BIPENNATE ARRANGEMENT OF SOLEUS MUSCLE IN HUMAN AND ITS RELEVANCE TO THE FORCE OF CONTRACTION

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ABSTRACT

Soleus muscle exhibits bipennate arrangement on its centro-anterior aspect and the longitudinal parallel muscle fibers on its posterior and lateral margins. Till date soleus muscle was studied as a whole muscle with less attention given on its bipennate arrangement. As per according to standard texts, increase in cross sectional area due to bipennate arrangement in soleus muscle augments the power and force of contraction.

The current study was done on 50 cadaveric lower limbs. Out of them 25 were of right side and 25 were of left side. The soleus muscle was divided into four equidistant hypothetical segments i.e- I, II, III, IV by imaginary lines drawn from the highest point of origin of muscle fibers to the lowest point of merging of muscle fibers to the tendocalcaneus. In 6% of cases the pennation was not clearly visible as it was covered anteriorly with nonseparable fascial sheath due to its adherence to subfascial muscle fibers. In 94% of cases pennation was present, out of which 6% cases showed pennation from segment I to IV, 4% cases showed pennation from segment I to III, 42% cases showed pennation from segment II to IV and 38% cases showed pennation from segments II to III, while 4% cases showed pennation only in segment III. The width, length and angle of muscle fasciculus of pennation are maximum in segment II.

Key Words: Soleus, Bipennate Arrangement, Central Tendon.

INTRODUCTION:

The soleus muscle is an antigravity muscle which helps to keep posture by its high content of slow, fatigue-resistant type-1 muscle fibers. It is concerned with steadying the leg on the foot in standing position (Standring, 2008)[1]. Soleus muscle is labeled as peripheral heart because of its profound effect on the venous return. The human soleus has three parts: posterior, marginal and anterior (Agur et al 1997)[2]. The soleus muscle contains two types of fiber arrangements: parallel on posterior and on margins; whereas bipennate on centro- anterior aspect (Standring, 2008)[1] (Fig 1).

Quantitative analysis of muscle architecture is important because the structural parameters have a profound effect on muscle function (Woittie,1983)[3]. Previous studies have focused on the muscle as a whole with little attention being paid to different regions within the muscle and one of them documented that architecture is non-uniform throughout volume of soleus (Agur et al 2003)[4]. What is of great interest and has not been documented much till now is bipennate arrangement. Muscle fiber orientation is important for calculating force generation, visualizing shape changes, and understanding role of skeletal muscle in the creation of human movement (Ng-Thow-Hing, 1998)[5]. Knowledge of structural properties of each part of muscle would help to establish the overall function, where function may include more sophisticated factors than simply the amount of shortening between the origin and insertion. The muscle fibers of the soleus on centro-anterior aspect converge at an angle on its centrally positioned tendon, as the barbs of feather converge on their shaft, this arrangement is called bipennate -feather shaped (Menton, 2000)[6]. The angles of pennation are usually less than 300 (Standring, 2008)[7]. The tendocalcaneus fibers spiral laterally through 900. Therefore fibers of Gastrocnemius are inserted laterally and those of the Soleus more medially (Standring, 2008)[8]. Bipennate muscles are particularly strong for their size. The relative strength of a muscle varies directly with cross sectional area. The bipennate configuration of the soleus results in a functional cross sectional area that is much larger than might be apparent from its size alone. Bipennate muscle maximizes the power of contraction at the expense of both the magnitude and speed of contraction. This is ideally suited to the function of the soleus which is slow but powerful

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plantarflexor of the ankle to steady the leg on the foot for maintaining the balance while standing (Menton, 20005 and Standring, 2008)[5,1].

That is why in any surgical procedure involving soleus muscle, the integrity of the bipennate fibers of the soleus which has more width of pennation and more length of muscle fascicles should be preserved.

MATERIAL AND METHOD:

The current study is aimed at finding out the bipennate arrangement of muscle fibers in soleus muscle on its anterior aspect.

