HOMO - Journal of Comparative Human Biology 67 (2016) 125–137

Contents lists available at ScienceDirect

HOMO - Journal of Comparative Human Biology

journal homepage: www.elsevier.com/locate/jchb

The cross-sectional area of the *gluteus maximus* muscle varies according to habitual exercise loading: Implications for activity-related and evolutionary studies

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ARTICLE INFO

Article history:
Received 22 January 2015
Accepted 22 June 2015

Keywords:
Bipedalism
Human evolution
Medical imaging
Endurance running
Sprinting
Hominin
Hunting

ABSTRACT

Greater size of the *gluteus maximus* muscle in humans compared to non-human primates has been considered an indication of its function in bipedal posture and gait, especially running capabilities. Our aim was to find out how the size of the *gluteus maximus* muscle varies according to sports while controlling for variation in muscle strength and body weight. Data on *gluteus maximus* muscle cross-sectional area (MCA) were acquired from magnetic resonance images of the hip region of female athletes ($N = 91$), and physically active controls ($N = 20$). Dynamic muscle force was measured as counter movement jump and isometric knee extension force as leg press. Five exercise loading groups were created: high impact (triple-jumpers and high-jumpers), odd impact (soccer and squash players), high magnitude (power-lifters), repetitive impact

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http://dx.doi.org/10.1016/j.jchb.2015.06.005

(endurance runners) and repetitive non-impact (swimmers) loadings. Individuals in high impact, odd impact or high-magnitude loading groups had greater MCA compared to those of controls, requiring powerful hip extension, trunk stabilization in rapid directional change and high explosive muscle force. Larger body size and greater muscle strength were associated with larger MCA. An increase in dynamic force was associated with larger MCA, but the strength of this relationship varied with body weight. Thus, gluteal adaptation in humans promotes powerful lower limb movements required in sprinting and rapid changes in direction, as well as maintenance and stabilization of an erect trunk which also provides a platform for powerful motions of the upper limbs. These movements have likely evolved to facilitate food acquisition, including hunting.

Introduction

The *M. gluteus maximus* has an important role in the evolution of human bipedalism and gait. To achieve efficient function in a bipedal posture the *gluteus maximus* muscle has changed greatly in size, shape and attachment compared to the situation found in non-human primates (Thorpe et al., 1999). The muscle has shortened and thickened especially at its cranial portion, with changes in lever and load arm lengths due to pelvic, sacrum and femur re-alignment (Aiello and Dean, 1990; Stern, 1972). In humans the *gluteus maximus* muscle originates at the iliac crest, sacrum and coccyx, and inserts on the gluteal ridge at the postero-lateral femoral shaft below the greater trochanter (Aiello and Dean, 1990; Stern, 1972). The muscle acts to extend the hip joint, but it can also act as adductor and lateral rotator of the lower limb and is active during locomotion (Aiello and Dean, 1990; Bartlett et al., 2014; Stern, 1972).

The evolution of the *M. gluteus maximus* in humans has been attributed to changes in its function. Powerful hip joint extension is needed, for example, for getting up from a chair or rising from a squatting position (Stern and Susman, 1981). This task activates the *M. gluteus maximus* in a similar fashion to the *M. gluteus superficialis* (=*maximus*) and the *M. gluteus medius* in climbing apes, which suggests that climbing might have been a pre-adaptation to bipedal walking (Stern and Susman, 1981). However, according to Bramble and Lieberman (2004) the anatomical features linked with human bipedalism are better suited for endurance running than walking because *M. gluteus maximus* activation is greater in running than in walking, even when compared to walking uphill (Lieberman et al., 2006). Bramble and Lieberman (2004) suggest that running capability is a feature evolved in the genus *Homo* rather than a by-product of walking. Protein-rich diet has been considered a promoting factor for the evolution of running where food was acquired either through hunting or scavenging (Bramble and Lieberman, 2004). In running, the role of *M. gluteus maximus* is to decelerate the swing limb at the midpoint of the swing-phase (Lieberman et al., 2006), and stabilize the trunk against flexion (Lieberman et al., 2006; Marzke et al., 1988). On the contrary, a recent study by Bartlett et al. (2014) notes that sprinting and climbing are activities which activate the *M. gluteus maximus* to a greater extent than endurance running.

Viewpoints on greater *gluteus maximus* muscle size have focused on finding those activities that use the muscle, i.e. climbing, walking, and running (Bartlett et al., 2014; Lieberman et al., 2006; Marzke et al., 1988; Stern and Susman, 1981). This implies that activation results in larger muscles. However, only specific loading results in muscle size and strength gain. An increase in muscle mass and strength requires both muscle fatigue and high mechanical loading (Van Roie et al., 2013). High resistance training (defined as repetitions performed until exhaustion due to muscle fatigue) increases muscle mass and strength (Brown and Wilmore, 1974; Buford et al., 2007; Campos et al., 2002; Chilibeck et al., 1998; Kongsgaard et al., 2004; Kraemer et al., 2004; Rønnestad et al., 2007; Wilmore, 1974; Young