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Original Research

Congenital Malformations of the First Sternal Rib

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ABSTRACT

During the dissection and skeletal examination of 151 horses, a congenital malformation (CM) of the first sternal rib that influenced the aperture of the Thoracic inlet was noted in six horses. The presentation of this CM was variable between horses in gross anatomic appearance; notably, an absent first sternal rib, bifid tuberculum costae, bifid sternochondral articulation onto the sternum, flared shaft, normal first sternal rib inserting onto the cranial branch of a bifid sternochondral articulating second sternal rib, straight costal shaft, and an articulating rudimentary tuberculum costae with a ligamentous extension replacing the bony shaft and attaching to a rudimentary sternochondral articulation onto the sternum. Of the 151 horses examined, the CM of the first sternal rib was restricted to 6/60 Thoroughbred horses, and only in those that were affected by either the unilateral or bilateral transposition of the caudal ventral tubercle from C6 onto the ventral surface of C7. The normal anatomic presentation of the thoracic inlet was altered, along with associative musculature including neurological pathways. These CMs are likely to produce clinical and functional ramifications of the thoracic inlet, thoracic limb, and thoracic viscera, with the probability of altering postural and locomotive function as noted in four horses demonstrating the CM.

1. Introduction

In the horse, there are supposedly eight paired sternal ribs that are often referred to as “true” ribs, this is due to their distal attachment onto the sternum via a costal cartilage [1,2]. A typical sternal rib articulates proximally with two thoracic vertebrae; however, this does not apply to the first sternal rib, it articulates cranially with the seventh cervical vertebra (C7) and caudally with the first thoracic vertebra (T1) [2]. In comparative anatomic terms, the first sternal rib is the shortest, it displays less convexity in the shaft, it has a smooth impression on the cranial border where the axillary vessels pass, its ventral extremity is the largest, and the first sternal rib is the only rib that displays a cranial deviation in its distal extremity (Fig. 1) [2,3]. Functionally, the sternal ribs are designed to protect the heart and lungs, although the first sternal rib is cranial to the heart, and therefore, its protective role relates to the lungs [1,3]. In addition, it provides rigidity and form; anchor points for muscles such as the scalenes and along with its articulation to the corresponding costal cartilage, limited movement during respiration [1–4].

The articulation of the first sternal rib to C7/T1 and to the manubrium of the sternum via the costal cartilage creates the cranial aperture to the thorax known as the thoracic inlet (Fig. 2). This aperture is ovoid in outline and is occupied by the Longus colli muscle, trachea, esophagus, nerves such as the Phrenic, large blood vessels, for example, carotid artery and jugular vein, lymphatic vessels, lymph nodes, and in the young horse, the thymus [1–3]. Furthermore, Bradley [3] notes that the pleural sac indirectly ends blindly on the left first sternal rib and on the right can extend beyond the first sternal rib and come into contact with the scalene muscles. The role of the thoracic inlet is not clearly defined in current literature; however, its shape helps guide important structures to and from their respective organs, provides a cranial restriction that aids in retaining organs within the thoracic cavity and due to the size and shape of the first sternal rib, it provides a

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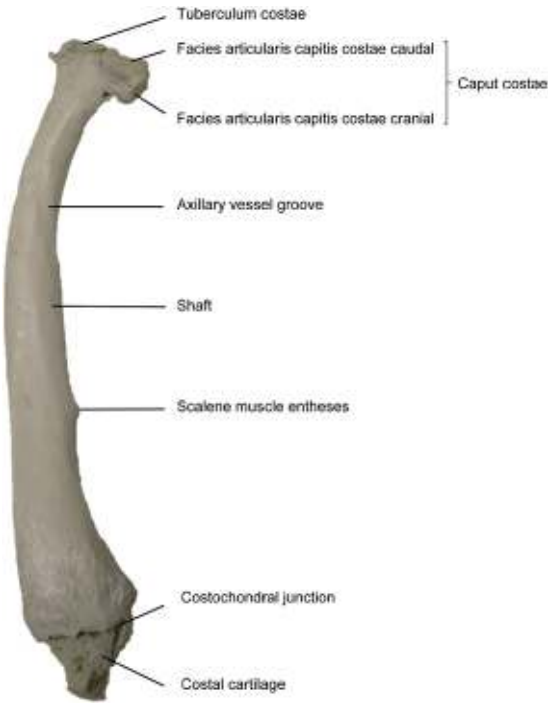

Fig. 1. The lateral view of a normal right first sternal rib in the horse.

protective barrier for those structures. In addition, the thoracic inlet is likely to contribute in respiration by means of providing a resistance against the compressive visceral forces applied to it during expiration, especially in the galloping horse [5].

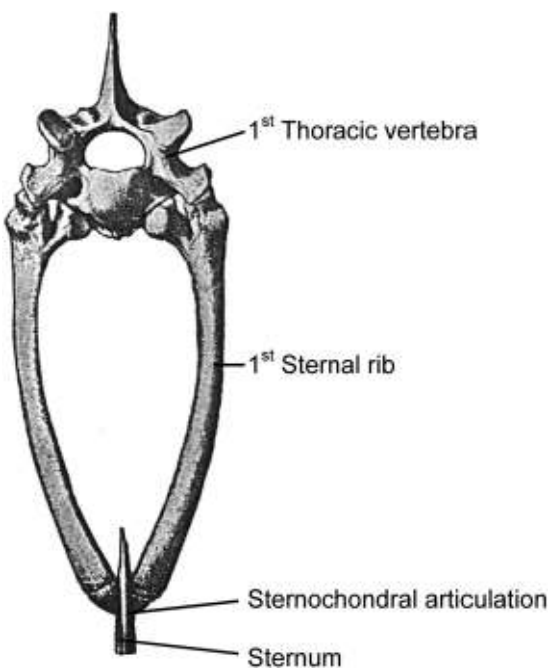

Fig. 2. The cranial view of the Thoracic inlet in the horse (Sisson and Gossman 1975).