50 cadaveric lower limbs, 25 right and 25 left were procured for dissection. The study was carried out for a period of 2 years in the department of Anatomy at SMIMER, Surat. Each soleus muscle was dissected from its origin and then was divided in four equal hypothetical segments namely I, II, III and IV by imaginary lines drawn from the highest point of origin of muscle fibers to the lowest point of merging of muscle fibers to the tendocalcaneus (Figure-2). Following measurements were taken:

1. Width of pennation
2. Length of muscle fascicles of pennation
3. Angle between muscle fascicles and central tendon
4. Length of the central tendon of bipennate muscle fibers
5. Shifting of Central tendon.

These measurements were taken at the midpoint of each hypothetical segment with the help of Vernier caliper, protractor and measuring tape. Length of muscle fascicles of pennation was measured from central tendon to merging of fascicle with longitudinal parallel fibers on either side.

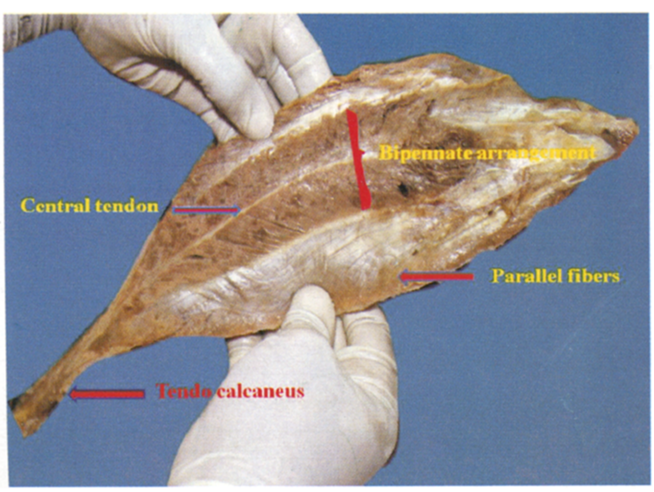


Fig. 1: Soleus muscle

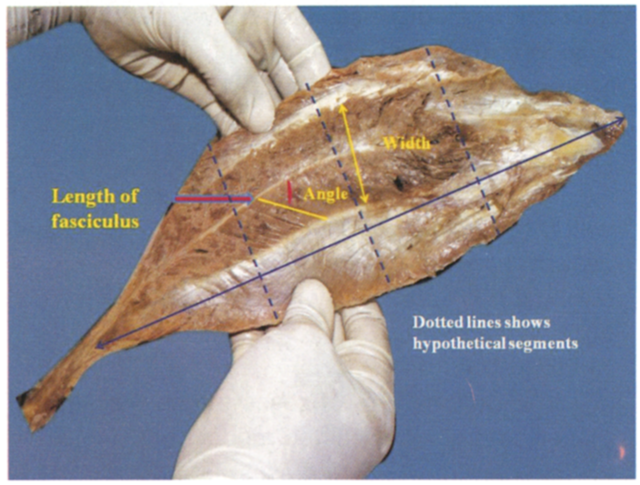


Fig. 2

OBSERVATION:

Following findings were observed in bipennate arrangement of soleus muscle of 50 dissected limbs in four hypothetical segments I, II, III and IV.

Extent of pennation in soleus muscle:

In 6% of cases the pennation was not clearly visible as it was covered anteriorly with nonseparable fascial sheath and its adherence to subfascial muscle fibers. In 94% of cases pennation was present. Out of which,

6% cases showed pennation from segment I to IV.
4% cases showed pennation from segment I to III.
42% cases showed pennation from segment II to IV.
38% cases showed pennation in segments II and III.
4% cases showed pennation only in segment III (Table I).

Width of pennation:

Present study shows that the width of pennation increases from segment I which is maximum in segment II and then gradually decreases towards segment IV(Table III, graph I).

Length of Fasciculus of pennation:

The length of the medial fasciculus of pennation is minimum in segment I and maximum in segment II and then it declines till segment IV (Table III, graph II). Length of lateral fasciculus gradually increases from segment I to segment II and then gradually declines to minimum in segment IV. Moreover the length of lateral fasciculus in segment IV is less than that of segment I (Table III, graph III).

