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Review article

The human acromion viewed from an evolutionary perspective

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ABSTRACT

The high prevalence of rotator cuff tendinopathy in modern humans may be partly related to the shape acquired by the scapula as species changed throughout evolution. Here, we compared the anatomic features of the scapula across members of the Hominoid group. The results support the hypothesis that the scapula of *Homo sapiens sapiens* exhibits distinctive anatomic characteristics compared to that of other Hominoids. We studied 89 scapulae from five species. For each scapula, we measured eight parameters and determined six index. We then compared the results across species. We identified two distinctive characteristics of the lateral aspect of the human scapula, namely, a lateral orientation of the glenoid cavity and a narrow coraco-acromial arch. Similar to the gorilla acromion, the human one is steeply sloped and, above all, larger and squarer than the acromion of other Hominoids. These features may explain, in part at least, the pathogenesis of rotator cuff tendinopathy in modern man.

1. Introduction

The high prevalence of rotator cuff tendinopathy probably reflects a mismatch between the anatomic characteristics of the shoulder of *Homo sapiens sapiens* (HSS or modern man) and the work imposed on the shoulder in terms of both loads and duration. Many studies have sought to identify the specific anatomic characteristics of the shoulder, most notably in primates [1–10]. In the Primates order, HSS is classified with the apes (gibbons, orang-utans, gorillas, and chimpanzees) within the taxon Hominoids (Fig. 1). Their scapulae share a number of features, which are probably related to the loss of strict quadrupedalism and to the development of directed hand motions. Some other features are specific of HSS, which is the only strictly bipedal Hominoid [11–14]. These features involve the position and shape of the scapula. Apart from primates, few mammals have clavicles, which allow upper limb movements outside the parasagittal plane [15]. The shape of the clavicle dictates the position of the scapula relative to the rib cage, which is posterior in Hominoids and lateral in Cercopithecoids [12,16]. Cercopithecoids, which are not hominoids, are all quadrupeds (both on the ground and in trees) and their limbs therefore work chiefly in compression. Their scapulae are positioned laterally and are relatively elongated, with underdeveloped supraspinatous and infraspinatous fossae, a small acromion, and a narrow glenoid cavity. These features are reminiscent of those seen in quadrupedal mammals such as cats and dogs [17]. In contrast, primates that use suspensory locomotion such as apes have broad scapulae with well-developed supraspinatous and infraspinatous fossae and a longer and broader acromion compared to that of quadrupedal primates. This shape increases the surface area of the deltoid muscle attachment [17,18]. The HSS scapula is characterized by high dorsalization in regard to the thorax and infraspinatous fossa further developed, together with a proportionally smaller supraspinatous fossa [7,8,12,14,17] (Fig. 2). Because the number of available fossilised scapulae from Homininae (the human lineage within the hominoids) is small, the time at which this anatomic specialisation occurred during the evolutionary process remains unknown. Information can be obtained only by performing comparative anatomical studies.

The aim of this original preliminary study was to obtain the first comparative data on the anatomic features of the lateral aspect of the scapula within the group of Hominoids (HSS and apes) and to discuss the impact of these features on function. Our hypothesis was that the HSS acromion exhibited specific anatomic features that might explain, at least in part, the high prevalence of tendinopathy in HSS.