Subsequently, the first sternal rib plays an important role in the cranial thorax, and CMs have not been clearly defined in equine anatomy and to date, their existence rarely reported or understood. Even when Bradley [6] reported a case where an aged mare exhibited a bilateral rudimentary first sternal rib with a ligamentous shaft in 1901 (Fig. 3), has there been any significant research found by the current author. However, this cannot be said for other species whereby numerous CMs of the first sternal rib have been reported in dogs and humans since the 1800s [6–8] and in Holstein calves since 1999 [9–11]. Moreover, associative symptoms reported in humans included neurological impingement, visceral displacement, and the relocation of musculature, such as the scalenes [6–8]. In addition, severe CMs of the first sternal rib reported in Holstein calves simultaneously displayed complex vertebral malformation (CVM) that was inclusive of severe CMs of the cervicothoracic junction [9]. In the affected calves, there were multiple axial skeletal CMs including proximal fusion of the first sternal rib to the second sternal rib and nonparallel intercostal spacing [9,10]. CVM is a congenital condition resulting in multiple malformations of the caudal cervical and anterior thoracic vertebrae including the first sternal rib [10]. It predominantly involves the cervicothoracic junction (C5–T2) but can also affect the lumbar vertebrae and appendicular skeleton; furthermore, these malformations have been linked to a lethal recessive gene [9–11].

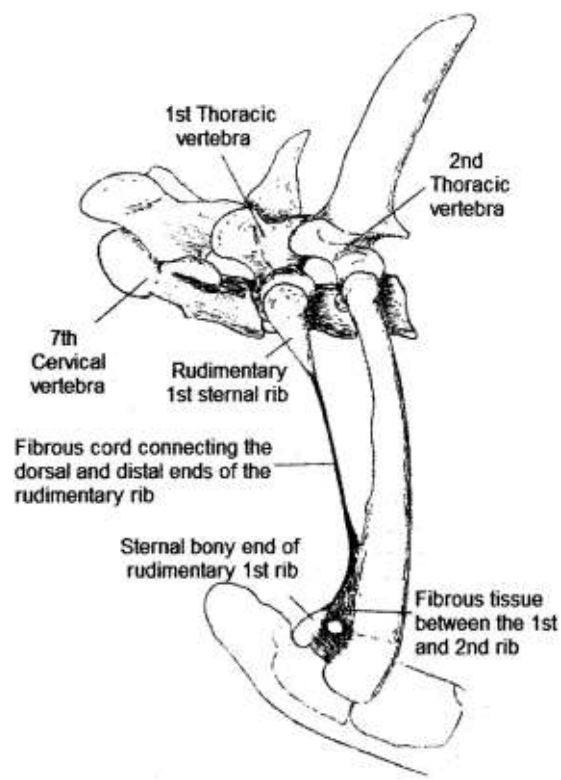

Fig. 3. The lateral view of a right rudimentary first sternal rib with fibrous cord in the horse (Bradley 1901).

Studies showing CMs of the first sternal rib in the dog and human have noted significant variations: bifid extremities, ligamentous shafts, flared shafts, and fused first to second ribs [6–8,12,13]. However, in Holstein calves, the CM of the first sternal rib was always expressed in conjunction with vertebral malformations of 2 or more vertebrae in the cervicothoracic junction, and in addition, multiple other skeletal and visceral defects were noted; for example, hemi vertebra and intraventricular septum [9–11]. In the horse, significant CMs have already been reported in the cervicothoracic junction in the same region of the axial skeleton as CVM in Holstein calves [14]. Additionally, coinciding secondary conditions in these affected horses found that normal function was impeded in the axial and appendicular skeleton in direct correlation to such CMs [14,15]. Aside from skeletally related deviations, for example, scoliosis and those studies already cited in this study, there were no other CMs noted by this author.

Although research into the birthing traumas of foals has reported the impact of sternal rib fractures and chondral displacement, fracture/s of the first sternal rib due to birth trauma are rarely noted [16–19]. However, when reported in the adult horse, first sternal rib fractures may result in forelimb lameness, muscle atrophy, neurological gait deficit, or abnormal behavior when the horse is tacked up or mounted [16]. Owing to the placement of the thoracic limb, radiographic imagery of the first sternal rib is problematic, and this also applies to the restrictions placed on ultrasonography, owing to muscle mass in the region [20–23]. Therefore, the purpose of this study will focus on postmortem data to establish the variability of a CM of the first sternal rib to normal presentation and where possible, correlate these findings to premortem data.

2. Materials and Methods

2.1. Normal Anatomy

At the proximal extremity of the first sternal rib, there exist two articulating facets: tuberculum costae and caput costae, the latter is further divided into a cranial and caudal Facies articularis capitis costae (Fig. 1). The tuberculum costae articulates into the transverse process of T1, the facies articularis capitis costae (cranial) into the Fovea costalis caudalis of C7, and the Facies articularis capitis costae (caudal) into the Fovea costalis cranialis of T1. The neck between the tuberculum costae and caput costae is thick and very short. At the distal extremity, the rib is linked to the sternum via the coastal cartilage. Where the rib and costal cartilage join, it is referred to as the costochondral junction and the joint between costal cartilage and sternum is known as the sternochondral articulation (Fig. 2) [2,3].