Angle of Fasciculus with central tendon:

Angle of lateral fasciculus of pennation is minimum in segment I, maximum in segment II and then declines till segment IV (Table III, graph IV) while the angle of medial fasciculus shows gradual increase from segment I to segment II and remains steady in segment III followed by a sudden decline in segment IV (Table III, graph V).

Length of central tendon:

In present study length of the central tendon is less than 10 cm in 6% of cases and more than 10 cm in 94% of cases. Interestingly in 22% of these 94% cases fall in range of 20-24 cm with Mean of 17.19 cm (Table III).

Shifting of central tendon:

Only in 12% of cases the central tendon is placed centrally. It is shifted medially in 54% of cases and laterally in 28% of the cases (Table II).

Extent of Pennation in muscle	No. of Cases	Percentage
Segment I to IV	3	6%
Segment I to III	2	4%
Segment II to IV	21	42%
Segment II to III	19	38%
Segment III	2	4%

Table 1: showing distribution of pennation in muscle

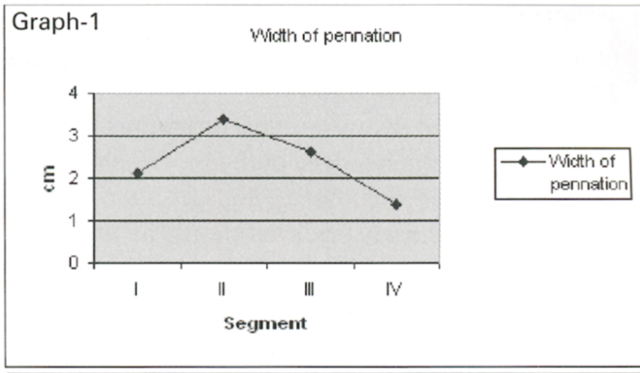
Shift of Central tendon	No. of Cases	Percentage
Central	6	12%
Medial	27	54%
Lateral	14	28%

Table 2

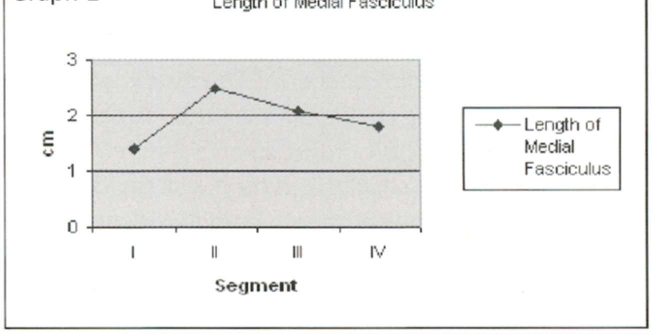
Pennation		Segments			
		I	II	III	IV
Width	Mean	2.15	3.46	2.6	1.46
	S D	0.41	1.39	1.25	0.75
Length of Fasciculation (Medial)	Mean	1.42	2.56	2.19	1.87
	S D	0.1	0.88	0.79	0.73
Length of Fasciculation (Lateral)	Mean	1.98	2.75	2.42	1.79
	S D	0.48	0.77	0.69	0.5
Angle of Fasciculation (Medial)	Mean	34.8	38	38.5	30.2
	S D	5.01	11.22	12.15	8.23
Angle of Fasciculation (Lateral)	Mean	28.8	38.51	36.91	32.54
	S D	8.04	11.11	10.46	12.41
Length of Central tendon	Mean	17.19			
	S D	4.78			

