Long Head of Biceps, a vestigial structure?

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Abstract

Long head of biceps has unique position both in terms of anatomy as well as function. Many regards is as important structure that helps in stability of the shoulder and also act as a shoulder depressor. Others have mentioned that tendodesis or tenotomy of LHB does not have any adverse functional impact on the shoulder joint. This raises the possibility that LHB is probably a vestigial structure which is diminishing in its role with evolution. To study this hypothesis a group of orthopaedic surgeons along with paleontologists studied the evolution of LHB by studying various mammals. It appears the in quadrupeds the LHB had important function of providing passive stability however in bipeds there is no need for passive stability and LHB may actually limit range of motion. Although this restriction may still work as beneficial in avoiding excessive motion but the exact importance cannot be justified. Moreover as the clinical studies have shown tenodesis or tenotomy of LHB has not deleterious effect on shoulder, it seems the hypothesis of LHB to be a vestigial organ has good grounds for more studies.

Keywords: Long Head of Biceps, Vestigeal organ, Paleontology study, evolution

Introduction:

The long head of biceps (LHB) is one of the main anatomical structures at the shoulder, and it's pathological conditions represent important causes of pain and disabilities, not only in the shoulder, but on the arm as well.

Many authors have reported the importance of the LHB in stabilizing the shoulder, and in acting as a depressor over the humeral head. These functions would prevent both glenohumeral translation, and humeral head elevation. Thus, according to such authors, it would seem quite rational to preserve the LHB, during any shoulder surgery, in order to avoid shoulder osteoarthritis, and rotator cuff lesions.

However, during daily practice, among many shoulder surgeons around the globe, surgical techniques treating the LHB with both tenotomy or tenodesis have lead to very satisfactory results, without any report of shoulder instability or osteoarthritis, after such LHB procedures[1].

A recent animal trial, that used a rotator cuff lesion model, including supraspinatus and infraspinatus tendons, compared the results of biceps tenotomy and a control group. Surprisingly, the most impressive result of such trial was that there was a protective effect in shoulder cartilage on the tenotomy group[2]. Other important data extracted from that paper was that there was a favorable difference in the group where the biceps was preserved, but only in the beginning of the study, once such difference simply disappeared over time[2]. Still, mechanical and histological properties of the subscapularis tendon also changed comparing the 02 groups, being worse in the control group, in which a biceps tenotomy was not done[2].

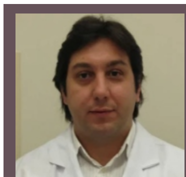
Nevertheless, many other authors have already theorized that the LHB is useless, remaining just as a vestigial structure, on the shoulder[3-5].

In this way, our main question, to better understand LHB, is : Can the biceps phylogeny, so as it's evolutionary comparative study, help us to understand whether the LHB has an important function at the shoulder, or whether would it be just a vestigial structure?

Seeking for such response, the authors reviewed the comparative anatomy of the shoulder and the proximal biceps tendon during evolution, assessing and comparing anatomy and physiology, focusing into the proximal biceps tendon.

Material And Methods

The first step of our study was to define when did the proximal biceps tendon first appeared during evolution, and what would be it's initial and original function. The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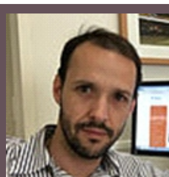
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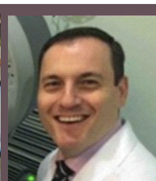
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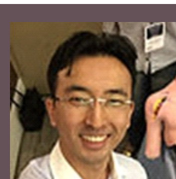
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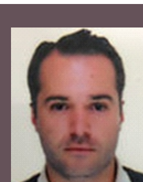
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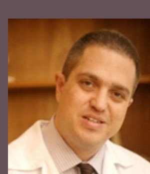
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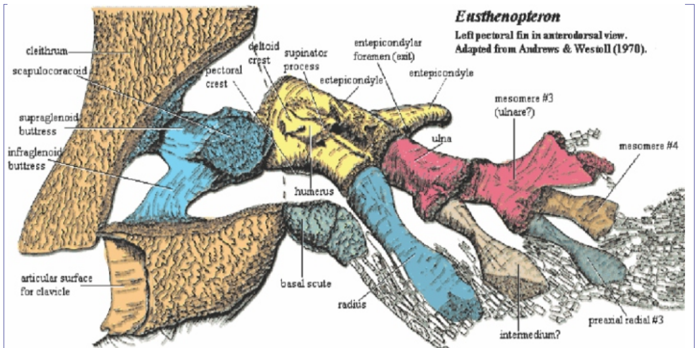

