# Biomechanics of Thorax

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## Introduction

The contribution of thorax about 20 percent to the overall length of the body comparison to 12 percent of the lumbar spine and 8 percent of the cervical spine.[1] The thoracic wall is bounded anteriorly by the sternum laterally by the ribs and posteriorly by the thoracic vertebrae as well as superiorly by the suprapleural membrane and inferiorly by the respiratory diaphragm.[2] functions of thoracic cage is 1) provides a base for the muscle attachment of the upper extremities, the head and neck, the vertebral column and the pelvis. 2) this provides protection for the heart, lungs and viscera.[3] The anterior chest wall sternum include the thick manubrium, The most superior portion of the manubrium is called jugular notch, and it is also the first to form during embryogenesis. Anatomically, the manubrium is located at the level of thoracic vertebral bodies T3 and T4, the manubrium is also the widest and thickest segment of the sternum, the middle long part is called body of the sternum, and inferior part of sternum called xiphoid process. The sternal body is located at the level of vertebral bodies T5 to T9, covers a significant portion of the mid-chest, and is very strong. The xiphoid process is a thin and very small bone, this may appear bifid, oval, or curve inward or outward and the bone's size may vary from 2 to 5 cm.[2] The ribs are the bony framework of the thoracic cavity, there are twelve pairs of ribs. According to their attachment to the sternum, the ribs are classified into three groups: true, false, and floating ribs. the first seven ribs are called true ribs as they are ribs that directly articulate with the sternum with their costal cartilages. the eighth, ninth, and tenth ribs are called false ribs, these ribs are indirectly articulate with the sternum, as their costal cartilages connect with the seventh costal cartilage. 11$^{th}$ and 12$^{th}$ ribs are called floating ribs as the ribs that do not articulate with the sternum at all. [4]

## General structure and functions of thoracic cage

### Sternum

Sternum lies in the midline of the anterior chest wall. It is a flat bone divided into three parts: manubrium sterni, body of sternum and xiphoid process.[5] The manubrium is the widest and thickest of these segments, situated superiorly.[6] The Jugular notch is at the manubrium's superior border, palpable between the clavicular heads.[6] This nearly triangular bone measures 4 cm in length and lies at the level of the T3 and T4 bodies.[6] The sternal angle lies at the T4 to T5 intervertebral (IV) disk level. The term xiphoid process comes from the word "xiphos," which is of Greek origin and means straight sword describing the morphology of this bone.[7] This is approximately 2 to 5 cm in length, the xiphoid is primarily triangular, with its base directed superiorly and the tip pointing inferiorly at the level of the T10 vertebra.[7] figure 1 showed part of sternum.

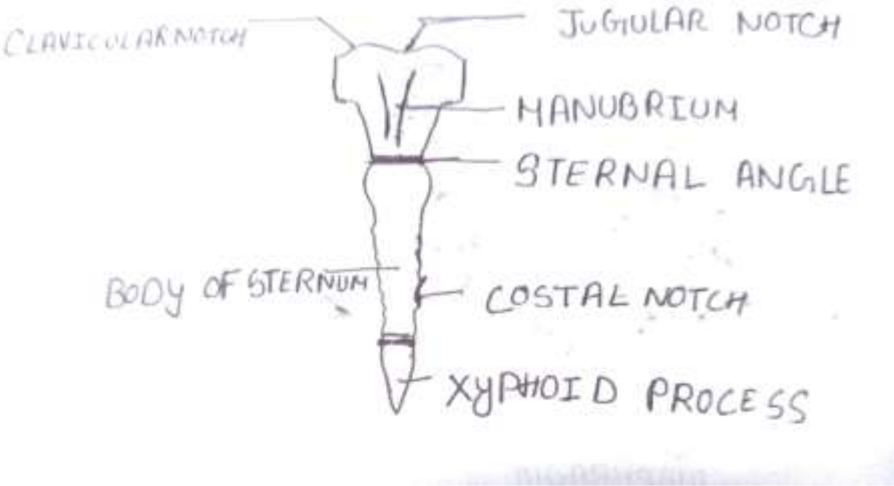


**Fig 1- manubrium sterni, body of sternum & xyphoid process**

**Ribs**

Ribs are curved, flat bones that attach posteriorly to vertebrae and anteriorly to the sternum.[8] Ribs are classified according to morphologically and according to their attachment with the costal cartilage anteriorly.[9] Morphologically, they are classified into typical or atypical ribs based on their anatomic features.[9] Morphologically the typical rib consists of a head, neck and body. Fig 2 shown parts of typical ribs. The head is wedge shaped, and has two articular facets separated by a wedge of bone. One facet articulates with the numerically corresponding vertebra, and the other articulates with the vertebra above, the neck contains no bony prominences, but connects the head with the body and the neck meets the body there is a roughed tubercle, with a facet for articulation with the transverse process of the corresponding vertebra.The body or shaft of the rib is flat and curved. The internal surface of the shaft has a groove for the neurovascular supply of the thorax.[8,7].