Gross anatomic postmortem examinations were collected from 151 horses that either died from natural causes or were euthanized for purposes unrelated to this study. The horses were sourced from Australia, England, North America, Japan, and Holland; they were of mixed gender and aged between 0 (stillborn) and 30 years. Four breed groups were established: Thoroughbreds, Thoroughbred derivatives, purpose bred horses, and nondescript breeding; they were categorized into normal first sternal rib and a CM of the first sternal rib. Where possible and using a Mitutoyo digimatic caliper, measurements of the first sternal rib were obtained; notably, overall length of the lateral rib; lateral length of the costal cartilage; circumference mid shaft; circumference, depth, and width at the costochondral junction (Fig. 4). For control purposes, identical measurements were made of 1 gelded (castrated male horse) Thoroughbred, 1 female Thoroughbred, and 1 gelded Australian Stock Horse. The control horses were between 15 and 16 hands height (hh), which equates to 1.5–1.6 meters, respectively, were deemed normal and mature, had a competitive or ridden life for at least 10 years with no adverse history to affect the study, for example; broken ribs.

Case reports of affected horses were compiled with history and premortem data including interviews with riders/trainers/handlers and known associates where possible.

Note: Not all specimens exhibiting a CM of the first sternal rib were available for measurement due to Government or university regulations, natural disasters, and predators.

3. Results

Of the 151 horses examined, six displayed a CM of the first sternal rib in either a unilateral (3) or bilateral (3)

Fig. 4. Six relative measurements of a normal first sternal rib. (A) Overall length; (B) circumference mid shaft; (C) width distal shaft; (D) length of costal cartilage; (E) circumference distal shaft; (F) depth distal shaft.

Table 1
Noted observations of 151 horses of mixed gender aged between 0 (stillborn) and 30, exhibiting normal presentation of the first sternal rib and a CM of the first sternal rib including CMs of C6 and C7 as per May-Davis [10].

Breed	No.	Normal, 1st Sternal Rib	CM, 1st Sternal Rib	CM, C6 Only	CM, C6 and C7
Thoroughbred	60	54	6[a] (3U, 3B)	26	11
Tb Derivative	4	4	—	3	1
Purpose Bred	67	55	—	—	—
Non-descript	20	20	—	1	—
Total	151	145	6 (3U, 3B)	30	12

Abbreviations: B, bilateral; Tb, Thoroughbred; U, unilateral.
[a] denotes in the presence of a CM of C6 and C7.

presentation. It occurred only in Thoroughbred horses displaying a CM of C6 and C7 as per May-Davis [10]. Of the 60 Thoroughbred horses in this study, 10% displayed a CM of the first sternal rib (6), 43.3% a CM of C6 (26), 18.3% a transposed caudal ventral tubercle (CVT) from C6 onto the ventral surface of C7 (11), and 55.5% of the combined C6 and C7 CM displayed a CM of the first sternal rib. Although the combined CM of C6 and C7 occurred in 1 Thoroughbred derivative, it did not present with a CM of the first sternal rib (Table 1).

Measurements of the left and right first sternal ribs were acquired from three normal horses. Two Thoroughbred horses had raced with only minor success in country provinces. The male upon retirement became a "B" grade showjumper and the female a pleasure hack. The ASH was an individual Bronze medalist in Endurance from the 1990 World Equestrian Games in Stockholm (Table 2).

Of the 6 Thoroughbred horses presenting with a CM of the first sternal rib, 5 were bred in Australia and 1 in Japan; the mean age was 11; the 2 females and 4 males were purposely euthanized; and the CM presented on the left (2), right (1), and bilaterally (3) (Table 3).

3.1. Thoroughbred No. 1: 22-year-old Stallion (Japan)

Right rib: Normal presentation of the first sternal rib.

Left rib: First sternal rib was straight with a medial deviation of the costochondral junction (Fig. 5).

Premortem observations: Postural preference left forelimb forward. Walk—left fore abduction with limited protraction when compared to the right fore; left and significant right hind lateral rotation of the Tarsus; limited protraction and restriction of left and right hind; constant tail swishing (unknown cause). Trot—left fore abduction with limited protraction when compared to the right fore; limited protraction and restriction of left and right hind; constant tail swishing (unknown cause). Veterinarian observed ataxia during the pre mortem observations.

Euthanasia: Planned due to ongoing behavioral and physical issues. Noted lameness at the time of euthanasia in all 4 limbs and ataxic (fore and hind veterinary diagnosis).

Postmortem observations: The CVT on the left aspect of C6 was absent and had transposed to the ventral surface of C7. On the left first-sternal rib Facies articularis capitis costae (cranial) was significantly small; the origin of the scalene muscles was medial to the shaft and not cranial/lateral; no Axillary vessel groove. Left-hind old medial condylar fracture of PI with noted osteophytes close to the fetlock joint. Right-hind ruptured Round ligament, right lateral meniscus significantly worn. Noted cartilage wear patterns in the joints of all four limbs with bilateral significant wear in the distal Humerus, proximal Radius, and Ulna.

3.2. Thoroughbred No. 2: 17-year-old Mare

Right rib: The normal first sternal rib was laterally displaced. It inserted onto the lateral aspect of the cranial branch of the bifid sternochondral articulating second sternal rib. The cranial branch of the bifid second sternal rib replaced the insertion onto the sternum of the first sternal rib (Fig. 6). There were 18 ribs.

Left rib: The first sternal rib was absent. The second sternal rib displayed a similar bifid presentation as that on the right side (Fig. 7). There were 17 ribs.

