PRINCIPAL INSPIRATORY MUSCLE OF *UROMASTIX HARDWICKII*

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Variations in the musculoskeletal system exist in different classes of animal. The chest muscles are specifically modified due to modifications in axial skeleton in each vertebrate class. In addition, diaphragm is one of the main respiratory muscle in mammals which is absent in reptiles, specifically lizards, having different modes of respiration, e.g., buccal, axial and hepatic piston. Additionally, they do not breathe well during locomotion. Since, sternum and chest cage both are properly developed in these animals, therefore, they must be having an alternate chest muscle involved in the act of inspiration. The purpose of this study was to identify the principal inspiratory muscle in the chest of the reptile *Uromastix*. Repeated dissections, visual observations and electrical stimulation of the exposed but intact chest muscle (pectoralis/supracoracoideus) of *Uromastix* have demonstrated three major parts in it. Being, superior (S), middle (M) and inferior (I), identified on the basis of their colour, position and response to electrical stimulation. Accordingly, the locomotor action of these parts S, M and I are forceful, mild and feeble adduction of fore limb, respectively. While, its inferior part (I) additionally showed further sub-divisions into 3 portions, Is, Im and Ii. On electrical stimulation, one of them, i.e., Ii portion of the chest muscle of Uromastix demonstrated rib-cage elevation and thus named, 'Rib Cage Elevator', helping inspiration. It is concluded that chest muscle of Uromastix play dual role, in locomotion as well as respiration.

Keywords: Diaphragm, Uromastix, Ribcage elevator muscle, reptile, Inspiratory muscle

INTRODUCTION

The chest muscles are modified in each vertebrate class due to the modification in axial skeleton (pectoral girdle, ribs, sternum, etc.). In amphibians, the 'batrachians', ribs are totally absent, while they are available in reptiles, but are cartilaginous. These ribs are fused, as found in turtle. Ribs are joined with the sternum in all limbed reptiles except turtle where no attachment found ventrally. In some reptiles posterior projections occur on the dorsal portions.[1] In mammals the ribs are usually composed of an ossified dorsal portion and a cartilaginous ventral portion, i.e., the costal cartilage.[1] Sternum is available in all vertebrates except, fish, some amphibians, limbless reptiles and turtles. It may appear as a cartilaginous plate in some amphibians, lizard and crocodiles or as an elongated bone in case of flying birds. In mammals the sternum is usually composed of a series of bone, the sternebrae.[1] In lacertilia and crocodilia there is an oblong, cartilaginous plate continuous with which are usually two horn like, posterior processes. The anterior end of the sternum is attached with the pectoral girdle. Ribs connect with the sides and with the posterior horns. These animals may have been the first to have the ribs attached to the sternum.[2]

In addition, Walter and Sayles[2] described the ventral axial muscles of some lizards and alligators which are further modified in the anterior half of the trunk region by the introduction of encircling ribs. In the belly region (posterior), the original three layers of muscles remain unchanged, but in the thoracic region (anterior), the oblique muscles become broken up into external and internal intercostals muscles, which extend from the rib to rib and aid in respiratory movements.[2]

Studies have also been reported on muscles between different classes of vertebrate. Pectoralis is one of the prominent muscle which lies near the ribs. In some reptiles[3], pectoralis lies on the under side of the shoulder which gives a strong pull backward and downward on the humerus. It spread fan wise far back over the sternum and ribs by inserting on a powerful process beneath the proximal end of the humerus.

In mammals this muscle tend to split into four more or less distinct derivatives the pectoantebrachialis, the deeper pectoralis major, the deeper pectoralis minor and the deepest of all the xiphihumeralis. This ventrally positioned muscle in reptiles (supracoracoideus) extends from its origin on the coracoid laterally to its insertion on the humerus. However, in mammals the supracoracoideus originates dorsally on the lateral face of the scapula.[4]

In addition, the nomenclature of skeletal muscles depends upon the direction of their fibres, their location/position, the number of sub divisions, their shape, origin/insertion, their action, size and other features. Sometimes name of a muscle may include the combination of these as well.[5] Originally, names were given to muscles in accordance with one or the other criteria without considering homology, (e.g. triceps, levator). Therefore, it is a fact that if two muscles in two different vertebrate groups bear the same name, doesn't mean that they are homologous[5], e.g., gastrocnemius in amphibians and mammals which has variation in its site of attachment.[4]