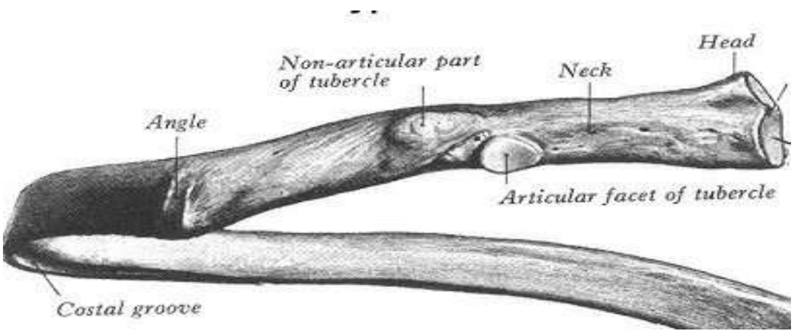


**Fig 2: Typical Rib**

Ribs 1, 2, 10 11 and 12 can be described as 'atypical' – they have features that are not common to all the ribs.Rib 1 is shorter and wider than the other ribs. It only has one facet on its head for articulation with its corresponding vertebra. Rib 2 is thinner and longer than rib 1, and has two articular facets on the head.Rib 10 only has one facet for articulation with its numerically corresponding vertebra.Ribs 11 and Rib 12 have no neck, and only contain one facet, which is for articulation with their corresponding vertebra. Figure 3 showed below for atypical ribs. Fig 4 shown in this chapter classification of ribs according to attachment with their costal cartilages, Ribs 1 through 7 are considered true ribs and attach directly to the sternum.[8] ribs 8 through 10 are considered false ribs in which the cartilage of each rib attaches to the cartilage of the rib above it, which terminates where the seventh rib attaches to the sternum.[8] Ribs 11 and 12 are considered floating ribs because they terminate in the posterior abdominal musculature and do not attach to the sternum.[8]

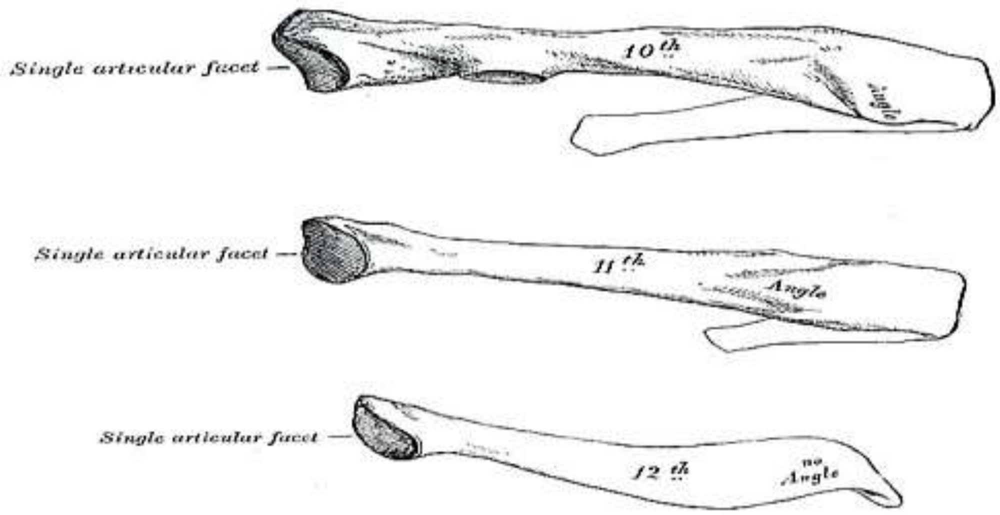


**Fig 3: posterior view of Atypical Ribs**

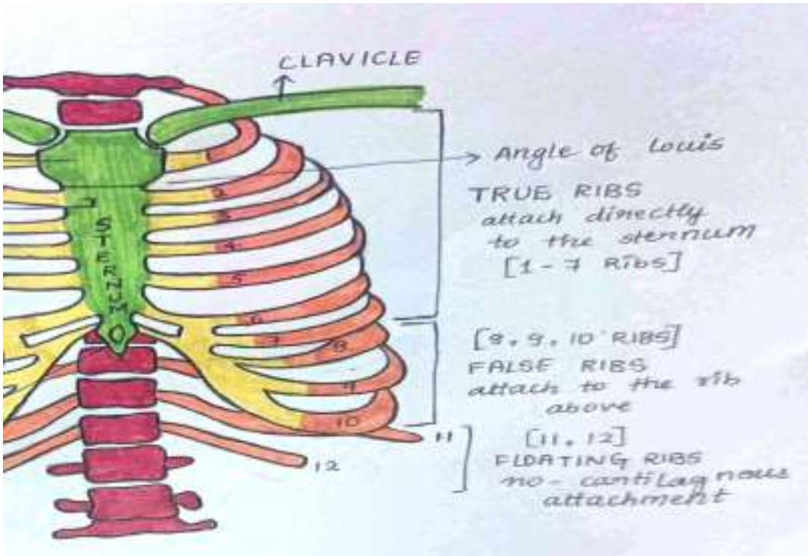


**Fig 4: True Ribs, False Ribs and Floating Ribs**

## <u>Articulation of Rib Cage</u>

### Manubriosternal joint and xiphisternal joint

The manubriosternal joint is an synarthrosis joint formed by the manubrium and sternum.[10] The body of sternum articulates with the manubrium and forms manubriosternal joint or Angle of Louis and below it articulates with the xiphoid process and forms the xiphisternal joint.[5] The Manubrium articulates with the body of the sternum at the manubriosternal joint and suprolaterally it articulates with the clavicle and with the first costal cartilage and the upper part of the 2nd costal cartilages on each side.[5] In figure 5 explained about manubriosternal joint and xiphisternal joint with their attachment, the manubrium and sternal body lie in different planes, hence, the angulation at the manubriosternal joint, the 2nd costal cartilage articulates with the lateral border of the joint. Thus, the angle of Louis is a convenient starting point for counting ribs anteriorly as the 1st rib is non palpable below the clavicle.[6] The angle of Louis is palpable as a transverse ridge in most individuals.[6] The proximal ribs, costal cartilage, and sternum are powerfully joined together with fibrous networks. These initiate as periosteum on the ribs, continue over costal cartilage then it forms the sternocostal joint capsule. These powerful fibrous networks then unite anteriorly and posteriorly on the sternum as sternocostal ligaments. This network and its innate strength makes the Manubriosternal very stable and resistant to dislocation.[10] The base of the xiphoid process articulates with the lower end of the body of the sternum forming the xiphisternal joint.[7] At birth, the xiphoid is purely cartilaginous and is made of 2 types of cartilage hyaline cartilage and elastic cartilage. Proximal portion made up of hyaline cartilage and distal part is made up of elastic cartilage.With growning age, the xiphoid process ossifies.[7] In elderly individuals manubriosternal joint and xyphisternal joint get fused completely with body of sternum superiorly and inferiorly.[6,7.5]