Figure 1: Primary forms of upper limb in ancient fishes. Source: Paleos, 2016[7]

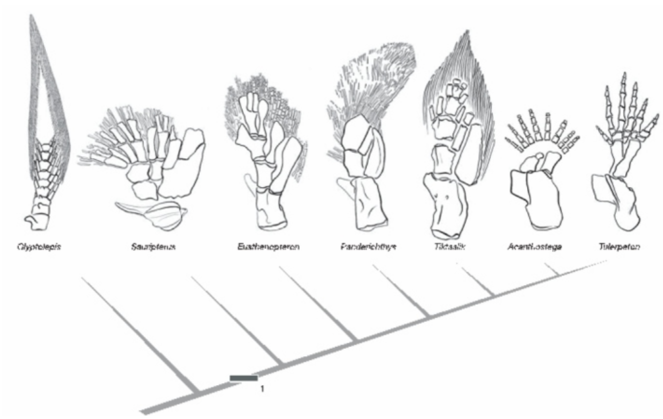

Figure 2: Source: Shubin et al, 2006[12]

authors hypothesized that, figuring out which was the first animal, from the chordata's phylum, that presented a rudimentary upper limb with a rudimentary biceps, one would be able to better understand LHB modications and adaptations, during evolution, until it's current presentation in the human being. Such data was obtained by bibliographical study, in cooperation with the Paleontology Department of the University of Sao Paulo-Brazil.

Mammalians of our current age were then assessed, and a comparative anatomical and physiological study was done, regarding the LHB.

A special attention was paid to the primate's shoulders assessments, mostly those ones closer to the homo sapiens.

All data was discussed with paleontologists from the Paleontology Department of the University of Sao Paulo-Brazil, and both observational Darwinian and neodarwinian approaches were applied over such data.

DISCUSSION

The first animals to take part of this study were from the Paleozoic era, which lasted from 542 to 251 million years ago. The Ostracoderm pteraspidomorphi, an ancestor of the fishes, presenting very rudimentar fins, was the first animal assessed to present some kind of upper limb. Ostracoderms evolved to Anaspids, extinct fishes which presented shorter paired anterior fin-folds. As per Paleontology, such paired anterior fin-flods would have originated fish fins as we know, today. On the Silurian period (443 to 416 million years ago), Acanthodii, a class of extinct fishes, sharing features with both bony fish and cartilaginous fish, evolved to better structured anterior fin-folds. However, Sarcopterygians (a class of lobe-finned fish, that would evolve to tetrapods, beings with four limbs), from late Silurian period, were those that presented the primary forms of a radius and a ulna, within their anterior fins. Using these osseous structures, these ancient fishes were, then, able to easily change their direction while moving under water, by pronation and supination of their anterior fins.

Such movements (pronation and supination) were originally performed by an ancient kind of biceps, originated on the humeral supinator process, or directly on the coracoid bone[6] (Fig. 1)[7].

Anyway, changing from navigating under water to a body that enables an animal to move on land was one of the utmost remarkable changes in evolution[8]. Such gain has been one of the most studied and understood transitions in evolution. Still, it's important to mention that knowledge about such transition is achievable due to the existence of many transitional fossils that have been found, and due to their respective phylogenetical evolutionary analysis [9].

Sarcopterygians, as said above, evolved to tetrapodomorph fishes, in the late Devonian period (416 to 358 million years ago). These transitional fishes presented rudimentary arms, shoulders and hands. The oldest tetrapodomorph fish fossil known is the Kenichty, dated as 395 million years old. Other latter tetrapodomorphs, as the Gogonasus and the Panderichthys, are dating 380 million years old [10].