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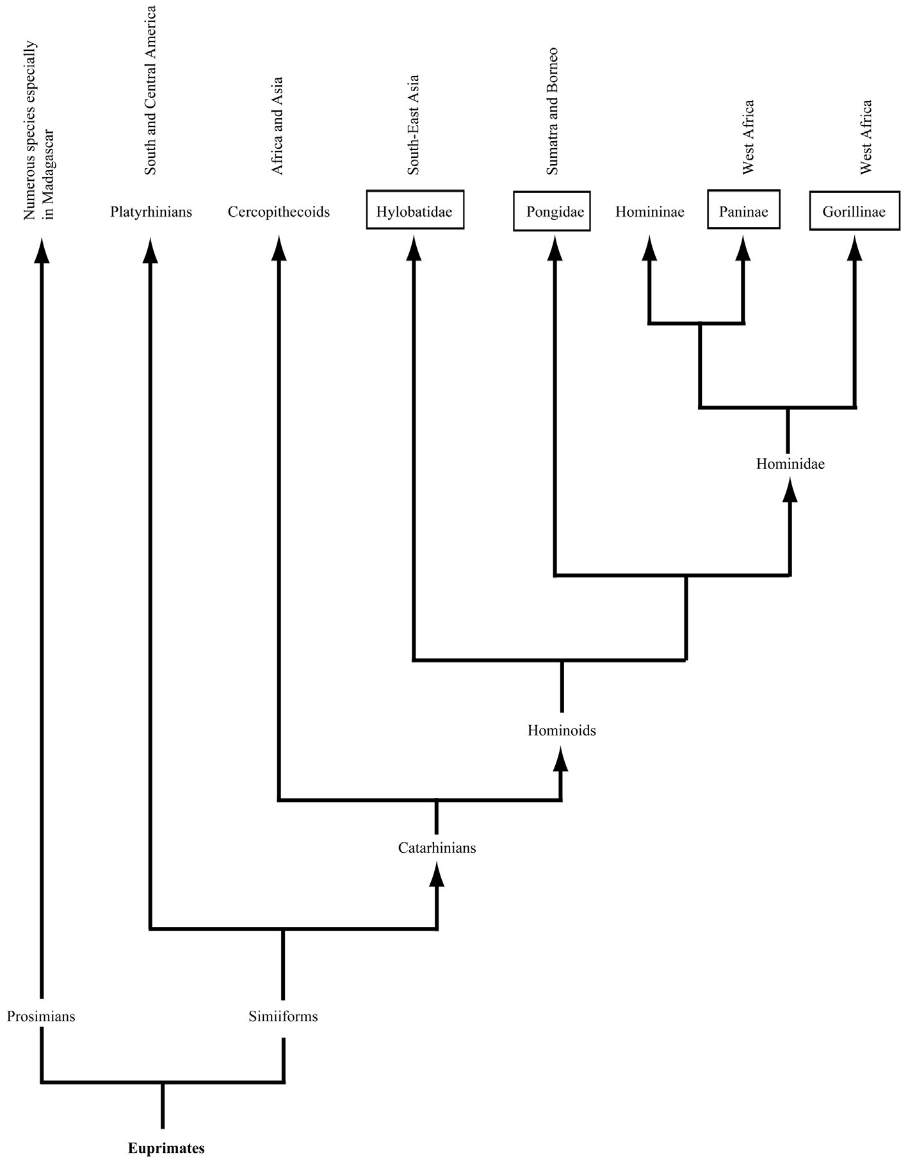

Fig. 1. Phylogenetic tree for Euprimates (anthropoid and pro-simian primates). *Homo sapiens sapiens* belongs to the Homininae subfamily and is closely related to the apes within the Hominoids, particularly the species found in Africa (Hominidae). Words framed: Apes, which is a paraphyletic group.

2. Material and methods

We studied human scapulae from the anthropology collection of the *Musée de l'Homme*, Paris, France; and ape scapulae from the zoology collection of the *Département d'Anatomie Comparée du Muséum National d'Histoire Naturelle*, Paris, France. Table 1 lists the species selected for the study. We used the classification of primates developed by Rowe [19], which recognises a single species of gorilla (*Gorilla gorilla*) and two separate species of orang-utan, one on Sumatra (*Pongo abelii*) and the other on Borneo (*Pongo pygmaeus*).

We used callipers to obtain the seven measurements, in millimetres, reported in Fig. 3. These measurements were used to compute six ratios or surface areas (Table 2) in order to characterise bone processes as long or short and broad or narrow independently from absolute measurement values, which varied with the size of the species. We used a protractor to measure the slope of the acromion (h) and orientation of the glenoid cavity (i) in degrees [12].

Statistical analyses were performed using PAST 2.17 software® [20]. The values of the morphological index and slopes were compared across groups. Because of the small sample sizes, most of the values were not normally distributed, and we therefore used the non-parametric Kruskal-Wallis test for comparisons. According to the null hypothesis, the overall sample came from populations having identical median values with the α risk set at 5%.

Table 1
Species and number of scapulae studied.