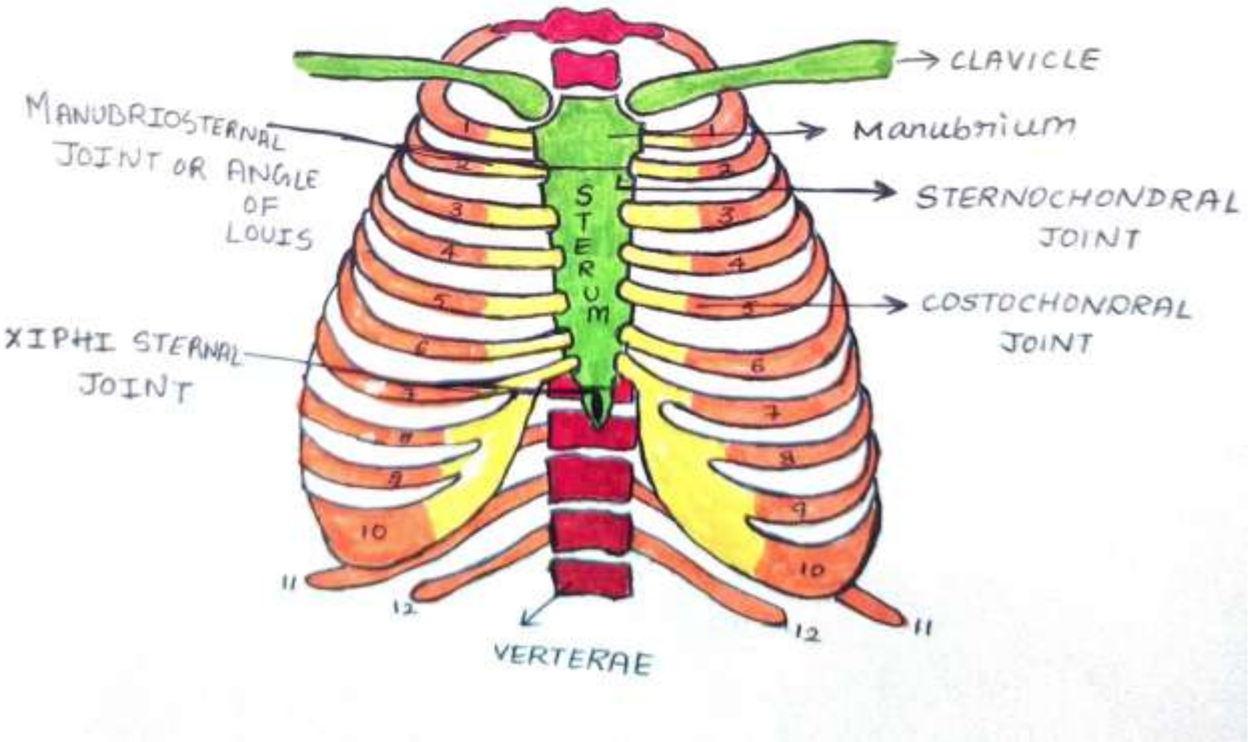


**Fig 5- a) manubriosternal joint or angle of Louis which gives articulation of 2nd rib**
**b) xiphisternal joint**

**Costovertebral joint**

The costovertebral joints and the rib cage have an important role in providing stability to the thoracic spine.[11] The costovertebral articulation is composed of two joints: the rib head joint, also called costocentral articulation and the costotransverse joint. The costocentral joint links the rib head with the vertebral bodies, it includes a capsule, the radiate and the interarticular ligaments.[11] The biomechanical properties of the costovertebral joint were first investigated by Schultz, he performed in vitro studies using five human costovertebral articulations at six rib levels by measuring the displacements in superior-inferior, posterior-anterior and medial-lateral direction and his results indicated that the stiffness varies depending on the loading direction and the rib level. The stiffness of the Costovertebral joint increased from T1 to the mid-thoracic region, and decreased towards the lower rib levels.[1] fig 6 explained costovertebral joint with red color, where head of the rib adjoined with vertebral body to form costovertebral joint. The axis of rotation of the costovertebral joint is not fixed, hence the kinematics cannot be represented by a single axis pivot element.[12] the axis of rotation of the joint is not in line with the anatomical axis of the rib neck axis during respiration, the Costovertebral Joint adheres to a moment angle relationship.[12] Kindig et al. noticed in his study in 2013 the total rib movement depends strongly on the stiffness of the costovertebral joint. He showed that the stiffness of the costovertebral affected mainly the magnitude, rather than the direction of rotation of the ribs.[13] costovertebral complex plays an important role in stabilizing, moving, supporting the load and protecting the rib cage, having a powerful influence on the physiological gestures of mobility, and ventilatory breathing movements.[14]

