progress and problems. Anat. Histol. Embryol. 1978; 7:226-244.
9. Getty R. Sisson and Grossman's The Anatomy of the Domestic Animals, 5th edition *(Saunders)* Philadelphia 1975; ISBN-13:978-0721641027.
10. Gorniak GC. Trends in the Actions of Mammalian Masticatory Muscles1, AMER. ZOOL. 1985; 25:331-337.
11. Herring SW. Masticatory Muscles and The Skull: A Comparative Perspective, 2007.
12. Herring SW. Muscles of mastication: architecture and functional organization. In: Davidovitch, Z. (ed.) The Biological Mechanisms of Tooth Movement and

Craniofacial Adaptation. The Ohio State University College of Dentistry, Columbus, Ohio, 1992, 541-548.
13. Hiiemae KM. Feeding in mammals. In: Schwenk, K. (ed.) Feeding: Form, Function and Evolution in Tetrapod Vertebrates. Academic Press, San Diego, California, 2000, 411-448.
14. Janis CM. Correlation of cranial and dental variables with dietary preferences in mammals: a comparison of macropodoids and ungulates. Mem Qld Mus. 1990; 28:349-366.
15. Kushkhov KhT. Masticatory muscles of domestic sheep and swine in ontogenesis. Arkh Anat Gistol Embriol Jan. 1991; 100(1):88-93.
16. Parker WS. Comparative Anatomy of the Internal and External Pterygoid Muscles, Functional Variations Among Species. The angle Orthodontist. 1983; 53(1):9-18.
17. Popowics TE, Herring SW. Teeth, jaws and muscles in mammalian mastication, Bels-Ch05.qxd. 2006; 6:61-83, https://www.researchgate.net/publication/282881060_ rsif.royalsocietypublishing.org J. R. Soc. Interface 11: 20140564
18. Sasaki K, Neptune RR. Muscle mechanical work and elastic energy utilization during walking and running near the preferred gait transition speed/Gait & Posture. 2006; 23:383-3902005 Elsevier B.V. All rights reserved
19. Serway RA, Jewett Jr JW. Physics for Scientists and Engineers. 6th Ed. Brooks Cole. 2003, ISBN 0-534-40842-7.
20. Smut M, Bezuidenhout A. Anatomy of the Dromedary. Clarendon: Oxford University Press, 1987.
21. Suzuki A. A Comparative Histochemical Study of the Masseter Muscle of the Cattle, Sheep, Swine, Dog, Guinea Pig, and Rat. Histochemistry. Histochemistry 9 by Springer-Verlag 1977. 1977; 51:121-131
22. Turnbull WD. Mammalian masticatory apparatus. Fieldiana Geolgy. 1970; 18:147-356.
23. Watson JP, Groning F, Curtis N, Fitton CL, Herrel A, McCormack WS, *et al*. Masticatory biomechanics in the rabbit:a multi-body dynamics analysis, 2017.
24. Weijs WA, Brugnan P, Klok EM. The growth of the skull and jaw muscles and its functional consequences in the New Zealand rabbit (Oryctolagus cuniculus). J.Morpho. 1987; 194:143-161.
25. Widmer CG, English AW, Carrasco DI, Malick CL. Modeling rabbit temporomandibular joint torques during a power stroke. Angle Orthod. 2002; 72:331-337.
26. Woledge RC, Curtin NA, Homsher E. Energetic aspects of muscle contraction. Monogr. Physiol. Soc. 1985; 41:1-357.