Premortem observations: Postural preference was base wide and right forelimb forward. The owner noted ongoing lameness and foot stomping right fore as if agitated/irritated; sometimes, the mare would stop during free exercise and stamp the right fore to the ground on a number of occasions. The right fore was a "club foot." A tendency to stumble/trip bilateral in front was found on gait analysis. The mare would knock down show jump rails (due to abnormal forelimb carriage over the jumps). When her forelegs were lifted for hoof care, she became difficult to handle and unbalanced, especially when it involved the right fore Facies articularis capitis costae.

Euthanasia: Planned due to ongoing behavioral and physical issues.

Postmortem observations: The CVT on the right aspect of C6 was absent and had transposed to the ventral surface of C7. On the right first sternal rib, the origin of the scalene

Table 2
Measurements of the first sternal rib in 3 normal performance horses—2 Thoroughbred horses (1 male and 1 female) and 1 Australian Stock horse (male) between 15 and 16hh.

Normal Rib	Gender	Length, cm	Mid Circum, cm	Distal Circum, cm	Distal Width, cm	Distal Depth, cm	Cartilage Length
Tb 1. left	M	25.4	6.6	10.8	3.9	1.6	2.0
Tb 1. right	M	25.9	6.8	11.2	4.0	1.7	1.9
Tb 2. left	F	26.9	6.6	9.5	3.7	2.4	4.1
Tb 2. right	F	26.6	6.7	9.3	3.5	2.0	4.3
ASH left	M	26.0	7.2	10.9	4.7	1.9	3.1
ASH right	M	26.2	7.1	10.9	4.9	1.8	3.2
Mean		26.2	6.8	10.4	4.1	1.9	3.1

Abbreviations: ASH, Australian Stock Horse; cm, centimeters; F, female; M, male; Tb, Thoroughbred.

Table 3
The 6 Thoroughbred horses displaying simultaneous CM of the first sternal rib, C6 and C7.

Breed	Age	Gender	Eu	CM 1st rib	C6 L-Ab	C6 R-Ab	C6 B	C7 L-Tr	C7 R-Tr	C7 B	C7 L-AF	C7 R-AF	C7 B-AF
J-Tb 1	22	M	Eu	L	Yes	—	—	Yes	—	—	Yes	—	—
Tb 2	17	F	Eu	B	—	—	Yes	—	—	Yes	—	—	Yes
Tb 3	10	M	Eu	R	—	—	Yes	—	—	Yes	—	—	Yes
Tb 4	8	F	Eu	B	—	—	Yes	—	—	Yes	—	—	Yes
Tb 5	6	M	Eu	B	Yes	—	—	Yes	—	—	Yes	—	—
Tb 6	4	M	Eu	L	Yes	—	—	Yes	—	—	Yes	—	—
Total	n = 11	4M 2F	6	2L 1R 3B	3	—	3	3	—	3	3	—	3

Abbreviations: Abs, CVT absent; AF, arterial foramen; B, bilateral; Eu, euthanized; F, female; J, Japan; L, left; M, male; N, mean age; R, right; Tb, Thoroughbred; Tr, transposed CVT.

muscles attached to the laterally displaced first sternal rib the entire length of the shaft (Fig. 8); the Phrenic nerve (roots CVI and CVII) were stretched and notably caudal to normal presentation (Fig. 8). On the left first sternal rib, the origin of the scalene muscles attached to the second sternal rib as per the right side; no Axillary vessel groove on either rib. Noted cartilage wear patterns in the joints of all 4 limbs with bilateral significant wear in the distal Scapula, proximal and distal Humerus, proximal Radius and Ulna. Bilateral Hemarthrosis in the elbow joints.

3.3. Thoroughbred No. 3: 10-year-old Gelding

Right rib: The first sternal rib displayed an articulating rudimentary tuberculum costae with a ligamentous extension replacing the bony shaft that inserted onto the sternum with a rudimentary Sternocostal articulation, as per Bradley [4] (Fig. 2).

Left rib: Normal presentation of the first sternal rib.

Premortem observations: Postural preference base wide in front that became wider with age (right fore particularly). During free exercise, he would start to bite his right forearm. By 10 years, he displayed ataxic behavior (veterinary observation). Free walk–right fore abduction. Free trot–right fore abduction. Free canter–right fore abduction. Congenital right side Laryngeal hemiplegia.

Euthanasia: Planned due to ongoing behavioral and physical issues. No noted lameness at the time of euthanasia.

Postmortem observations: The CVT on the left and right aspect of C6 was absent and had transposed to the ventral surface of C7. On the right side, the origin of the scalene muscles traversed medial of the ligamentous extension and attached to the second sternal rib; no axillary vessel groove.

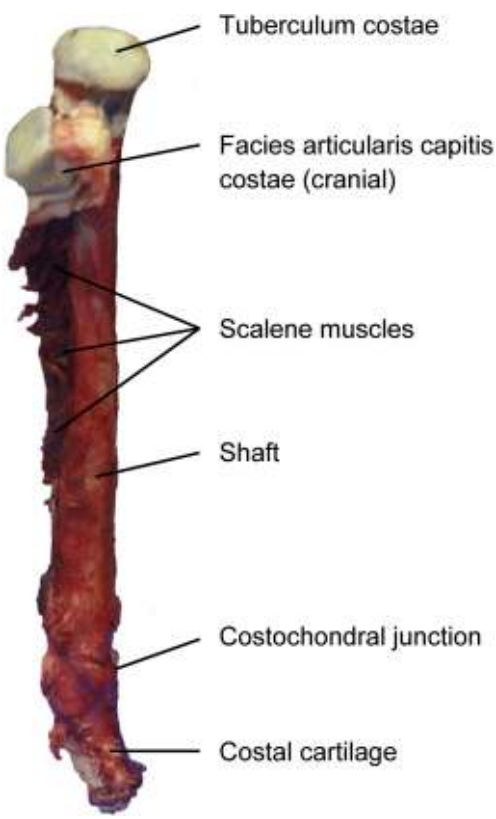

Fig. 5. The left first sternal rib with a straight shaft and medial deviation of the costochondral junction (cranial view) Tb No. 1.