Most of the reptiles and all the lizards have no muscular diaphragm, a structure found only in mammals. It is possible that lizards may be having a muscle in their chest along with sternum and cartilaginous ribs which is involved in inspiration, either at rest, or movement. Certain lizards seem to avoid activity during active respiration[6] due to the involvement of axial musculature both in breathing and locomotion. Hence, they face difficulty in getting air into their lungs during locomotion. Adult female green sea turtles also do not breathe when they move at their nesting beaches. On the other hand, the North American box turtles breathe continuously during locomotion, and the ventilation cycle is not coordinated with the limb movements.[7]

Limited respiration poses a challenge for reptiles that actively forage for their food. One such lizard is the South American 'Tegu', which has a primitive diaphragm, the post hepatic septum.[8] Smaller or lazier lizards lack this membrane.[9] However, studies regarding pleuro-peritoneal cavity and post hepatic septum in reptiles[9,10] are mentioned in the literature, which helps in respiratory action. The mechanism of respiration had also been studied, which is either through buccal pumping, axial breathing or by hepatic piston mechanism.

Interestingly, diaphragmatic action as found in mammals is not known in all lizards except alligators, but many studies are available regarding the lung ventilation mechanism[11] (in lizards), lung ventilation volumes[7,12] (in terrestrial turtles and Uromastix), vital capacity[13] (in American alligators), buccal bumping[11,14] (in Vertebrates and Uromastix), respiratory reflex and oxygen consumption[15] (in reptiles, namely lizards). There are only a few aquatic or marine reptiles that can depend almost exclusively on lungs for gas exchange, supplemented by respiration through the pharyngeal membranes as found in some aquatic turtles.[16] In general, the reptiles suck air into the lungs by enlarging the pleuro-peritoneal cavity, as a respiratory mechanism, either by expanding the rib cage as in snakes and lizards or by the movement of internal organs as observed in turtles and crocodilians.[17] Crocodiles, possess a diaphragm that is analogous only in its general respiratory function but not in its mode of action. It retracts the liver, while the mammalian diaphragm uses the liver as fulcrum. This finding may involve important evolutionary implications, e.g., the true diaphragm in mammals. It is the main muscle, which supports breathing. Perhaps the mammalian diaphragm also started out as a membrane similar to the post hepatic septum, but evolved from an assisting role, to become major inspiratory muscle.[9]

Besides the above mentioned literature about reptilian chest muscles as well as respiration, no study has been done for the identification of an inspiratory skeletal muscle, either in Uromastix or other lizards and to name them according to their action. Uromastix is a desert adapted reptile available in the desert areas of Pakistan, India, Egypt, Saudi Arabia and Africa. This animal survives in adverse climate at high temperature with tremendous locomotory speed. Further, in the absence of diaphragm, this animal use buccal and axial means of respiration. Therefore, present study was carried out to identify the main inspiratory muscle in the chest of Uromastix which might be contributing in the absence of diaphragm.

MATERIALS AND METHODS

a) Animals:

Both sexes of 10 adult *Uromastix hardwickii*, were used in the present study.

b) Dissection and Identification of muscles:

International Ethic was followed for the handling of animals, which were obtained and decapitated just before the experiments. After decapitation, the animal was fixed on a dissection board with the ventral surface facing upward. A large incision was then made in the skin of the chest with careful scalping to remove the underneath connective tissues. The origin and insertion of chest muscle (pectoralis/supracoracoideus) was noted with the identification of superior, middle and inferior portions. These portions were identified on the basis of colour along with their muscular action. For the determination of their action, electrical stimulation was provided by using hand-held silver chloride electrodes (via stimulator; Palmer Bioscience. CAT. No: 220; 10V strength, 1Hz frequency and 0.5 ms of duration).

RESULTS

As shown in Figure-1, the whole chest muscle is triangular in shape, extending from the condoyle of humerus (origin) and having distal end attachment in the last cartilaginous rib of the ribcage (insertion) which is fanning upward and inserting in the collar to make the axillary groove. Anatomically, it may be the pectoralis or possibly the supracoracoideus.

Careful dissections and visual observations of different colours in the parts of chest muscle, pectoralis/ supracoracoideus, indicated the presence of 3 main parts, i.e., superior (S), middle (M) and inferior (I) as shown in Figure-1. Their anatomical details and response to electrical stimulation has been presented in Table-1.