Species	Number of scapulae
Gibbon	
Hylobates sp.	7
H. gabrielli	2
H. moloch	2
Orang-utan	
Pongo pygmaeus	9
Gorilla	
Gorilla gorilla	21
Common chimpanzee	
Pan troglodytes	22
Human	
Homo sapiens sapiens	26

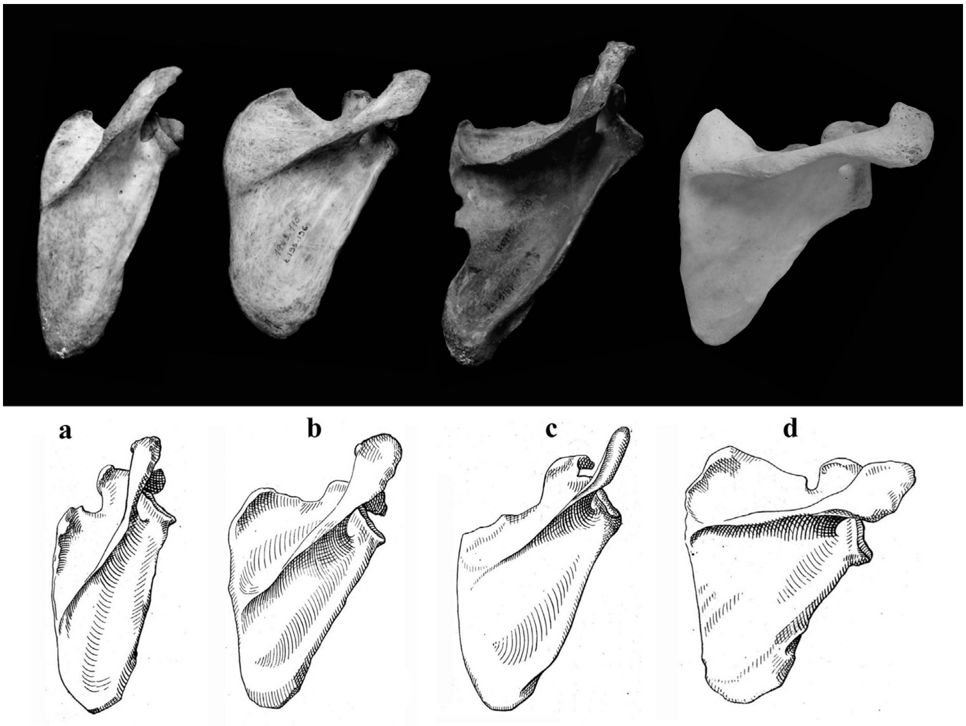

Fig. 2. Scapulae of a chimpanzee (a), gorilla (b), orang-utan (c), and *Homo sapiens sapiens* (d). Note the large size of the infraspinatous fossa in the *Homo sapiens sapiens* scapula.
Drawings from [9] and photographs by the authors.

Table 2
The six morphological indices defined based on the measures described in Fig.3 (a and b).

Name	Description
Shape of acromion	(b) width of acromion / (a) length of acromion
Surface area of acromion	Width of acromion × length of acromion: (a) × (b)
Shape of glenoid cavity	(d) width of glenoid cavity / (c) height of glenoid cavity
Width of coraco-acromial arch	(e) distance from acromion to coracoid process / (c) height of glenoid cavity
Shape of coracoid process	(g) width of coracoid process / (f) length of coracoid process
Surface area of coracoid process	Width of coracoid process × length of coracoid process: (f) × (g)

Table 4
Shape of the glenoid cavity. Results of the Kruskal-Wallis test; significant differences between paired groups are in italics. The shape of the glenoid cavity shows remarkable uniformity among Hominoids.

	Gorilla	Chimpanzee	Orang-utan	Gibbon	Human
Gorilla		0.64	0.36	0.13	0.79
Chimpanzee	1		0.42	0.29	0.54
Orang-utan	1	1		*0.037*	0.33
Gibbon	1	1	0.37		0.069
Human	1	1	1	0.69	

H = 4.87; p(H0) = 0.3009.

3. Results

Table 3 reports the overall results of the comparisons of morphological indices in the various Hominoid species. Pairwise comparisons of these indices and measures of the dispersion of the most significant qualitative values are reported in Tables 4–7 and in Figs. 4–7, respectively. Glenoid cavity shape showed no significant differences between apes and HSS (Table 4). Absolute acromial surface area was greatest in gorillas and smallest in gibbons, but gorillas are the largest of all Hominoids (with a weigh around 170 kg for wild males [19]) and gibbons the smallest (with an average weigh between 5 to 12 kg depending of species for wild individuals [19]). Computation of relative values showed that the HSS acromion was broad, almost square, with a marked lateral overhang. Among the other Hominoids, only gorillas shared these features (Table 5 and Fig. 4). In contrast, the coraco-acromial arch was narrower in HSS than in all the other species, including gorillas (Table 6). The HSS coracoid process showed no specific features in terms of shape or size (Fig. 5). The slope of the acromion was steepest in humans

Table 3
Main characteristics of Hominoid scapulae. Both *Homo sapiens sapiens* (HSS) and Gorilla had a broad, nearly square, acromion. Note that the shape of the glenoid cavity was the same in all species.