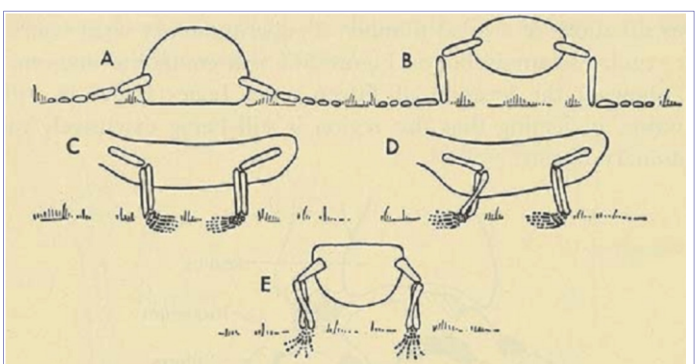

Figure 3: Evolution of the upper limb position. Source: Paleos, 2016[7]

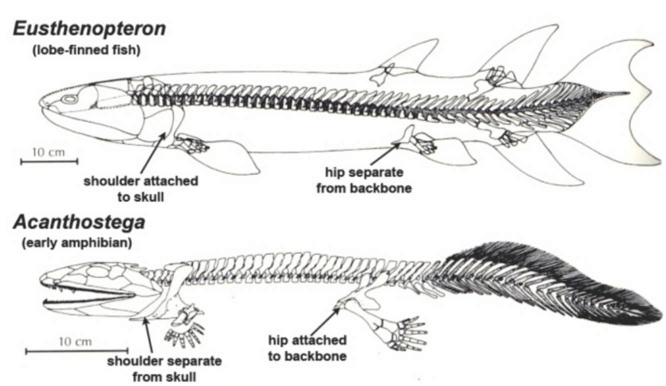

Figure 4: Comparison Acanthostega and ancient fishes. Source: LabSpaces, 2011[16]

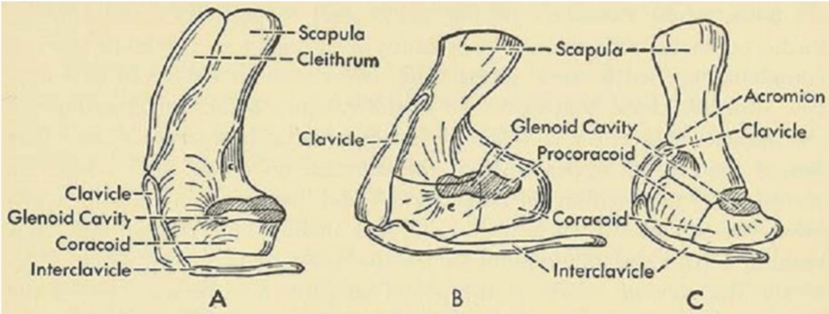

Figure 5: Ancient Scapula Source: Paleos, 2016[7]

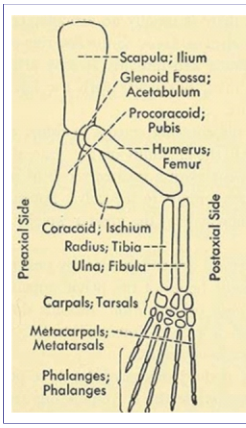

Figure 6: girdles comparison Source: Paleos, 2016[7]