3.4. Thoroughbred No. 4: 8-year-old Mare

Right rib: First sternal rib had a bifid insertion onto the sternum with normal scalene muscle insertions.

Left rib: First sternal rib had a bifid insertion onto the sternum with normal scalene muscle insertions.

Premortem observations: postural left forelimb forward and severely lame left fore.

Euthanasia: Planned due to ongoing reproductive issues (couldn't hold a foal).

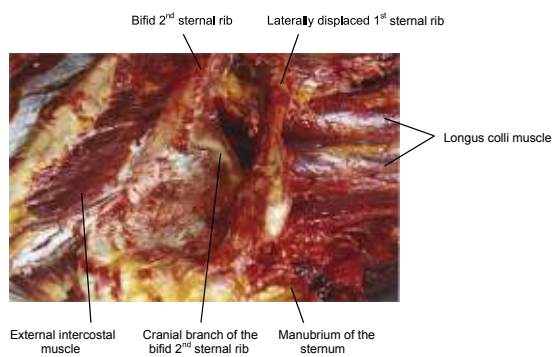

Fig. 6. The cranial branch of the right bifid second sternal rib attaching to the manubrium of the sternum with the first sternal rib displaced laterally (lateral view) Tb No. 2.

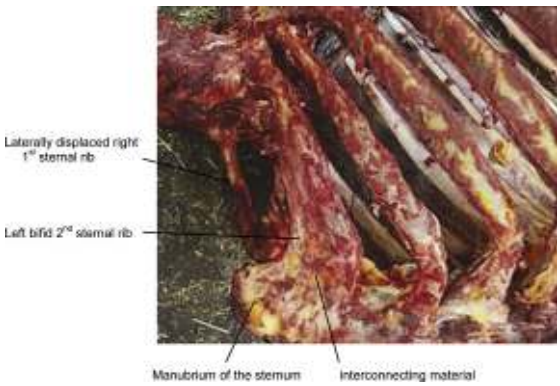

Fig. 7. The left distal bifid second sternal rib (lateral view).

Postmortem: The CVT on the left and right aspect of C6 was absent and had transposed to the ventral surface of C7. In the left fore, severe distal ringbone had fused the interphalangeal joint. No other information was available.

3.5. Thoroughbred No. 5: 6-year-old Gelding

Right rib: First sternal rib displayed a significant flat and flared shaft (Fig. 9A).

Left rib: First sternal rib displayed a bifid tuberculum costae and caput costae that could not articulate correctly into C7 or T1 (Fig. 9B) (Table 4).

Premortem observations: Videos of his 7 race starts noted left and right abduction of the forelimbs at the gallop. The jockey noted that the horse was always difficult to ride mentally and physically and would lug to the inside (right). He rode him in training, track work, and all seven starts.

Euthanasia: It was due to falling unimpeded in a race and fracturing the right fore lateral condyle of the third metacarpal. The jockey noted that the horse "went behind first" before throwing himself forward and breaking the right foreleg.

Postmortem observations: The CVT on the left aspect of C6 was absent and had transposed to the ventral surface of C7. No axillary vessel groove. Fracture of the right fore lateral condyle of the third metacarpal, intermediate tarsal in the left and right hind tarsus, left ilium, and the pubic symphysis was separated.

3.6. Thoroughbred No. 6: 4-year-old Gelding

Right rib: Normal presentation of the first sternal rib.

Left rib: First sternal rib displayed an articulating rudimentary tuberculum costae with a ligamentous extension replacing the bony shaft that attached to a rudimentary sternochondral articulation, as per Bradley [4] (Fig. 3).

Premortem observations: Postural preference left forelimb forward. He struggled to remain balanced when being transported and had a history of falling over when trucked. Veterinarian suspected ataxia.

Euthanasia: It was due to falling over in transport and unable to get up.

Postmortem observations: The CVT on the left aspect of C6 was absent and transposed to the ventral surface of C7. On the left side, the origin of the scalene muscles traversed medially of the ligamentous extension and attached to the second sternal rib. No axillary vessel groove.

There were 2 incidental findings during this study; firstly, Tb No. 5 was the product of a same mare and stallion mating during 6 breeding seasons—the mare aborted twice and delivered a nonviable premature foal on one occasion. She delivered three viable foals, the first "weaved" (filly), the second was diagnosed a "wobbler" (colt), and finally Tb No. 5. Secondly, a bilaterally absent CVT of C6 was found in a Thoroughbred mare and her premature stillborn Quarter horse cross foal that had the same CM as its mother. The Thoroughbred mare had one viable foal and one nonviable foal.