Table-1: Anatomical detail of chest muscle (pectoralis/supracoracoideus) and its parts identified in *uromastix hardwickii*

PARTS	COLOUR	ORIGIN	INSERTION	MUSCULAR ACTION
Superior (S)	Dark Red	Mid line of the chest	Main body of the Condyle of humerus	Adduction of fore limb
Middle (M)	Pinkish Red	Curvature of last rib	Condyle of humerus and fascia of biceps	Mild adduction of fore limb
Inferior (I)	Pinkish white	1/3rd of the curvature of last rib.	Inferior portion of the condyle of humerus and fascia of biceps	Feeble adduction of fore limb, expansion and elevation of chest cage.

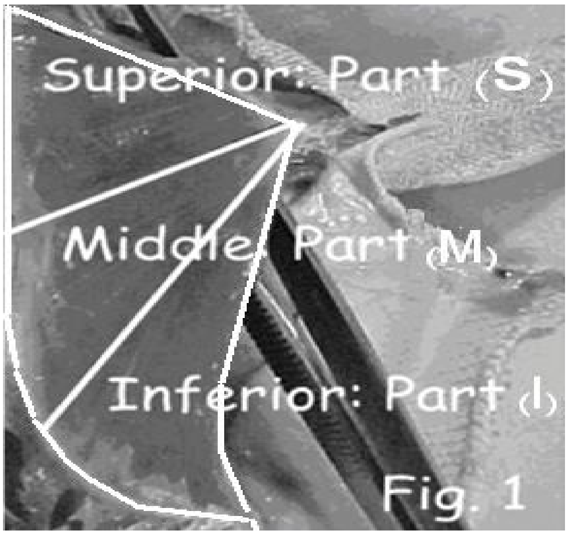

Figure-1: Gross structure of pectoralis/ supracoracoideus muscle of *Uromastix hardwickii* showing chest in unilateral view for its parts, superior (S), middle (M) and inferior (I).

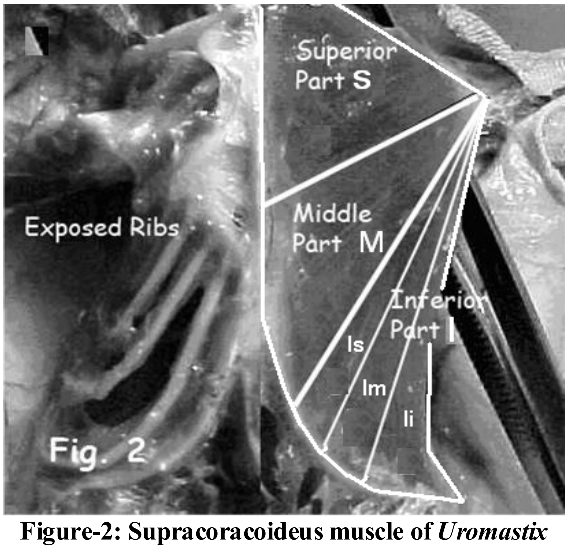

Figure-2: Supracoracoideus muscle of *Uromastix hardwickii*: Right side chest view showing removed chest muscles to show exposed cartilaginous ribs. Left side chest view showing white lines drawn over the picture to separate Part S, M and I. The part I is further shown to possess 3 portions; Is=Superior, Im=middle and Ii=Inferior.

Superior Part of Chest Muscle:

It covers the superior portion of the chest of *Uromastix*. This muscle originates from the mid line of the chest and neck and insert into main body of the condyles of humerus. This part appears to have analogy to the pectoralis major muscle available in other animals and supracoracoideus in birds. On stimulation, its contraction resulted in the adduction of fore limb in *Uromastix*.

Middle Part of Chest Muscle:

This part has its complex origin from the mediastinum at the beginning of last cartilaginous rib and its curvature that partially covers the lower portion of the chest. It inserts at the condyles of humerus and fascia of biceps. In fact the body of this muscle after insertion at the upper arm forms the collar for the axillary groove that can be seen on stretching the arm of this animal. On stimulation this middle part is seen responsible for mild adduction of fore limb.

Inferior Part of Chest Muscle (Rib Cage Elevator):

This part is present beneath the above discussed muscle in the form of a narrow strip originating from the rib cage at mediastinum from where the cartilaginous last ribs ends after its curvature. It converges to insert at the inferior portion of the condyles of humerus and fascia of biceps by running obliquely. However, this inferior part I further showed 3 portions, superior (Is), middle (Im) and inferior (Ii), on the basis of their colour difference, attachment and response to electrical stimulation. This study leads to the identification of their action as shown in Table-2 along with their anatomical details of origin and insertion.