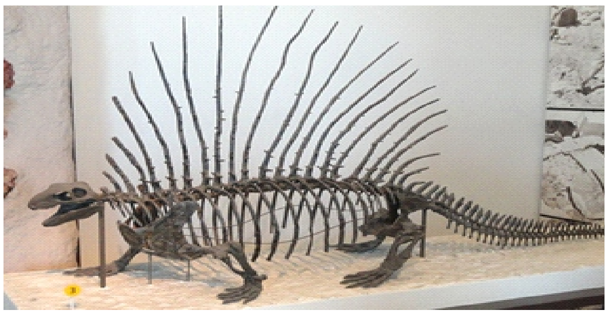

Figure 7: Pelycosaur

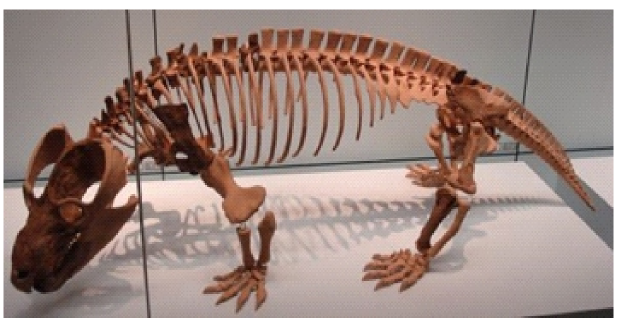

Figure 7: Cynodont, evolving from a sprawling posture to upright posture Source: www.dandebat.k

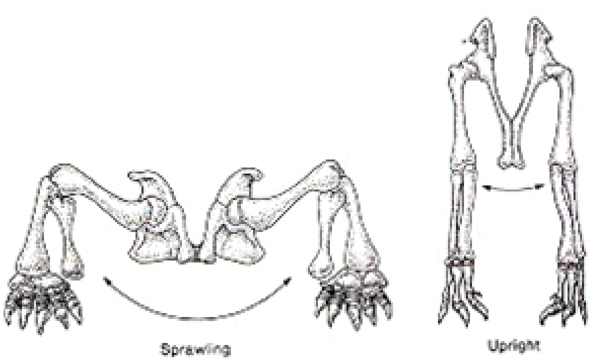

Figure 7: Cynodont, evolving from a sprawling posture to upright posture Source: www.dandebat.k

These animals used their fins to move in tidal channels and shallow waters.

Bodies of the Tiktaalik, a tetrapodomorph fish, that existed around 375 million years ago, suggest that locomotion using anterior limbs was originated in water before terrestrial adaptations [11]. The text of Shubin et al [12] reports the Tiktaalik's upper limb functions and evolution, as follows: "Glenohumeral architecture and trans-coracoid musculature augment flexion and stability at the shoulder joint; a broad and deep posterior glenoid allows transmission of substantial propulsive stresses through the pectoral girdle; a robust coracoid plate provides broad areas for flexor muscle origins; elaborate ventral processes on the humerus represent extensive surface area for flexor insertions; flexion/extension, pronation/supination and rotation are possible at the elbow. Notably, the highly mobile yet robust distal fin segments could provide a stable but compliant extremity that could conform to complex and varied substrates." Small movements for prono-supination were possible because of the radius translation along the humeral facet, in this animal [12].

These tetrapodoforms presented anterior limbs very similar to the sirenians (an order of aquatic herbivorous mammals that have forelimbs resembling paddles), as shown in A and C (Fig. 3). So, from a morphological point of view, all such changes happened to make prono-supination something real. Still, according to some authors, possibly the biceps could already exist in these animals, coming from the coracoid bone with a double function : supination, and fair abduction/extention [12].

On land, the first real tetrapods had to live as opportunists. They could reach land from tidal flats, and they in fact had some had facility in hunting marine animals that were brought by the tide [13]. Regarding chemical aspects, the evolution of tetrapods 1 has been related to the expression of HOXD13 gene and/or to the absence of actinodin 1 and actinodin 2 proteins[14,15].

After tetrapods definitely reached land, the necessity of velocity and the need of faster movements required that evolution moved forward. And, that become possible once evolution changed some anatomical characteristics that would make motion easier : rotating internally the humerus, pronating the radius over the ulna, and leaving fingers to the front, evolution allowed those animals to have better motion and motion control B,D,E(Fig. 3). That is seen in Acanthostegas, an extinct kind of tretrapod, considered the first vertebrate animal to have recognizable limbs (Fig.4). Such changes were the evolutionary answers to the new terrestrial demands of these animals.