4. Discussion

In this study, the CM of the first sternal rib appeared to be breed related and its concurrent presentation with the CM of C6 and C7 [10] would suggest an embryonic

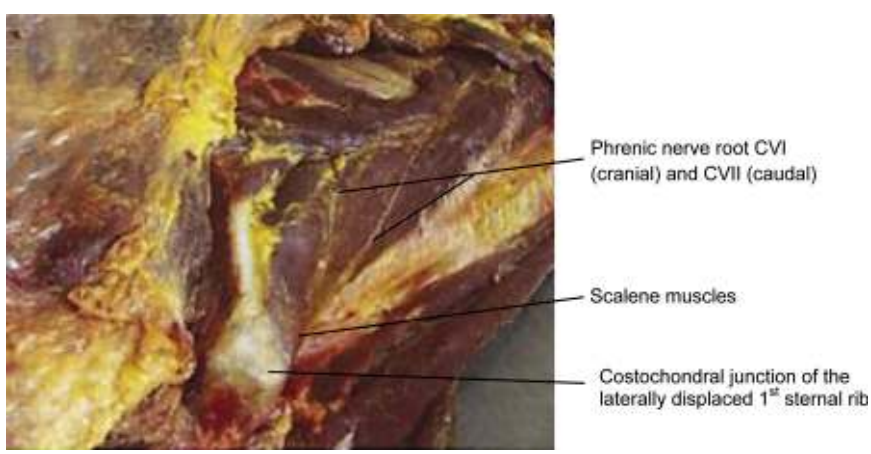

Fig. 8. The scalene muscles attaching to the entire length of the shaft in an abnormal presentation to the laterally displaced right first sternal rib (lateral view). In conjunction with the scalene displacement the Phrenic nerve (roots CVI and CVII) have an altered pathway.

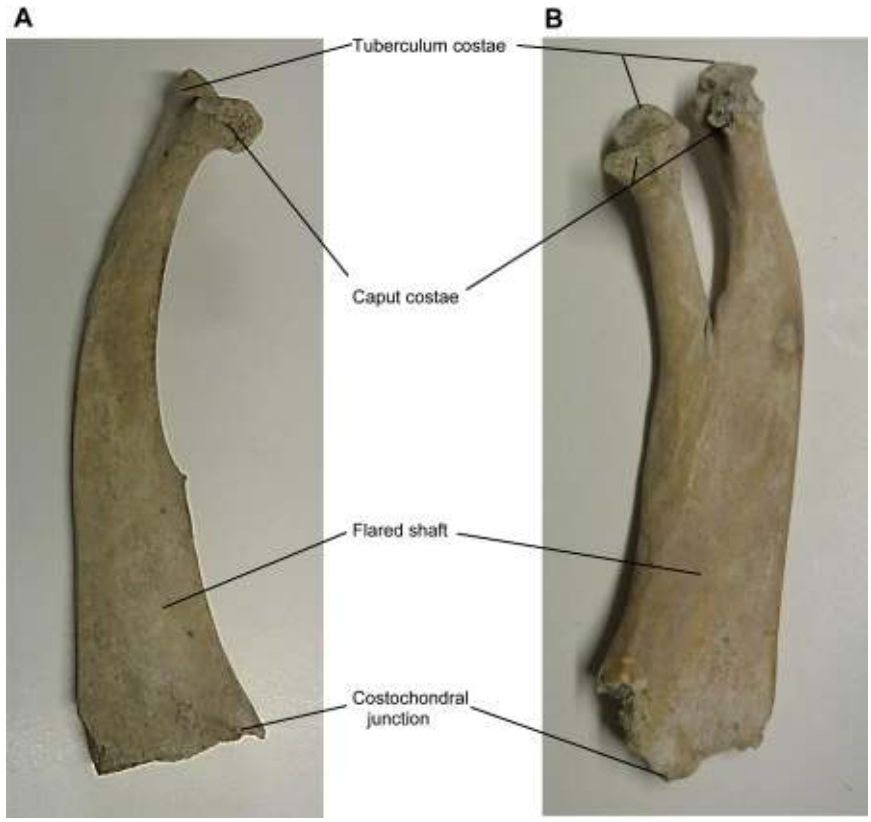

Fig. 9. (A) The right flared first sternal rib (lateral view). (B) The left bifid tuberculum costae first sternal rib (lateral view) Tb No. 5.

mutation similar to that found in Holstein calves [7–9]. Further research identified that CVM in Holstein calves was a recessive syndrome directly linked to a transversion mutation within the SLC35A3 gene high [17] and that an incidence of high embryonic mortality and severe phenotypic abnormalities existed in nonviable calves. This was noted in the present study where embryonic mortality and premature delivery of a nonviable foal were noted in the incidental findings of the siblings of Tb No. 5. Also noted in the incidental findings was a bilaterally absent CVT C6 Thoroughbred mare that delivered a nonviable premature foal with the same C6 expression. This indicates a heritable link that was also noted by Watson and Mayhew [18] in the occipitiatlantoaxial malformation (OOAM) in the Arabian horse. However, unlike Holstein calves displaying CVM and Arabian horses with OOAM, the phenotypic variations in this study are vague and diagnostics are difficult due the proximity of the forelimbs to the thorax and the muscle mass in this region [14–16].

However, in a study of 20 horses tested for front end lameness, bucking, and tacking issues, it was noted that when scintigraphy was used as a diagnostic tool, 52% had lesions involving the first sternal rib, and there were 3 areas of significance to report: (1) the costovertebral articulation (1); (2) sternochondral articulation (4); and (3) the costochondral junction (8) [19]. Of the 20 horses presented, eight Thoroughbreds were used and one displayed a significant nonunion fracture or bony anomaly of the first sternal rib that was unchanged after 5 months and the only horse in the study to exhibit such an anomaly. This 1/8 presentation in the scintigraphy study correlates to the current study of 6 of 60 Thoroughbreds exhibiting a CM of the first sternal rib. Furthermore, the scintigraphy study noted that cranial rib abnormalities could exhibit unusual gait deficits with some characterized by forelimb abduction with decreased extension during protraction at the walk [19]. Similar findings were made by Butler et al [16] in the presence of first sternal rib fractures whereby it could result in forelimb lameness, muscle atrophy, neurological gait deficit, or

Table 4
Measurements of the right first sternal flared rib and the left first sternal bifid rib from Tb No. 5.