Characteristics	Gorilla	Chimpanzee	Orang-utan	Gibbon	HSS
Shape of acromion	Wide	Narrow	Narrow	Narrow	Wide
Surface area of acromion	Large	Intermediate	Intermediate	Small	Intermediate
Shape of glenoid cavity	Oval	Oval	Oval	Oval	Oval
Width of coraco-acromial arch	Wide	Intermediate	Intermediate	Narrow to wide	Narrow
Shape of coracoid process	Wide	Narrow	Wide	Narrow to wide	Narrow
Surface area of coracoid process	Large	Intermediate	Intermediate	Small	Intermediate
Slope of acromion	Steep	Gentle	Gentle	Gentle	Steep
Orientation of glenoid cavity	Cranial	Cranial	Cranial	Cranial	Lateral

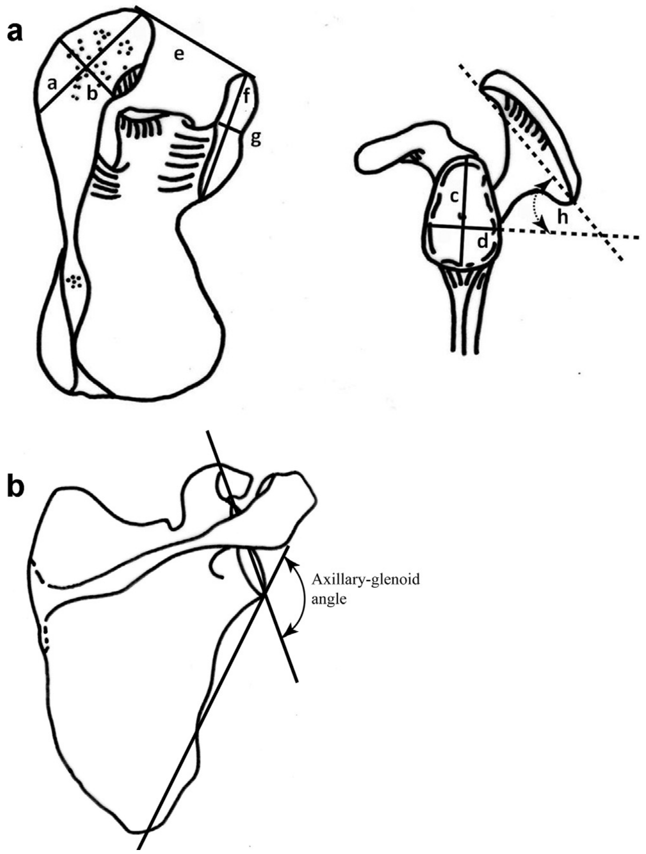

Fig. 3. Measurements performed on each scapula. a: greatest length measured along the long axis of the acromion; b: width of the acromion measured perpendicularly to the long axis and just under the acromio-clavicular joint; c: greatest height of the glenoid cavity [7]; d: greatest width of the glenoid cavity measured perpendicularly to the greatest height [7]; e: distance between the tips of the acromion and coracoid process [21]; f: greatest length of the coracoid process [12]; g: greatest width of the coracoid process measured perpendicularly to the greatest length [12]; h: slope of the acromion [22]; i: axillary-glenoid angle [7].

Table 5
The shape of the *Homo sapiens sapiens* (HSS) acromion differs markedly from that in other Hominoids, the only exception being gorillas, which also have a broad acromion.

	Gorilla	Chimpanzee	Orang-utan	Gibbon	Human
Gorilla		*0.002*	*0.001*	*0.007*	0.3303
Chimpanzee	*0.03*		0.25	0.66	*0*[*]
Orang-utan	*0.02*	1		0.34	*0*[*]
Gibbon	0.08	1	1		*0.001*
Human	1	*0*[*]	*0.005*	*0.01*	

H = 30.63; p(H0) = 0[*].
Shape of the acromion. Results of the Kruskal-Wallis test; significant differences between paired groups are in italics.