Figure 9: Horse proximal Biceps tendon with one strong head.

The locomotion of these ancient tetrapods was defined by studies of tracks of walking, along the bottom of shallow waters [17]. The Carboniferous period (from 360 to 299 million years ago), is that one in which the amphibians really appeared, having limbs with digits and other adaptations for terrestrial life.
The number of digits was standardized by natural selection as five[17]. The current scapula, as we know, evolved from the fusion of three bones : the coracoid bone (also described as the metacoracoid), the procoracoid and the scapula(Fig. 5). It's, in fact, interesting to mention that such 03 bones worked, respectivelly, like the ischium, the pubis and the ilium in the hip (Fig. 6). The Pelycosaurs (large extinct reptiles of the late Carboniferous period, typically having a line of long bony spines along the back), were one of the most important evolutions of the amphibians. They presented their glenoid and humerus parallel to the ground, and robust bones for strong upper limb muscles (Fig. 7).

After the Carboniferous period, it came the Permian period. The Permian period was a geological period from 298,9 million years to 252 million years ago, and refers to the last period of the Paleozoic era. Over the Permian period, Cynodonts appeared on earth. Cynodonts were mammal-like reptiles, with well-developed and specialized teeth [18]. Some traits, seen today as unique to mammals, had origin in Cynodonts and in Therapsids, extinct reptiles which are related to the ancestors of mammals [18].
Cynodonts had their four limbs extending vertically beneath the body, in an upright posture, differently from the sprawling posture of other animals. The glenoid and humerus position followed this evolution rotating inferiorly(Fig.8).

Since the Pelycosaur (large extinct reptiles of the late Carboniferous period, typically having a line of long bony spines along the back), the coracoid bone (also known as metacoracoid) presented an expansion that have been related to conjoined tendon muscles in almost all current mammalians[18].