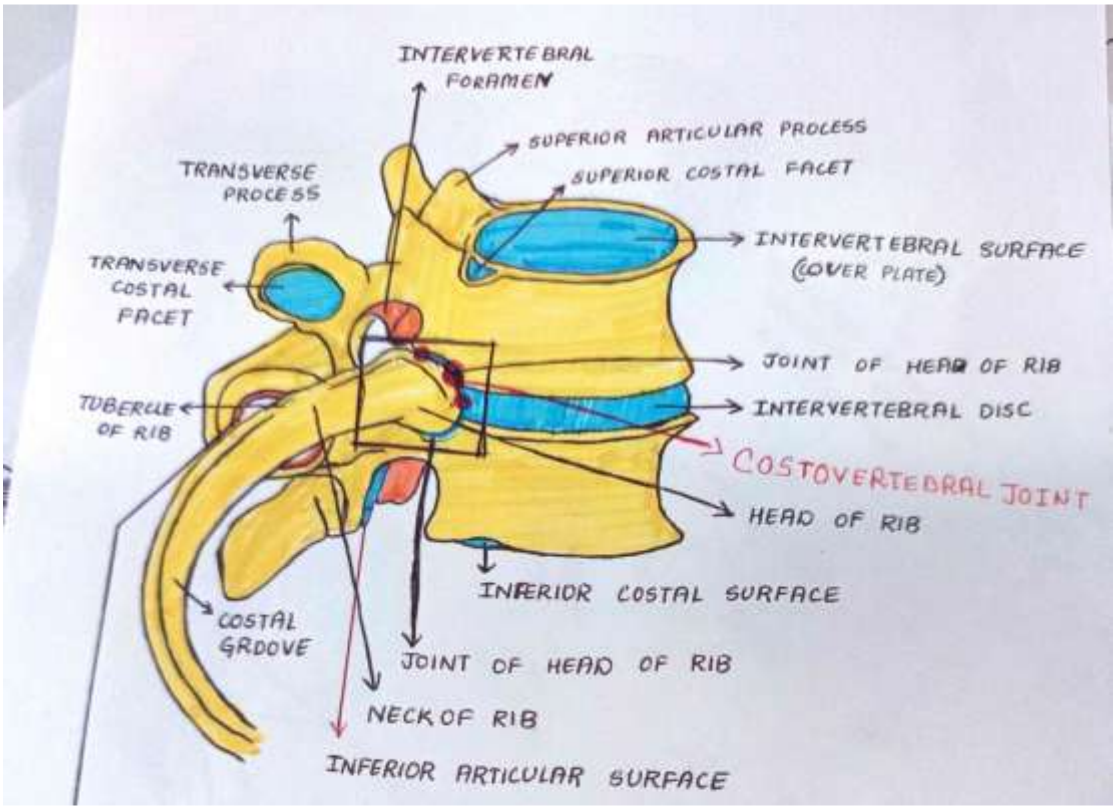


**Fig 6: with red color dots showing head of the rib adjoins with vertebral body and forms Costovertebral joint.**

**Costotransverse joint**

The costotransverse joint connects the rib tubercle with the transverse process of the vertebra, it is made up of a capsule, the anterior and posterior costotransverse ligaments, the neck and tubercle ligaments.[11] The costotransverse joint connects the ribs to the transverse process of the thoracic vertebrae. On the ribs, the costotransverse joint of the ribs are located a few centimeters from the head of the rib on ribs 1-9, figure 7 and figure 8 are shown below which explained formation of costotransverse joint and its articulation. These rib joints function to both protect the body by forming the ribcage and are given slight mobility due to the nature of the inflation of the lungs and other respiratory function.[15]