[*] *P* < 0.001.

Table 6
The width of the coraco-acromial arch varies considerably across Hominoid species, with the lowest values being found in *Homo sapiens sapiens* (HSS).

	Gorilla	Chimpanzee	Orang-utan	Gibbon	Human
Gorilla		*0.002*	*0.03*	0.2	*0.000008*[*]
Chimpanzee	*0.02*		0.7	0.74	*0.008*
Orang-utan	0.26	1		0.81	*0.016*
Gibbon	1	1	1		0.56
Human	*0.00008*[*]	0.08	0.16	1	

H = 22.86; p(H0) = 0[*].
Coraco-acromial arch. Results of the Kruskal-Wallis test; significant differences between paired groups are in italics.

[*] *P* < 0.001.

Table 7
The orientation of the glenoid cavity is noticeably more lateral in humans than in all other Hominoids. In contrast, glenoid cavity orientation is more cranial in gibbons than in other Hominoids, which are the most brachiating Apes.

	Gorilla	Chimpanzee	Orang-utan	Gibbon	Human
Gorilla		0.7	*0.02*	*0*[*]	*0*[*]
Chimpanzee	1		*0.02*	*0*[*]	*0*[*]
Orang-utan	0.29	0.23		*0*[*]	*0*[*]
Gibbon	*0*[*]	*0*[*]	*0*[*]		*0*[*]
Human	*0*[*]	*0*[*]	*0*[*]	*0*[*]	

H = 90.39; p(H0) = 0[*].
Glenoid cavity orientation. Results of the Kruskal-Wallis test; significant differences between paired groups are in italics.

[*] *P* < 0.001.

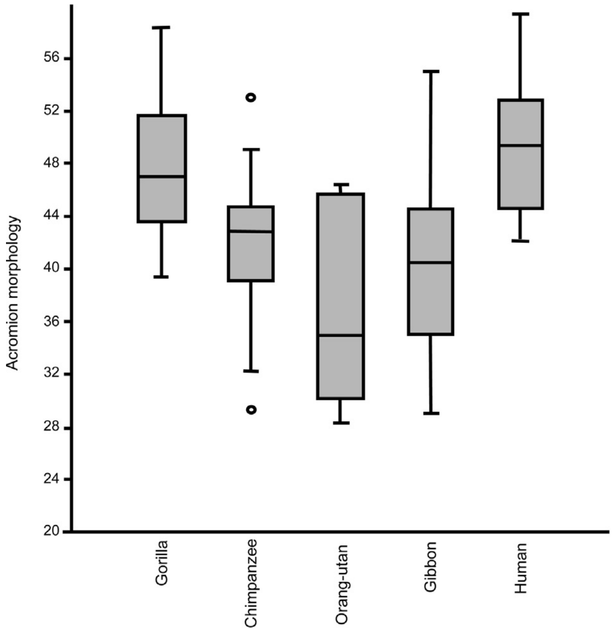

Fig. 4. Variability in the morphology of the acromion in Hominoids. Both humans and gorillas have a broad and markedly projecting acromion.

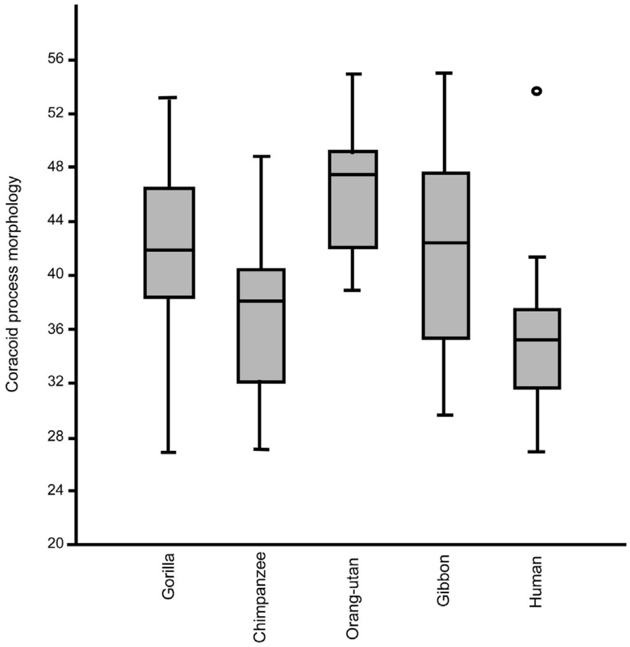

Fig. 5. Variability in the morphology of the coracoid process.