	Lemur (22 muscles: 17 pectoral; 5 arm)	*Tarsius* (22 muscles: 17 pectoral; 5 arm)	*Aotus* (21 muscles: 16 pectoral; 5 arm)	*Macaca* (22 muscles: 17 pectoral; 5 arm)	*Hylobates* (19 muscles 14 pectoral; 5 arm)	*Pongo* (20 muscles: 15 pectoral; 5 arm)	*Gorilla* (19 muscles: 14 pectoral; 5 arm)	*Pan* (19 muscles: 14 pectoral; 5 arm)	*Homo* (18 muscles: 14 pectoral; 4 arm)
AXIAL: PEC. GIRDLE	Serratus anterior	Serratus anterior	Serratus anterior	Serratus anterior	Serratus anterior	Serratus anterior	Serratus anterior	Serratus anterior	Serratus anterior
	Rhomboideus	Rhomboideus	Rhomboideus	Rhomboideus major	Rhomboideus major	Rhomboideus major	Rhomboideus major	Rhomboideus	Rhomboideus major
	—	—	— (pres. *Callithrix*)	Rhomboideus minor	—	—	—	—	Rhomboideus minor
	Rhomboideus occipitalis	Rhomboideus occipitalis	Rhomboideus occipitalis	Rhomboideus occipitalis	—	Rhomboideus occipitalis	—	—	—
	Levator scapulae	Levator scapulae	Levator scapulae	Levator scapulae	Levator scapulae	Levator scapulae	Levator scapulae	Levator scapulae	Levator scapulae
	Levator claviculae	Levator claviculae	Levator claviculae	Levator claviculae	Levator claviculae	Levator claviculae	Levator claviculae	Levator claviculae	—
	Subclavius	Subclavius	Subclavius	Subclavius	Subclavius	Subclavius	Subclavius	Subclavius	Subclavius
APPENDICULAR: PEC. GIRDLE AND ARM	Pectoralis major	Pectoralis major	Pectoralis major	Pectoralis major	Pectoralis major	Pectoralis major	Pectoralis major	Pectoralis major	Pectoralis major
	Pectoralis minor	Pectoralis minor	Pectoralis minor	Pectoralis minor	Pectoralis minor	Pectoralis minor	Pectoralis minor	Pectoralis minor	Pectoralis minor
	Panniculus carn. (part)	Panniculus carn. (part)	Panniculus carn. (part)	Panniculus carn. (part)	—	—	—	—	—
	Infraspinatus	Infraspinatus	Infraspinatus	Infraspinatus	Infraspinatus	Infraspinatus	Infraspinatus	Infraspinatus	Infraspinatus
	Supraspinatus	Supraspinatus	Supraspinatus	Supraspinatus	Supraspinatus	Supraspinatus	Supraspinatus	Supraspinatus	Supraspinatus
	Deltoideus scapularis	Deltoideus scapularis	Deltoideus	Deltoideus	Deltoideus	Deltoideus	Deltoideus	Deltoideus	Deltoideus
	Deltoideus acro. et clav.	Deltoideus acro. et clav.	—	—	—	—	—	—	—
	Teres minor	Teres minor	Teres minor	Teres minor	Teres minor	Teres minor	Teres minor	Teres minor	Teres minor
	Subscapularis	Subscapularis	Subscapularis	Subscapularis	Subscapularis	Subscapularis	Subscapularis	Subscapularis	Subscapularis
	Teres major	Teres major	Teres major	Teres major	Teres major	Teres major	Teres major	Teres major	Teres major
	Latissimus dorsi	Latissimus dorsi	Latissimus dorsi	Latissimus dorsi	Latissimus dorsi	Latissimus dorsi	Latissimus dorsi	Latissimus dorsi	Latissimus dorsi
	Triceps brachii	Triceps brachii	Triceps brachii	Triceps brachii	Triceps brachii	Triceps brachii	Triceps brachii	Triceps brachii	Triceps brachii
	Dorsoepitrochlearis	Dorsoepitrochlearis	Dorsoepitrochlearis	Dorsoepitrochlearis	Dorsoepitrochlearis	Dorsoepitrochlearis	Dorsoepitrochlearis	Dorsoepitrochlearis	—
	Brachialis	Brachialis	Brachialis	Brachialis	Brachialis	Brachialis	Brachialis	Brachialis	Brachialis
	Biceps brachii	Biceps brachii	Biceps brachii	Biceps brachii	Biceps brachii	Biceps brachii	Biceps brachii	Biceps brachii	Biceps brachii
	Coracobrachialis	Coracobrachialis	Coracobrachialis	Coracobrachialis	Coracobrachialis	Coracobrachialis	Coracobrachialis	Coracobrachialis	Coracobrachialis

Table 1: Muscles present in Primates Shoulders. Source: Diogo & Wood 2001 [24]

Coracoid have varied in many features during evolution, including size, curvature, and shape. These coracoid variations are related to functional differences of the biceps and coracobrachialis muscles among species of different habits[19-22]. Still, it's important to mention that the coracoid expansion occurred in the same axis of the humerus in all the primitive mammaliforms and mammalians, in a way that elbow flexion muscles could act in the same mechanical axis as the humeral axis[19-22].
The rotator cuff appears in evolution together with the beginning of bipeditism. Infraspinatus was the first tendon to be developed in the shoulder, specially to give stability for an articulation with so many degrees of movement, and with less bony stability, when compared to the hip. Supraspinatus was added after, to improve such stabilization[23].
The ancient mammals presented a biceps tendon coming from the coracoid bone, on the scapula, and passing between these two muscles mentioned above (infra and supraspinatus), adding some degree of passive stability for the quadrupeds' shoulders. The ancient and the current quadrupeds mammals, like the horse, present just one head of the biceps (Fig.9).