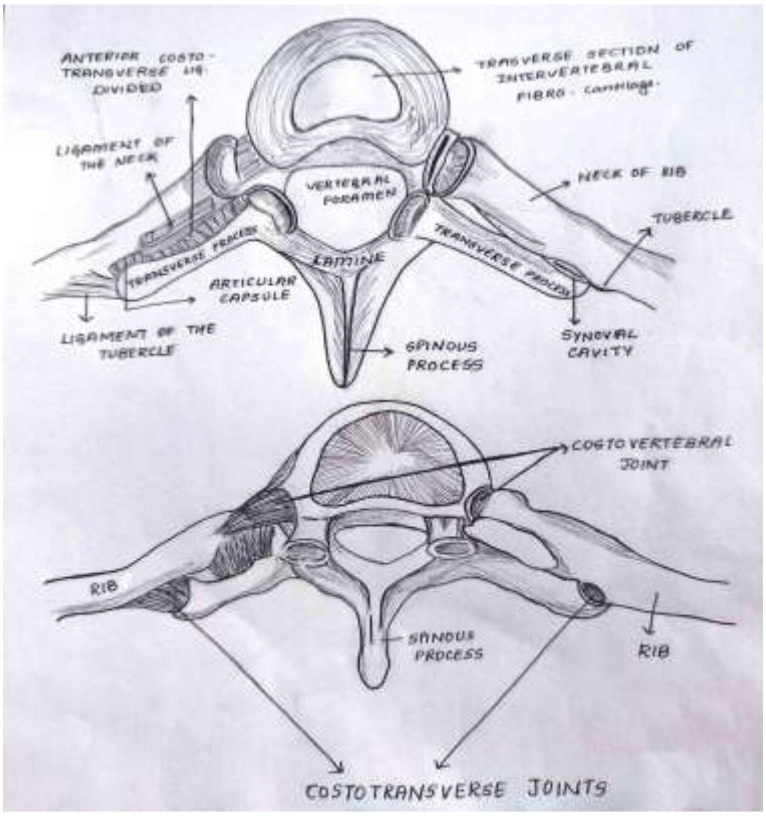


**Fig 7: attachment of costotransverse joint**

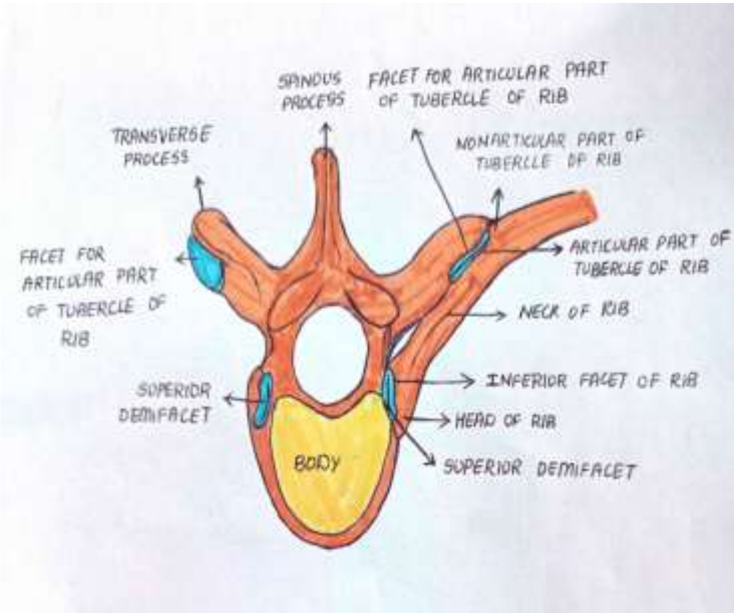


**Fig 8: costotransverse joint**

The costovertebral joints and the costotransverse joints are mechanically related by their natural dependent movements as they have a common horizontal axis of rotational movement passing through the center of these two joints. The costotransverse joint reciprocally has a natural dependence on the costovertebral joint movements, as they have a common anterior-posterior joint axis.[14]

**Costochondral and Chondrosternal joint**

Costochondral joints are formed by the articulation of the 1st rib through 10th ribs anteriorly and laterally with the costal cartilages. The costochodral joints are synchondroses.[16] The chondrosternal joints are formed by the articulation of the costal cartilages of rib 1 through 7 anteriorly with the sternum. The chondrosternal joints of ribs 1,6 and 7 are synchrodroses. Chondrosternal joints of ribs 2nd to 5th are synovial joint. [17]

**Kinematics of the ribcage**

There are two types of motions seen in the ribcage, the pump handle motion seen on upper ribs and the bucket handle motion in lower ribs.[18] On pump handle motion, the movement is limited by joint articulations from anteriorly and posteriorly. The upper ribs move upward because of the costosternal joint, the sternum follows by moving forward and gliding upward. This thoracic movement increases the anterior posterior diameter and depth of the thorax.[18] in figure 9 pump hand movement explained, the rib cage expands during inspiration to make possible an increase in lung volume and to increase the negative intra thoracic pressure which is generated by the diaphragm. The expansion of the rib cage occurs along with two dimensions: an increase in the anterior and posterior diameter in the sagittal plane and an augment in the transverse diameter in the coronal plane, which is called bucket handle rib cage motion.[19] which is explained in figure 9.

The anatomy of the ribs and their attachments with the thoracic vertebrae increase the dimensions of the rib cage involves a combination of movements that lifts the entire rib cage transversely relative to the spine. Individually each rib glides about the hinge-like costovertebral and costotransverse joints in a predominantly upward and outward motion, these two components of rib motion are commonly referred to as pump-handle and bucket-handle movements.[19] Figure 10 and figure 11 shown bucket handle movement and how rib cage helps in respiration.

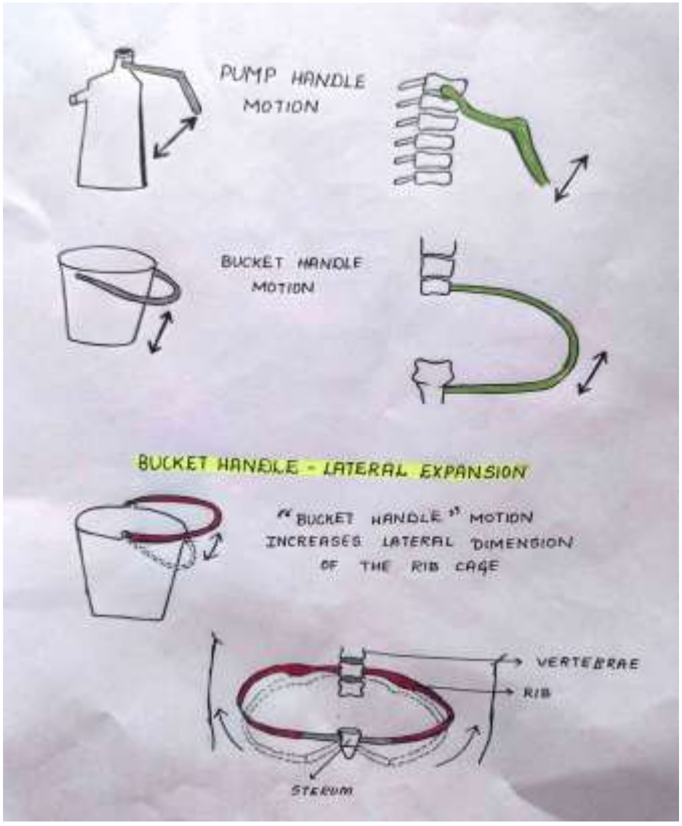


**figure 9: shows a) upper rib cage pump form handle movement. b) lower rib cage form bucket handle movement**

Wilson et al.[20] who described pump-handle movement as the component of angular rotation of each rib in the sagittal plane and bucket handle movement as the component of angular rotation of each rib in the coronal plane.[19] Wilson et al.[20,21] used computed tomography scans of the thorax to create three dimensional models of the ribs from which they determined the angular rotations needed to transform an axial plane to align with the best-fit plane passing through each rib. Pump handle motion to describe the rotation of the ribs that primarily affects the anteroposterior diameter of the rib and bucket-handle movement to describe the rotation that mainly contributes to changes in the transverse diameter of the rib cage, pump angles were smaller and bucket angles were larger. [19]