Table 3

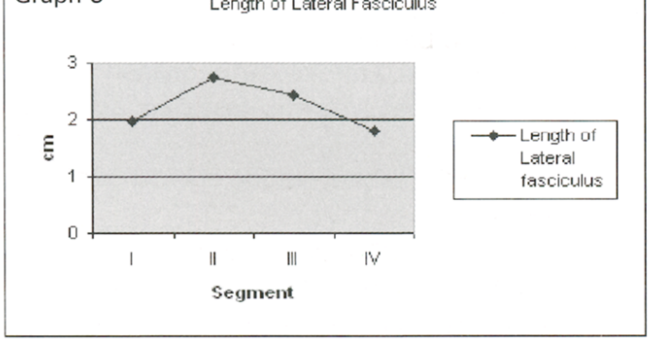
Graph-1



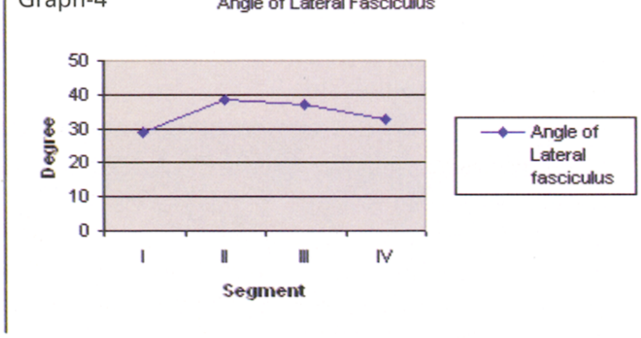
Graph-2



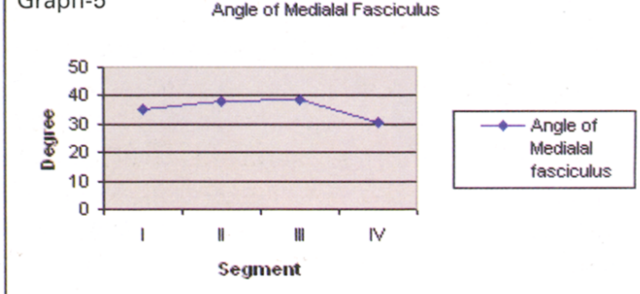
Graph-3



Graph-4



Graph-5



DISCUSSION:

Soleus muscle exhibits two types of muscle fibers arrangement:

- Parallel fibres which enclose bipennate arrangement from three sides. These fibers extend from origin to tendocalcaneus. The muscle shortens and widens when it contracts, thus providing range of movement.
- The bipennate muscle fibers arise from central tendon and are attached to parallel muscle fibers at an angle. These muscle fibers on contraction shorten in length and pull the parallel muscle fibers towards central tendon.
- The force of contraction will be transmitted through central tendon.
- Thus this dual arrangement ensures both force and range of contraction.

In standard anatomical text, more functional importance has been given to soleus muscle per-se. Bipennate arrangement on the centro-anterior aspect of soleus muscle has been mentioned by Standring (2008)7. Unfortunately detailed information regarding the bipennate arrangement of the muscle fasciculus has not been documented so far and more attention has been paid to qualitative parameters rather than quantitative parameters.

In present study, we found that in 42% cases pennation extends from IInd to IVth hypothetical segments and in 38% cases pennation extends from IInd to IIIrd hypothetical segments. Hence majority of cases possess pennation in IInd and IIIrd segments. Anatomical description regarding the bipennate arrangement mentions the central tendon, on which the muscle fibers converge. Medial shifting of central tendon in majority cases can be explained by lateral 900 spiralization of tendocalcaneus. The angle of the pennation is less than 300 (Standring, 2008)7 while in our study the angle of pennation varies from 28.880 to 38.510 in different hypothetical segments of the muscle on medial and lateral side (Table III). In our study we found that width of pennation and length of fascicles are more in segment II in comparison to all other segments, though no description was found regarding the width of pennation and length of muscle fascicles of pennation till now.

The central tendon receives longitudinal parallel fibers from above in segment I (if pennation is present) otherwise in segment II. When these longitudinal muscle fibers contract, they tend to increase the length of central tendon. The muscle fascicles form an angle to the central tendon. According to standard anatomical text, increased cross sectional area of muscle because of this angulation of fascicles will increase the force of contraction of muscle.

CONCLUSION:

The bipennate arrangement on anterior aspect of soleus exhibits different arrangement of muscle fascicles in different hypothetical segments of muscle. The width, length and angle of pennation are maximum in segment II of the muscle.

The central tendon of pennation is central only in 12% cases and rest of the cases; the central tendon either deviated laterally or medially. Medial shift of central tendon in maximum cases can be explained by 900 lateral spiralization of tendocalcaneus. Moreover the lateral deviation of central tendon and correlation between physiological components of muscle with its anatomical components need to be studied further.

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