Normal Rib	Length, cm	Mid Circum, cm	Distal Circum, cm	Distal Width, cm	Distal Depth, cm	Cartilage Length
Left bifud	26.6	12.4	14.7	6.2	0.57	N/A
Right flared	26.0	9.7	14.0	6.1	0.89	N/A
Mean	26.3	11.0	14.3	6.1	0.73	

Table 5
Observations of 6 mature horses exhibiting a congenital malformation of the first sternal rib.

Tb No.	C6 & C7, L R B	CM 1st rib, L R B	Scalene Deviation	Axillary Vessel Groove Absent	Forelimb Action	Postural Forelimb	Proprioception Dysfunction
1	L	L	Yes	Yes	L Abd	L Fwd	Yes
2	B	B	Yes	Yes	LRom	BW-R Fwd	NA
3	B	R	Yes	Yes	R Abd	BW	Yes
4	B	B	NA	NA	NA	NA	NA
5	L	B	Yes	Yes	B Abd	NA	NA
6	L	L	Yes	Yes	NA	R Fwd	Yes
	3L 3B	2L 3B 1R	5 Yes 1 NA	5 Yes 1 NA	3 Abd 1 Re 2 NA	4 Alt 2 NA	4 Yes 2 NA

Abbreviations: Abd, abduction; B, bilateral; BW, base wide; Fwd, forward; L, left; LRom, limited range of motion; NA, not available; R, right; Tb, Thoroughbred.

abnormal behavior when the horse is tacked up or mounted. In the present study, abduction was noted in the ipsilateral forelimb to the CM of the first sternal rib in 3 of 6 horses; 2 of 6 could not be evaluated premortem, whereas 1 of 6 expressed a limited range of motion in the forelimbs concurrent with severe degenerative changes (Table 5). This would suggest that forelimb abduction coexists with a CM of the first sternal rib. Restricted protraction of the forelimb was noted in the present study, but it coincided with other forelimb defects.

Neurological gait deficit has also been previously mentioned [16], and two horses in this study showed unusual behaviors that could indicate sympathetic neural involvement, notably Tb Nos 2 and 3. While in free exercise, both horses elicited irritation of the ipsilateral forelimb exhibiting a severe CM of the first sternal rib. Tb No. 2 would stop and stamp her right foot repeatedly, and Tb No. 3 would stop and bite at his right forearm. In both horses, the scalene muscles were significantly displaced, and in Tb No. 2, the Phrenic nerve was stretched over the muscle leaving an imprint whilst traversing in a more caudal presentation close to the displaced first sternal rib. Similar findings have been reported in human studies when the relocated scalene muscle elicited neurological impingement resulting in thoracic outlet syndrome [8]. Patients could experience hand atrophy, tender scalenes on palpation plus paresthesia and these symptoms were aggravated with limb abduction. This correlates to Tb No. 2 resenting the limb being lifted, the right fore foot being “clubbed” and stomping the same foot to the ground as if aggravated during exercise. In Tb No. 3, the right scalenes traversed medial of the ligamentous material that replaced the shaft of the first sternal rib and attached to the second sternal rib, this significantly narrowed the thoracic inlet. With this in mind, it could be postulated that compression of the sympathetic nerves elicited the forearm paresthesia and simultaneously, the right recurrent Laryngeal nerve resulting in congenital right Laryngeal hemiplegia.

Subsequently, it is likely that mutational variances of the first sternal rib gives rise to locomotive impediment and postural asymmetry, as noted by the following; 1) the relocation of musculature as noted in Tb Nos 1, 2, 3, 5, 6, influencing the extrinsic muscle groups involved in postural and locomotive functions to the thoracic limb [24]; 2) impediment to the Axillary vessels passing over the cranial surface of the first sternal rib to the forelimb as seen in thoracic outlet syndrome in humans [6] and noted in Tb No. 2 stamping her foot and Tb No. 3 biting his right forearm. In Tb Nos 2, 3, 5, 6, it is likely that the above relationships were in combination due to the relocation of the scalenes and when the presentation was unilateral, left to right asymmetry was quite evident. This impacted upon the Axillary vessels and particularly the phrenic nerve traversing between the scalenes in differing left to right positions. Especially, when the scalenes attached to the second sternal rib as noted in Tb Nos 2, 3, 6 and more so in Tb Nos 3, 6, where they traversed medial of the ligamentous shaft of the congenitally malformed first sternal rib.

The relationship of thoracic musculature to locomotion and respiration has already been well documented in anatomic text and studies. However, when associative musculature relocates or is absent, for example, the scalene muscles, Serratus ventralis thoracis and intercostals; their functional capabilities are altered and particularly when the presentation is asymmetrical [11] as noted in Tb Nos 1, 2, 3, 5, 6. It also brings into question where the pleural sac ends in Tb Nos 2, 3, 5, 6 and the potential for this to impact upon respiration. This assumption is based upon the transverse and dorso-ventral changes in the thorax during asymmetrical gaits [4] being compounded by a congenitally malformed thoracic inlet, as noted in all those horses in this study. As the thoracic inlet is a pathway for major structures any deviation to it could be an impediment with detrimental effects, for example the Phrenic nerve passing between the scalene muscles and entering the thoracic inlet in close proximity to the first sternal rib [2,25]. Its involvement in a number of visceral structures such as the pericardium and diaphragm must raise questions as to the potential for its function to be impaired, especially as the primary roots descend from the sixth and seventh cervical nerves. Such combined deviations to normal anatomy of the cervicothoracic junction and thoracic inlet must raise questions as to the function of all those structures involved and the genetics behind such variations.