According to Table-2, the Is portion of Inferior part of chest muscle originates at 1/3rd curvature, Im portion at ½ curvature and Ii portion towards the end of last cartilaginous rib. While, all of these three portions inserts the inferior portion of the condyles of humerus and fascia of biceps.

On stimulation, the superior (Is) and middle (Im) portions of Inferior part (I) of chest muscle demonstrated feeble adduction of fore limb and expansion of rib cage, respectively. While, the inferior (Ii) portion, has been found to elevate the rib cage.

Table-2: Anatomical detail of the inferior part of chest muscle (supracoracoideus) and its 3 portions identified in *Uromastix hardwickii*

PORTIONS	COLOUR	ORIGIN	INSERTION	MUSCULAR ACTION
Superior (Is)	Pinkish	1/3rd of the curvature of last cartilaginous rib.	Inferior portion of the condyle of humerus and fascia of biceps	Feeble adduction of fore limb
Middle (Im)	Pinkish white	1/2 of the curvature of last cartilaginous rib.	Inferior portion of the condyle of humerus and fascia of biceps	Expansion of Rib Cage and minute adduction of fore limb
Inferior (Ii)	Reddish pink	Towards the end of last cartilaginous rib.	Inferior portion of the condyle of humerus and fascia of biceps	Elevation of Rib Cage

DISCUSSION

In the present study, chest muscle of *Uromastix hardwickii* was studied for the identification of main inspiratory muscle available in the absence of diaphragm. In general, the identification of the principal action of a muscle or its individual muscle fibre colonies is not easy. The comparative anatomist always undergo complex problems in determining the homologies of muscle in different vertebrates, since the name applied to them are borrowed from human anatomy. Therefore, they concentrate on already available information regarding the role of a particular muscle in other animals.

The chest muscle of Uromastix, judged by its origin (ventral part of the most posterior rib) and insertion (proximal humerus) the muscle appears to be the pectoralis or possibly the supracoracoideus. If the arm is fixed, they could serve to elevate the rib-cage, as the pectoralis does in mammals. This manoeuvre is recommended to assist laboured breathing in asthmatics. Other muscles of the arm and shoulder also perform this function: serratus anterior, pectoralis minor, scalenus to name a few. It is important to note that both the pectoralis and supracoracoideus muscles in birds are responsible for wing movements.[18] While in lizard like Uromastix, their function or rather action is not worked out. Interestingly, throughout the vertebrate class, action of a particular muscle differs as per skeletal requirements or some physiological reasons in individual animals. Therefore, investigator may slip off the evolutionary track[2] and identify these muscles for a different function in the animal they are studying. By taking care of the above mentioned ignorance, the present work has concentrated on the mechanical response of the exposed but intact chest muscle of *Uromastix* on electrical stimulation.

On the basis of mechanical response of the chest muscle observed in the present study, i.e., 3 sub-divisions of Inferior part (I) of the chest muscle of Uromastix (Table-2), it is suggested that the movements in fore limb and action of chest muscle of this animal both are helping simultaneously in locomotion as well as inspiration. Similarly, in a species of turtle (Chelonia), it has been reported that respiration is achieved by the movement of muscle groups especially related to the fore limb.[19] It is also suggested that before the evolution and origination of diaphragm as a respiratory muscle in higher animals, muscles nearby the sternum and cartilaginous ribs participate in the act of inspiration, especially in the lizards like *Uromastix*.

Therefore, according to the above discussion, it is obvious that the chest muscle of *Uromastix* performs dual role. Its superior (S) and middle (M) parts are generally involved in fore limb movement and its inferior (I) part is mainly involved in rib-cage expansion and elevation. This act of rib-cage expansion and elevation is similar to the action of respiratory muscles (including diaphragm) in mammals that increase the volume of their chest to allow inflation of lungs. It is worth to mention a recent study[20] the mechanical characteristics of the inferior part and its 3 portions have been reported and compared with superior and middle parts of the chest muscle of *Uromastix*. These characteristics match with their action of rib-cage expansion and elevation, since, the inferior (I) part showed greater endurance to tetanic stimulation than superior (S) and middle (M) parts.

