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Humeral torsion does not dictate shoulder position, but does influence throwing speed

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1. Introduction

A debate has emerged in the last few years over the shape and position of the shoulder in early *Homo*. That the shoulder joint underwent changes approximately 2 million years ago is not in dispute. A number of newly discovered and relatively complete scapulae show that the orientation of the glenohumeral joint shifted caudally from the more cranial orientation seen in the apes and earlier hominins (Walker and Leakey, 1993; Larson et al., 2007; Lordkipanidze et al., 2007; Haile-Selassie et al., 2010; Green and Alemseged, 2012; Churchill et al., 2013). However, just how modern human-like this caudally rotated shoulder complex is remains less clear. Larson (2007, 2009) has proposed that early *Homo* possessed a novel, transitional shoulder morphology in which the shoulder joint faced anteriorly. We have proposed that *Homo erectus* had an essentially modern human-like shoulder complex with a laterally oriented glenohumeral joint (Roach et al., 2013; Roach and Richmond, 2015). Why does this debate matter? These differing reconstructions of the shoulder have important functional implications for a number of crucial behavioral shifts hypothesized to occur at or near the origins of our genus (e.g., reduced climbing behavior, intensification of tool manufacture and use, endurance running, and high speed throwing).

Much of this debate has hinged on the length of the clavicle. As the only bony strut attaching the shoulder complex to the torso, clavicle length may be an important factor in determining shoulder position. Along these lines, Larson (2007, 2009) has argued that relatively short clavicles found in early *Homo* suggest that their shoulders had a more anterior orientation. We tested this idea, but found that the relative clavicle length measure Larson used as data support for her model does not accurately predict shoulder position (Roach and Richmond, 2015). We further concluded that the data better support the presence of modern human-like, laterally facing shoulders dating back to *H. erectus* or earlier. Larson (2015) does not agree with our conclusions or with the way we present her research.

Our paper addressed the role of clavicle length in determining shoulder position and throwing performance (Roach and Richmond, 2015). Larson's reply (2015), “Humeral torsion and throwing proficiency in early human evolution,” does not address clavicle length and does not dispute either the data we present or our methodology. Instead, Larson refocuses her anterior shoulder model on humeral torsion (Fig. 1). She argues that 1) we misrepresent her anterior shoulder hypothesis, 2) very low humeral torsion presents an unresolved problem for our reconstruction of the *H. erectus* shoulder as modern human-like, 3) low torsion is associated with higher injury risk in throwers, and 4) very low torsion does not support the capacity for high-speed throwing dating back to *H. erectus*. We disagree with Larson on all of these points and in this paper present data that strongly support our position.

2. A distinction without a difference

We disagree that we misrepresented Larson's work by stating that she proposed an anterior facing shoulder joint was necessary

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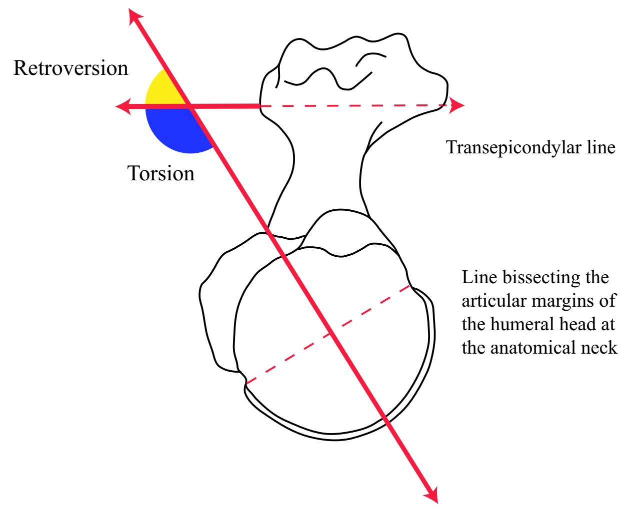

Figure 1. Humeral torsion. The degree of humeral torsion (in blue) is measured as the difference between the orientation of the humeral head and the distal condyle in the elbow. In the clinical literature, humeral retroversion (in yellow) refers to the same angle measured in the opposing direction. Used with permission from Roach et al. (2012). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

to overcome deficits in internal rotation at the shoulder due to low humeral torsion (Larson, 2015). Larson (2015: 199) states that very low torsion in early hominins "(does not) make sense if they all possessed a human-like scapular position." She further states that "the need for internal humeral rotation with growing dependence on tools" makes low torsion without an anteriorly facing shoulder unlikely (Larson, 2015: 200). The "problem" Larson proposes for combining a laterally oriented shoulder with low humeral torsion is the same in both of our descriptions.