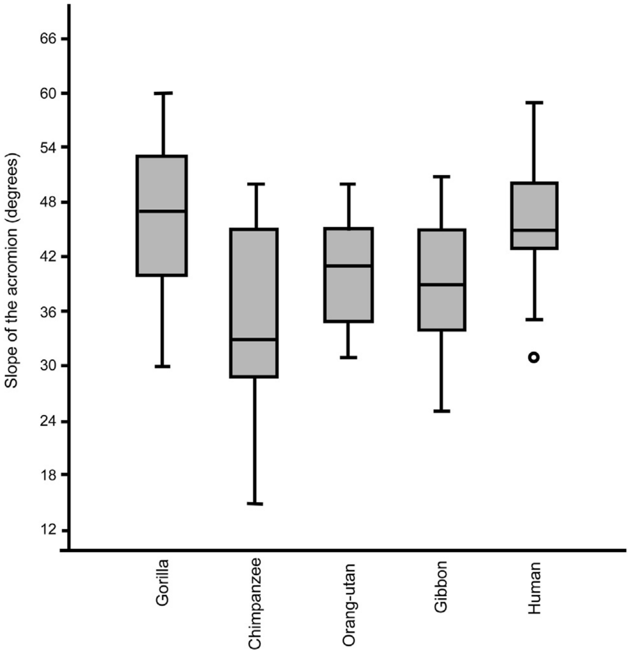

Fig. 6. Variability in the slope of the acromion. The slope is steepest in humans and gorillas.

and gorillas (Fig. 6). Finally, the axillary-glenoid angle was wider in HSS than in the other Hominoids (Figs. 2 and 7 and Table 7). Thus, the glenoid cavity in apes has a considerably more cranial orientation than in HSS, whose glenoid cavity faces laterally.

In sum, the lateral part of the human scapula exhibits two distinctive features, namely, a laterally oriented glenoid cavity and a narrow coraco-acromial arch. Both HSS and gorillas have a steeply sloped acromion that is broader and squarer than in other Hominoid species.

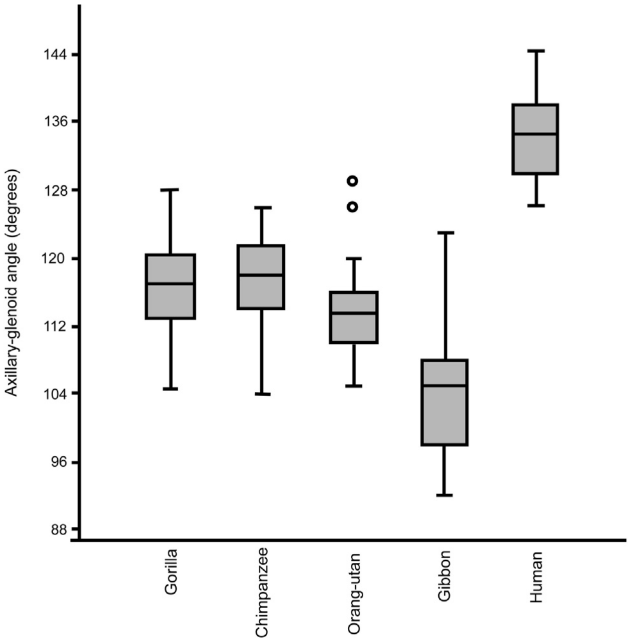

Fig. 7. Variability in glenoid cavity orientation in Hominoids. Greater axillary-glenoid angle values are associated with a more lateral orientation of the glenoid cavity.

4. Discussion

Rotator cuff tendinopathy is among the most common shoulder disorders in humans [23]. Among the many hypotheses put forward to explain this high prevalence, most involve the morphology of the acromion. Two radio-clinical studies in humans reported in 2006 [24,25] and 2013 [19] established that a large lateral extension of the acromion was among the bone morphology factors associated with rotator cuff tears. Although scapular anatomy and morphology has been the focus of a large number of studies in hominoids (gibbons, orang-utans, gorillas, chimpanzees, and humans) since the nineteenth century [1–10], very few of them involved comparisons of acromial process, coracoid process, or coraco-acromial arch morphology across hominoid species [12,21,26–28].