In the light of present work, it is concluded that lizard like Uromastix do breath during locomotion with the expansion and elevation of rib cage by using the inferior (Ii) portion of their chest muscle. This inferior part is the principle inspiratory muscle in the absence of diaphragm in this animal and thus named 'Rib Cage Elevator' in this and one of our previous study[20] on its mechanical characteristics. In general, it can be described that the chest muscle of this animal play dual role, i.e., for locomotion and inspiration simultaneously. It is also suggested that this inferior (Ii) portion is active during rest with gulping (buccal respiration), and also during locomotion but, without gulp. Therefore, the concept that lizards do not breath during movement[21,6] is not true at least for Uromastix, also a lizard. However, our suggestion is similar to the example quoted by[7] regarding other reptiles, that continuously breath during locomotion, i.e., North American box turtle (using abdominal muscles) and red-eared sliders. However, in-vivo study is required to confirm the correlation of inspiratory activity of Inferior (Ii) portion of chest muscle of Uromastix coupled with locomotion using electromyography and respiratory cycle measurements.

REFERENCES

1. Grispens CG. The vertebrates, their forms and function. USA: Charles C. Thomas Pub Ltd; 1978. pp 47.
2. Walter HE and Sayles LP. Biology of the vertebrates: A comparative study of man and his animal allies. 3rd edition. New York: Macmillan Co; 1949. p. 551–655.
3. Romer AS. The vertebrate body (shorter version) 4th edition. Philadelphia and London: WB Saunders Co; 1971. p 205.
4. Kardong KV. Vertebrate, Comparative anatomy, function, Evolution. 3rd edition. Reproduced by National Book Foundation, Pakistan; 1962. p. 376–87.
5. Kent GC. Comparative anatomy of vertebrates. 6th edition. Mosby: Times Mirror; 1987. p. 321–2.
6. Adam, S. "Monitor marathons: how one group of lizards turns a gasp into a gulp". Natural History. FindArticles.com. 24 May, 2010. Available at: http://findarticles.com/p/articles/mi_m1134/is_5_112/ai_102275156/
7. Landberg T, Mailhot JD, Brainerd EL. Lung ventilation during treadmill locomotion in a terrestrial turtle, Terrapene carolina. J Exp Biol 2003;206(Pt 19):3391–404.
8. Arney K. No lounging for lizards. J Exp Biol 2003;206:2090.
9. Klein W, Andrade DV, Abe AS, Perry, SF. Role of the post hepatic septum on breathing during locomotion in Tupinambis merianae (Reptilia: Teiidae). J Exp Biol 2003;206(Part 13):2135–43.
10. Klein W, Böhme W, Perry SF. The mesopneumonia and the post-hepatic septum of the Teiioidea (Reptilia: Squamata). Acta Zoologica 2000;81:109–19.
11. Brainerd EL. New perspectives on the evolution of lung ventilation mechanisms in vertebrates. Presented 24th March 1999 at the Annual Meeting of the Society for Experimental Biology, Edinburgh, Scotland. www.brown.edu/Departments/EEB/brainerd_lab/pdf/Brainerd-1999-EBO.pdf
12. Klein W, Andrade DV, Wang T, Taylor EW. Effects of temperature and hypercapnia on ventilation and breathing pattern in the lizard Uromastyx aegyptius microlepis. Comp Biochem Physiol 2002;132:847–59.
13. Uriona TJ, Farmer CG**.** Contribution of the diaphragmaticus muscle to vital capacity in fasting and post-prandial American alligators (Alligator mississippiensis). J Exp Biol 2006;209:4313–8.
14. Al-Ghamdi MSAD, Jones, JFX, Taylor EW. Evidence of a functional role in lung inflation for the buccal pump in the agamid lizard Uromastyx Aegyptiusm microlepis. J Exp Biol 2001;204:521–31.
15. Bennet AF. Ventilation in two species of lizards during rest and activity. Comp Biochem and Physiol Part A: Physiology 1973;46(4):653–71.
16. Gage SH, Gage SP. Aquatic respiration in soft-shelled turtles: A contribution to the physiology of respiration in vertebrates. The Am Nat 1886;20:233–6.
17. Huchzermeyer FW. Crocodiles, Biology Husbandry and Diseases. Chapter 1; Cambridge CA: CABI Publishing Co; 2002. p.12.
18. Hinchliffe JR and Johnson DR. The development of the vertebrate limb: an approach through experiment, genetics, and evolution. Oxford University Press. 1980.
19. Chelonia–The Art of the Possible. Available at: www.aquavet.i12.com/Chelonia.htm.
20. Azeem MA, Saima G, Sadaf A. Mechanical characteristics of rib cage elevator muscle of reptile Uromastix hardwickii. Pak J Physiol 2006;2(2):38-44.
21. Klein W, Abe AS and Perry S F. Static lung compliance and body pressures in Tupinambis merianae (Reptilia: Teiidae) with and without post-hepatic septum. Respir Physiol Neurobiol. 2003;135:73-86

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