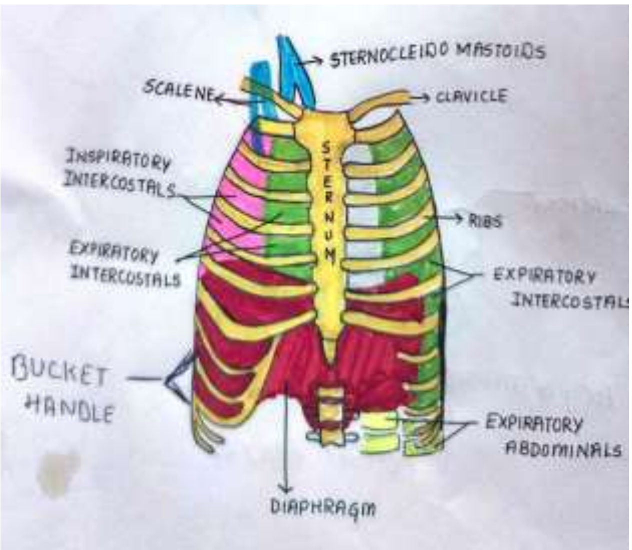


**figure 10: shows during inspiration elevation of lower rib cage transverse diameter which is called bucket handle motion.**

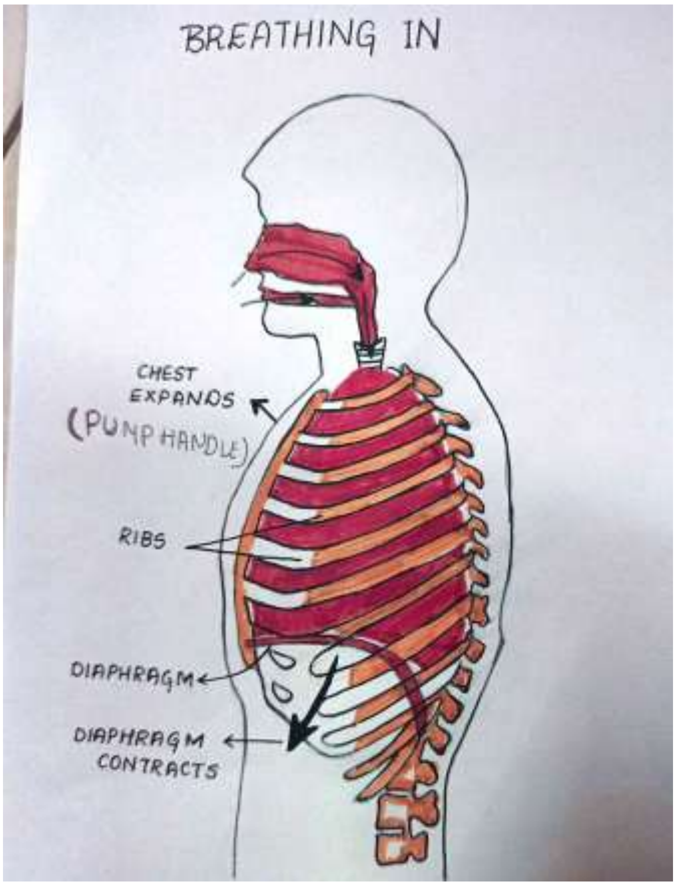


**Fig 11: during inspiration upper rib cage moving anteroposteriorly, hence elevation of anteroposterior diameter to accommodate inspiratory volume.**

**Muscles help in respiration**

**Inspiratory muscles**

**Diaphragm**

The diaphragm is the primary muscle of inspiration, this is a thin, flat, musculotendinous structure separating the thoracic cavity from the abdominal wall. The muscle fibers of the diaphragm radiate from the central tendon to either the three lumbar vertebral bodies (i.e. crural diaphragm) and to the inner surfaces of the lower six ribs (i.e. costal diaphragm). The tension within the diaphragmatic muscle fibers during contraction generates a caudal force on the central tendon that moves downward in order to expand the thoracic cavity along its craniocaudal axis. In addition, the costal diaphragm fibers apply a force on the lower six ribs which lifts and rotates them outward.

**External Intercostals muscle**

The external intercostals muscles are thin layers of muscle fibers that run obliquely descends and ventrally from each rib to the neighboring rib below.[22] The lower insertion of the external intercostals muscles is more distant from the ribs axis of rotation than the upper one and as a result, contraction of this muscle exerts a larger force acting on the lower rib which lift of the lower rib with respect to the upper one,[22] the net effect of the contraction of these muscles raises the rib cage. [21]

**Sternocleidomastoid and Scalene**

The sternomastoid and the scalene muscles are secondary muscles of inspiration. The sternomastoid muscles descend from the mastoid process to the ventral surface of the manubrium sterni and the medial of the clavicle. The scalene muscles composed three bundles that run from the transverse processes of the lower five cervical vertebrae to the upper surface of the first two ribs, Contraction of these muscles raises the sternum and the first two ribs hence this assists in expanding the rib cage.[23]

**Internal Intercostals muscle**

The internal intercostals muscle fibers are run obliquely downward and dorsally from each rib to the neighboring rib below. The lower insertion of these muscles is less distant from the ribs axis of rotation than the upper one and during their contraction they pull the ribs down. [24,25]