5. Conclusion

This study showed that of the 151 horses investigated, 6 of 60 Thoroughbred horses displayed a CM of the first sternal rib, and that this CM was breed related. Furthermore, it only appeared in the presence of a congenitally malformed C6 and C7, and this implies a genetic mutation as found in Holstein calves. In addition, correlating data and incidental findings noted embryonic mortality in four

potential siblings of Tb No. 5; that Tb No. 4 could not hold a foal and one CM C6 mare delivered a premature non-viable foal exhibiting an inherited CM of C6. Furthermore, as the CM of the first sternal rib in this study was concurrent only with a CM of C6 and C7, it could be surmised that when this condition is positively radiographed, that a CM of the first sternal rib could coexist in 55.5% of those horses.

With this in mind, it would be the recommendation of this author that this CM of the cervicothoracic junction and thoracic inlet be further investigated so to isolate a predisposition to a potential genetic mutation as per Holstein calves.

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References

[1] Frandson RD, Spurgeon TL. Anatomy and physiology of farm animals. 5th ed. Philadelphia: Lea & Feberger; 1992.
[2] Sisson S, Grossman JD. The anatomy of the domestic animals. 5th ed. Philadelphia: Saunders; 1975.
[3] Bradley O. The topical anatomy of the head and neck of the horse. 2nd ed. Edinburgh: Green and Sons; 1947.
[4] Thorpe CT, Marlin DJ, Franklin SH, Colbourne R. Transverse and dorso-ventral changes in thoracic dimension during equine locomotion. Equine Vet J 2009;179:370–7.
[5] Hodgson DR, Rose RJ. The athletic horse. Philadelphia: W.B. Saunders; 1994.
[6] Bradley OC. A case of rudimentary first thoracic rib in the horse. J Anat Physiol 1901;36:54–62.
[7] Gladstone RJ, Wakeley CP. Cervical ribs and rudimentary first thoracic ribs considered from the clinical and etiological standpoints. J Anat 1932;66:334–70.
[8] Sanders RJ, Hammond SL. Management of cervical ribs and anomalous first ribs causing neurogenic thoracic outlet syndrome. J Vasc Surg 2002;36:51–6.
[9] Agerholm JS, Bendixen C, Andersen O, Arnbjerg J. Complex vertebral malformation in Holstein calves. J Vet Diagn Invest 2001;13:283–9.
[10] Nagahata H, Oota H, Nitanai A, Oikawa S, Higuchi H, Nakade T, Kurosawa T, Morita M, Ogawa H. Complex vertebral malformation in a stillborn Holstein calf in Japan. J Vet Med Sci 2002;64:1107–12.
[11] Agerholm J, Bendixen C, Arnbjerg J, Andersen O. Morphological variation of "complex vertebral malformation" in Holstein calves. J Vet Diagn Invest 2004;16:548–53.
[12] Evans HE, de Lahunta A. Miller's anatomy of the dog. 2nd ed. Missouri: Saunders; 2013.
[13] Rutherford Dow A. The anatomy of rudimentary first thoracic ribs with special reference to the arrangement of the brachial plexus. J Anat 1925;59:166–79.
[14] May-Davis SE. The occurrence of a congenital malformation in the sixth and seventh cervical vertebrae predominantly observed in Thoroughbred horses. J Equine Vet Sci 2014;34:1313–7.
[15] May-Davis SE, Walker C. Variations and implications of the gross morphology in the Longus colli muscle in Thoroughbred and Thoroughbred derivative horses presenting with a congenital malformation of the sixth and seventh cervical vertebrae. J Equine Vet Sci 2015;35:560–8.
[16] Ross MW, Dyson SJ. Diagnosis and management of lameness in the horse. 2nd ed. Missouri: Saunders; 2011.
[17] Jean D, Laverty S, Halley J, Hannigan D, Leveille R. Thoracic trauma in newborn foals. Equine Vet J 1999;31:149–52.
[18] Schambourg MA, Laverty S, Mullim S, Fogarty UM, Halley J. Thoracic trauma in foals: post mortem findings. Equine Vet J 2003;35:78–81.
[19] Jean D, Picandet V, Macieira S, Beauregard G, D'anjou MA, Beauchamp G. Detection of rib trauma in newborn foals in an equine critical care unit: a comparison of ultrasonography, radiology and physical examination. Equine Vet J 2010;39:158–63.
[20] Butler JA, Colles CM, Dyson SJ, Kold SE, Poulos PW. Clinical radiology of the horse. 3rd ed. Chichester: Wiley-Blackwell; 2008.
[21] Thomsen B, Horn P, Panitz F, Bendixen E, Petersen AH, Holm LE, Nielsen VH, Agerholm JS, Arnbjerg J, Bendixen C. A missense mutation in the bovine SLC35A3 gene, encoding a UDP-N-acetylglucosamine transporter, causes complex vertebral malformation. Genome Res 2006;16:97–105.
[22] Watson A, Mayhew I. Familial congenital occipitiatlantoaxial malformation (OOAM) in the Arabian horse. Spine 1986;11:334–9.
[23] Dahlberg JA, Ross MW, Martin BB, Davidson EJ, Leitch M. Clinical relevance of abnormal scintigraphic findings of adult equine ribs. Vet Radiol Ultrasound 2011;53:573–9.
[24] Payne RC, Veenman P, Wilson AM. The role of the extrinsic thoracic limb muscles in equine locomotion. J Anat 2004;2004:479–90.
[25] de Lahunta A, Glass E, Kent M. Veterinary neuroanatomy and clinical neurology. 4th ed. St. Louis: Elsevier Saunders; 2015.