However, continuing the evolution to the humans, primates started using the erect position, and that meant two important repercussions on the shoulder [24]:
1) The upper limb (previously, the anterior limb) gained more movement, and passive stability lost mostly of it's utility, when we compare primates to quadrupeds. That happens because passive stability means movement restriction, what was good for quadrupeds (that had to do only flexion/extension on their shoulders) and what was not that good for bipeds, who now would have to use their shoulder to many more movements, like aduction/abduction, and elevation.
2) Coracoid migrated anteriorly, keeping the same axis of the humerus, as happens in evolution, since the ancient fishes.
Once bipeds started to exist (primates, and men), the proximal biceps tendon was divided in two ones : the LHB, and the short head (conjoined tendon). The LHB continued to exist in the original biceps position, as it had always been in quadrupeds – that means, between the turbercles. That would, in fact, help on static shoulder stabilization; anyway, such LHB position, now on bipeds, could negatively affect gain of motion, once the original biceps tendon function was, in quadrupeds, to stabilize the shoulder, avoiding movements different from flexion/extension.
Monkeys presenting a wider shoulder range of motion tend to present a medialized LHB, when compared to humans. More than that, some monkeys even present their shoulder with absence of the LHB [24].
In the recent decades, the human being has increased his activities using the upper limb, specially in sport playing. The SLAP lesion, for example, is a good condition in which we can understand how the LHB can present negative influences in the shoulder, once the individual starts practicing activities with a higher shoulder ROM.
Still, we must not forget that the evolutionary response to improve the dynamic stability of the shoulder, in bipeds, was the development of the rotator cuff [23].
Rotator cuff adaptations have been suggested to happen in experiments using tenotomy of the LHB, in rats. Even such animal, a rat, who has a rotator cuff, and who uses less his upper limbs compared to humans, easily adapts to living with a tenotomized LHB, suggesting that the LHB have become more a vestigial structure that impedes movements on the shoulder than a necessary structure for stabilization [2].
In humans, biceps tenotomy and tenodesis have presented good results for pain control, with no repercussion in shoulder stability. That is particularly true when the most ancient active shoulder stabilizer, infraspinatus, is present.
In primates, rotator cuff presents 4 strong muscles, providing active shoulder stabilization, and a wide range of motion(Table 1).
In quadrupeds, even since the ancient Pelycosaurs, the biceps tendon never presented angles near 90º, like the LHB has, in it's intra-articular position, in humans; instead, in such animals, the biceps tendon presents an angle close to 0º (Fig. 9). In fact, almost all current quadrupeds mammals present only a single head of the biceps tendon, that has near 0º of angulation, from it's bony origin to the muscle belly.
As said above, biceps tendon has an important stabilization function, in quadrupeds' shoulders.
In some primates, the LHB presents angulation of 90º, with possible repercussions in it's health.
Hence, once we consider that the the conjoined tendon acts, mechanically, parallel to the long axis to the humerus (just as the LHB had always worked, in quadrupeds) and once we consider that the rotator cuff presents full capacity to offer to the shoulder active motion and stability, we can suggest that the LHB is a vestigial structure – which is, by definition, a structure that "had an important function in the past, but that has lost it's importance, in the course of evolution".
The proximal biceps tendon (LHB) was important in quadrupeds, allowing the shoulder to be stable; however, it loses it's importance in bipeds, which need wider upper limb movements, and which have rotator cuffs, providing dynamic stabilization to their shoulders.
Other important point to be considered is the fact that the human coracoid and conjoined tendon, that keeps it's angle near 0º, is a healthy tendon with whimsy pathologic affections.
Keeping this in mind, one can conclude that, in the human being, that present a strong rotator cuff, and whose shoulder needs a wide range of motion, the LHB, whose intra articular angulation is near 90º, not only can bring many problems to the shoulder, but also can be considered to be just a vestigial structure.
This conclusion supports many papers in literature, that describe biceps tenodesis and tenotomies with no functional negative repercussions to the patients.
Still, published papers suggest that a LHB tenotomy corrects the LHB axis, putting it in concordance to the axis of the humerus.
Biceps tenotomy and tenodesis is widely known to diminish shoulder pain, with absent or minimal strength loses. [25]

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Conflict of Interest:
Jake Ni, MD – NIL
David Auerbach - Consultant: Smith & Nephew, Fastform, Breg, and Integra; Royalties: Hely Weber, Stryker, Top Shelf, Fastform and Wolters Kluwer
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