**Abdominal Muscles**

The four abdominal muscle pairs forming the abdominal wall are the rectus abdominis, external oblique, internal oblique and transverse abdominis. The rectus abdominis is the most ventral one that runs caudally from the ventral aspect of the sternum and the 5th, 6th and 7th costal cartilages along the length of the abdominal wall to its insertion into the pubis. The external oblique is the most superficial that originates from the external surface of the lower eight ribs, well above the costal margin, and covers the lower ribs and intercostals muscles. Fibers of this muscle radiate caudally to the iliac crest and inguinal ligament and medially to the linea alba. The internal oblique lies deep to the external oblique, its fibers arise from the inguinal ligament and iliac crest and insert into the anterolateral surface of the cartilages of the last three ribs and into the linea alba. The transverse abdominis is the deepest muscle of the lateral abdominal wall. Its fibers run around the abdominal visceral mass from the inner surface of the lower six ribs, lumbar fascia, iliac crest and the inguinal ligament to the rectus sheath. Contraction of the abdominal muscles pulls the abdominal wall inward causing the diaphragm to move cranially into the thoracic cavity and pulls the lower ribs caudally to deflate the ribcage.[26] Here diagram a) showed muscles for respiration around rib cage. B) hoe muscle helps in in respiration.

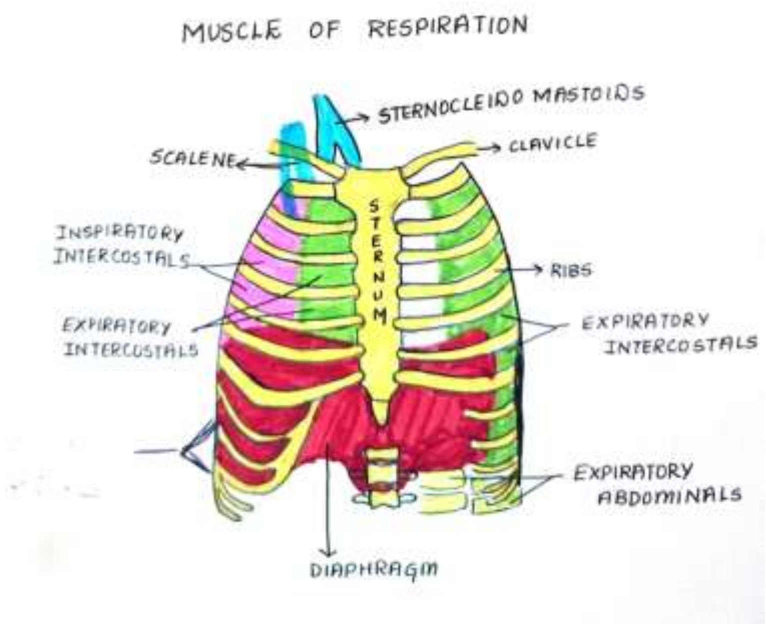


**Figure a- location of inspiratory ( primary and secondary) and expiratory muscles (during forceful expiration.**

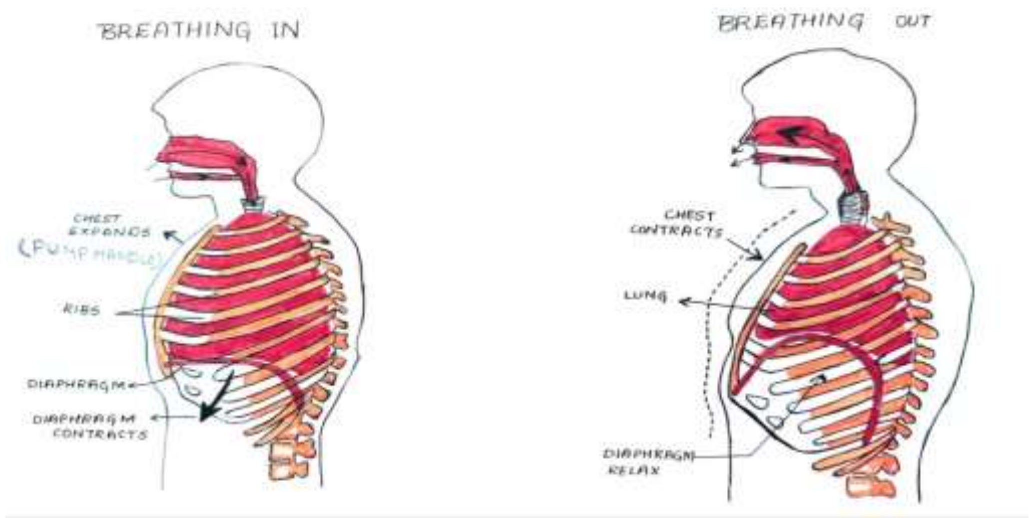


**Figure b- explains normal inspiration, in which diaphragm contracts and descends downward and upper chest moves upward and outward with the help of intercostals muscles, hence anteroposterior diameter increases for ventilation as well as lower ribs move obliquely outward hence transverse diameter of lower rib cage increases for lower lobes ventilation.**

**Pathomechanics**

**COPD**

Muscle dysfunction is defined as the loss of the two main muscle properties: strength and endurance. This is characterizedby the ability to maintain a submaximal exercise load through-out a more prolonged period of time, strength depends on muscle mass, muscle resting length, velocity of shortening, and the recruitment pattern of motor units. endurance is mainly determined by the coordination of all different elements involved in oxygen delivery and utilization by the muscle type I fiber proportion, capillary density,and oxidative enzyme activities. The function of respiratory muscles which is frequently impaired in COPD patients, may contribute to hypercapnic respiratory failure and exercise limitation. Inspiratory muscle dysfunction is associated with increased risk for repeated hospital admissions. As already mentioned, respiratory muscle dysfunction in COPD is caused by the combination of different local and systemic factors, On the other side muscles are facing an increase in mechanical ventilatory loads. Since COPD is mainly characterized by airflow limitation, pulmonary hyperinflation and increased compliance, which is having important mechanical consequences. Different elasticity of parenchyma, resistive caused by air passage through the narrowed airways and threshold which is derived from the intrinsic positive and end expiratory pressure results increase work of breathing and overloading on respiratory muscles. On the other hand static pulmonary hyperinflation, shortening the diaphragmatic length, asituation that can be even accentuated by dynamic pulmonaryhyperinflation. The diaphragm displace away from its optimal length to generate force, and its costal and crural parts probably become less coordinated. All these factors lead to a mismatching between mechanical requirements of the respiratory system and functional capacity of the ventilatory muscles as well as between the metabolic demands and the energy supply to these muscles.[27]