Our preliminary study establishes that the HSS scapula exhibits a number of distinctive morphological features compared to the scapulae of other hominoids. Interestingly, the morphology of the glenoid cavity is remarkably uniform across species and the differences predominantly involve the bony appendages. It is as if, for a given glenoid pivot, evolutionary changes chiefly involved the zones of muscle attachment to bones, both in terms of surface area, which extended outside the axis of the skeleton, and in terms of orientation, to better meet the new needs of upper limb function related to intermittent or continuous (HSS) bipedalism. The increased width of the acromion is thus among the main distinctive features of the HSS scapula, together with the narrowness of the coraco-acromial arch, and complements the large size of the infraspinatous fossa and posterior location of the scapula on the rib cage.

The considerable width of the acromion that is characteristic of the human shoulder has allowed an increase in the attachment surface area and, therefore, in the strength of the deltoid muscle. Thus, during elevation and flexion of the arm, the humerus tends to move upwards under the effect of the deltoid muscle. Although this upwards movement is limited by contraction of the supraspinatus muscle, this muscle is small in humans, as shown by the smaller relative and absolute dimensions of the supraspinatous fossa compared to those of apes (Fig. 2) [9,29]. This relative weakness of the supraspinatus muscle compared to the deltoid muscle in humans, combined with the narrowness of the coraco-acromial arch [26], results in permanent contact under normal conditions between the humeral head and coraco-acromial arch during elevation of the arm. Thus, a neo-articulation connecting the humeral head, deltoid muscle, and coraco-acromial ligament probably developed in humans. The coraco-acromial ligament exists only in hominoids [21] and probably reflects the need to extend the anterior and lateral corner of the scapula in response to the loads imposed by the humeral head on the neo-articulation. The direction of these loads varies considerably during suspension or the alternating suspension-compression-goal-directed prehension movements specific of this taxon and not seen in strictly quadrupedal primates, in which the orientations show less variability.

Our study confirms the greater value of the axillary-glenoid angle in humans compared to other Hominoids. Thus, the orientation of the ape glenoid cavity is considerably more cranial compared to that of humans (Fig. 2), in whom the glenoid cavity faces laterally. This orientation is used as a criterion to determine whether a scapula fragment is associated with tree-climbing behaviour [12,14,28–31]. Given the lateral orientation of the human glenoid cavity, the axis of the scapula and that of the upper limb are not aligned until a considerable degree of flexion is achieved [32] (Fig. 8). Therefore, control of the humerus is necessarily dynamic and not static as seen in apes, whose upper limbs are usually carried above the head to allow suspensory behaviours. Finally, the risk of loss of humeral head centring is increased by the fact that humans

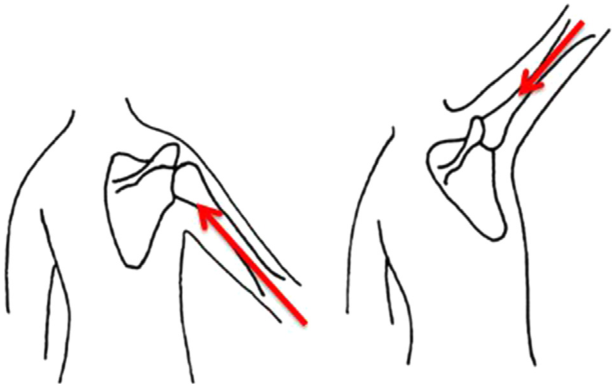

Fig. 8. Diagram showing the position of the humerus relative to the axis of the scapula according to upper limb position.

usually use their upper limbs for open kinetic chain activities and is further increased by carrying eccentrically positioned loads at the end of the upper limb [33].

In sum, the site of contact between the humeral head and coraco-acromial arch may deserve to be viewed as a neo-articulation that developed during evolution to compensate for the relative weakness of the supraspinatus muscle in humans. This neo-articulation is poorly suited to the current long lifespan of humans, which is the result of cultural developments, as opposed to evolution. Its existence may contribute to explain the high prevalence of rotator cuff tendon disorders in humans.

5. Conclusion

Our comparative anatomical study in Hominoids confirms that the human scapula is characterised by a wide acromion that projects laterally above a horizontally oriented glenoid cavity. The slope of the acromion is steeper and the subacromial space narrower than in other Hominoids. These morphological features probably contribute to the high prevalence of rotator cuff tendinopathy in modern man.

Disclosure of interest

The authors declare they have no conflicts of interest concerning this article.

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