What Larson (2007, 2009) has previously argued is that when relatively short clavicles are found in association with a caudally rotated scapula, the result is a shoulder pulled anteriorly around the ribcage. With the glenoid fossae now facing anteriorly, Larson (2007, 2009, 2015) argues that low humeral torsion does not provide any impediment to tool use as shoulder rotational range of motion (ROM) easily allows the hands to overlap. Based on this logic, and an observation that clavicle lengths in KNM-WT 15000 and LB1 appear to be short relative to humeral length, Larson (2007, 2009) proposed the anterior shoulder model for early *Homo*. Furthermore, she explicitly argued that this anterior shoulder morphology would "negatively (affect) overhand throwing ability" (Larson, 2007: 182). Given that relative clavicle length is both the only data support for the anterior shoulder model and the primary logic behind it, understanding the clavicle is clearly the key to evaluating Larson's hypothesis.

Larson (2015) suggests that our summary of her work conflates what anatomical factors are causes and what are effects. We have not proposed any hypotheses about cause and effect. However, Larson does. In her reply to our paper, Larson (2015: 200) defines her anterior shoulder model as "essentially a neutral by-product of other evolutionary changes, and low torsion (as) an accommodation to the resulting more anteriorly facing glenoid fossae." While it is difficult to reconcile this "neutrality" with her statements about tool use (Larson, 2007, 2015), here we focus instead on what the evolutionary changes Larson alludes to might be. If this is meant to reference a more caudally rotated glenoid, modern humans living today have caudally rotated glenoids and do not have anteriorly facing shoulders, demonstrating that these features are not necessarily linked. Moreover, if low humeral torsion is simply an accommodation to an anterior shoulder position, then torsion cannot simultaneously be the evolutionary change driving this novel shoulder configuration. Larson's earlier papers (2007, 2009) make it clear that the evolutionary change she is alluding to is clavicle length.

Our recent paper shows that reconstructions of the shoulder using relative clavicle length are flawed (Roach and Richmond, 2015). The claviculohumeral ratio (clavicle length/humeral length*100) that Larson used to justify her anterior shoulder model failed to account for independent changes in the breadth of the thorax that occur in human evolution. These changes to the ribcage have a significant effect on shoulder position. Furthermore, we show that *H. erectus* had significantly greater variation in relative clavicle length than previously thought, with the Dmanisi individuals falling squarely in the modern human range (Jashashvili, 2005; Lordkipanidze et al., 2007). We also reported very short clavicles in some of the Daasanach people living today on the eastern side of Lake Turkana (Roach and Richmond, 2015). Importantly, these individuals have no shoulder pathology, suggesting that an anteriorly oriented scapula is not required to accommodate such a short clavicle. Larson (2015: 200) now recognizes that these data "(call) into question" her hypothesis that "a more laterally positioned scapula in early *Homo* was largely the result of a relatively short clavicle."

3. The humeral torsion "problem"

Larson (2015) remains unconvinced that an anterior shoulder model is unnecessary and believes there is an unresolved problem with humeral torsion in early *Homo*. She argues that some amount of shoulder internal rotation must be necessary for manipulation (Larson, 2015), reinforced by the assumption that *Homo* must be more dependent on manipulatory abilities than earlier hominins (Larson, 2007). Given that shoulder rotation ROM is tightly linked to humeral torsion (and that low torsion individuals have reduced internal rotation; Osbahr et al., 2002; Reagan et al., 2002; Chant et al., 2007; Roach et al., 2012), Larson sees the combination of very low torsion in early *Homo* with a laterally facing shoulder as being at odds with evidence of stone tool use in the genus *Homo* (Larson, 2007, 2009, 2015). We do not believe such a problem exists.

We agree with Larson that early *Homo* used tools and also that *H. erectus* had very low humeral torsion ($\leq 120^\circ$). Furthermore, we agree that torsion in *H. erectus* is significantly lower than in modern humans or even than most baseball players, who generally have lower torsion in their dominant, throwing arm than non-athletes (Larson, 2015). However, Larson's statistical support for lower torsion in *H. erectus* does not make the point that she aims to make. In Figure. 5 of her reply, Larson (2015) shows mean and standard deviation data from a number of studies measuring humeral torsion in baseball players. While early *Homo* humeri generally have lower torsion, four of the seven studies Larson cites contain individual subjects with humeral torsion less than 120° (Fig. 2). Our own previous work on torsion and ROM, which Larson does not reference, also contains CT measurements of adult, modern human subjects with less than 120° of humeral torsion (Roach et al., 2012). Some of these baseball players have torsion as low as the *H. erectus* individuals Larson reports. Furthermore, Larson's arguments about measurement technique do not discredit these low modern human values, as two of the lowest three measurements reported come from the more accurate CT studies (Chant et al., 2007; Roach et al., 2012). These very low torsion subjects matter because they show that the low torsion "problem" does not exist (Fig. 3). These low torsion individuals are not described as having abnormal, anteriorly