**REFERENCE**

1. The thorax and integrated approach. Diane Lee. Forwarded Gregory S Jhonson. Handspring publishing. 2018.

2. Hussain A, Burns B. Anatomy, Thorax, Wall. In: StatPearls. StatPearls Publishing, Treasure Island (FL); 2023.

3. Pamela K Levangie, Cynthia C Norkins. Joint structure and function. 5th edition. Jaypee publisher. 2011.

4. Safarini OA, Bordoni B. Anatomy, Thorax, Ribs. StatPearls Publishing; 2024 Jan.

5. Richard s snell. Clinical anatomy. 9th edition. Lipincott wiliams and wilkins.

6. Ball M, Falkson SR, Adigun OO. Anatomy, Angle of Louis. StatPearls Publishing;2023.

7. Anderson BW, Holme MR, Alkhammash L, Burns B. Anatomy, Thorax, Xiphoid Process. StatPearls Publishing; 2023.

8. Donley ER, Holme MR, Loyd JW. Anatomy, Thorax, Wall Movements. StatPearls Publishing;2023.

9. Haase, Douglas R. MDa; Shaikh, Humza S. MDb. Anatomy of the Ribs, Sternum, and Costal Margin. Journal of Orthopaedic Trauma.38(12S):p S1-S6, December 2024.

10. Alent, J., Narducci, D.M., Moran, B. *et al.* Sternal Injuries in Sport: A Review of the Literature. *Sports Med* **48**, 2715–2724 (2018).

11.S onia Duprey, Damien Subit, Hervé Guillemot, Richard W. Kent. Biomechanical properties of the costovertebral joint. Medical Engineering & Physics. Volume 32, Issue 2. 2010. Pages 222-227.

12. Schlager, B., Niemeyer, F., Liebsch, C., Galbusera, F., Boettinger, J., Vogele, D., & Wilke, H. J. Influence of morphology and material properties on the range of motion of the costovertebral joint – a probabilistic finite element analysis. *Computer Methods in Biomechanics and Biomedical Engineering*, *21*(14), 731–739.

13. Kindig M, Li Z, Kent R, Subit D. 2013. Effect of intercostal muscle and costovertebral joint material properties on human ribcage stiffness and kinematics. Comput Methods Biomech Biomed Engin. 18:556–570.

14. Antonio J & Costa B.Unusual costotransverse joints found in laboratory bones. International journal of cadaveric studies & anatomic variations. 2020.1(1),1-4.

15. Keeling BA. Frequency of Costovertebral and Costotransverse Osteoarthritis in the Schroeder Mounds Site. Field Notes: A Journal of Collegiate Anthropology. 2019;10(1):12.

16. Moore K L, Dalley A F, Agur A R. Clinically oriented anatomy 6th ed. Baltimore, Lippincott Wiliams & Wilkins. 2010.
17. Winkel D. Diagnosis and treatment of the spine. Gaithersberg,MD,Aspen.1996.

18. pheasant S. The aging bony thorax. A comprehensive guide to geriatric rehabilitation. Elsevier. 3rd edition.

19. Billy L. Luu, Rhys J. McDonald, Bart Bolsterlee, Martin E. Héroux, Jane E. Butler, and Anna L. Hudson.Movement of the ribs in supine humans for small and large changes in lung volume Journal of Applied Physiology 2021 131:1, 174-183.

20. Wilson TA, Rehder K, Krayer S, Hoffman EA, Whitney CG, Rodarte JR. Geometry and respiratory displacement of human ribs. J Appl Physiol (1985) 62: 1872–1877, 1987.

21. Wilson TA, Legrand A, Gevenois PA, De Troyer A. Respiratory effects of the external and internal intercostal muscles in humans. J Physiol 530: 319–330, 2001.

22. Anat Ratnovsky, David Elad, Pinchas Halpern. Mechanics of respiratory muscles.Respiratory Physiology & Neurobiology.163;1–3.2008.Pg 82-89.

23. Ratnovsky, A., Zaretsky, U., Shiner, R.J., Elad, D., 2003. Integrated approach for in vivo evaluation of respiratory muscles mechanics. J. Biomech. 36 (12), 1771–1784.

24. De Troyer, A., Kirkwood, P.A., Wilson, T.A., 2005. Respiratory action of the intercostal muscles. Physiol. Rev. 85 (2), 717–756.

25. Cassart, M., Hamacher, J., Verbandt, Y., Wildermuth, S., Ritscher, D., Russi, E.W., de Francquen, P., Cappello, M., Weder, W., Estenne, M., 2001. Effects of lung volume reduction surgery for emphysema on diaphragm dimensions and configuration. Am. J. Respir. Crit. Care Med. 163 (5), 1171–1175.

26. De Troyer, A., 1997. The respiratorymuscles. In: Crystal, R.G. (Ed.), The Lung: Scientific Foundation. Lippincott Raven, Philadelphia, pp. 1203–1215.

27. Gea J, Agustí A, Roca J. Pathophysiology of muscle dysfunction in COPD. Journal of applied physiology. 2013 May 1;114(9):1222-34.