MUSCLE STRENGTH AND ENTHESEAL SIZE IN HUMAN THUMBS: TESTING THE RELATIONSHIP WITH A CADAVERIC MODEL

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INTRODUCTION

In this study we analyze the relationship between strength and the entheseal area of the *opponens pollicis* (OP) and *abductor pollicis longus* (APL) muscles, two muscles of the hand whose main function is to oppose the thumb and move the thumb anteriorly, respectively.

We were interested in this link for two reasons: (1) to determine if muscular strength is related to entheseal size, and (2) to evaluate the predictive power of enthesis, age, sex and body size on muscular strength. With the latter objective we attempt to discuss whether it is reasonable to infer behaviour from entheses in the archaeological record. To figure out if the recruitment of muscles leaves a distinctive mark on the bone is a key component for understanding human hand evolution. This is because manipulative activities, like tool-related behaviours, could contribute to the anatomical changes in the hand of our lineage as well as explain the high dexterity we have (e.g. Hamrick et al. 1998; Key & Dunmore 2015; Kivell et al. 2015).

The ability of entheses to provide information on activity patterns has a long history of debate. Briefly, there are studies concluding that manual labour has an effect on entheseal morphology (Karakostis & Lorenzo 2016; Karakostis et al. 2017), and others stating that entheseal anatomy is strongly dependant on the biological profile of individuals (e.g. age and body size) which makes them poor behavioural indicators (Zumwalt 2006; Williams-Hatala et al. 2016; Djukic et al. 2015).

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MATERIAL AND METHODS

To investigate these issues, we have dissected 20 hands and forearms from fresh human cadavers of known sex and age at death held at the Human Donation Service of the Universitat de Barcelona (for details of the dissection procedures see Sacks and Roy 1982). The sample was composed by 15 different individuals (five of them were represented by their left and right hands and forearms). The mean age at death was 73.63 ± 10.29 years, 12 hands and forearms were from the right side, and eight were from the left side. We measured the physiological cross-sectional area (PCSA) of the OP and APL (Figure 1), which is proportional to muscular strength (Alexander 1975).

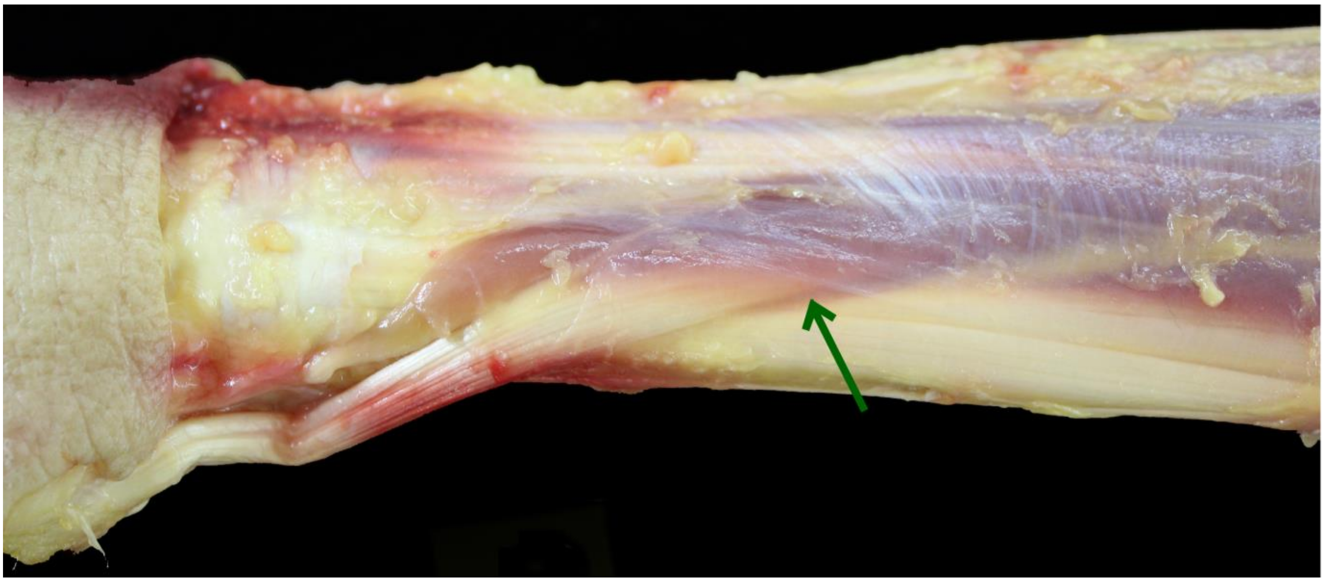

Fig. 1: Photograph of one of the individuals dissected in this study (lateral view). Green arrow shows the *abductor pollicis longus* muscle (APL).

To analyze the entheseal area we used the recent methodology proposed by Karakostis and Lorenzo (2016). High resolution 3D models of the bones were obtained using Breuckmann SmartScan structured-light scanner (Breuckmann Inc., Baden, Germany) and the absolute area (in mm2) of the entheses of the OP and APL were measured.

We also measured the length of the radius as an estimation of body size (mm).

A Pearson correlation test between entheseal area, PCSA, age and body size were performed, while the association between sex and entheseal area and PCSA was evaluated through an independent t-test. We then made simple and multiple linear regression of enthesis area on all other variables (PCSA, age, body size and sex) to evaluate their relative contribution, and the same test was carried out with PCSA as the dependent variable. Data analyses were performed in R Studio (R Development Core Team 2018).

Two out of the 20 individuals dissected presented evidence of osteoarthritis and were excluded from further analysis.

RESULTS

For the APL, entheseal area show a significant and relatively strong correlation with PCSA (0.61, $p<0.01$) (Figure 2), and with sex: on average females presented 23.63 mm^2 of entheseal area less than males ($t_{17}= -7.9556$, $p<0.01$). There was also a significant average difference between males and females in PCSA, with females having less muscular strength (t17= -3.8833, p<0.01). Age and body size did not show a correlation with entheseal area of the APL.

Interestingly, in the multiple regression analysis of insertion area on sex and PCSA of this muscle, PCSA was the only significant predictor of the size of the enthesis (p<0.01), $F(2,15)=4.609$, $p<0.05$, $R^2=0.38$. In turn, age and entheseal size significantly predicted PCSA, $F(2,15)=6.094$, $p<0.05$, $R^2=0.45$, and entheseal size alone predicted the 37% of the variance of the PCSA: $F(1,16)=9.25$, $p<0.01$, $R^2=0.366$.

OP only correlated significantly with the length of the radius (0.57, p<0.05), which significantly predicted 32% of the variance of the PCSA: $F(1,16)=7.605$, $p<0.05$.

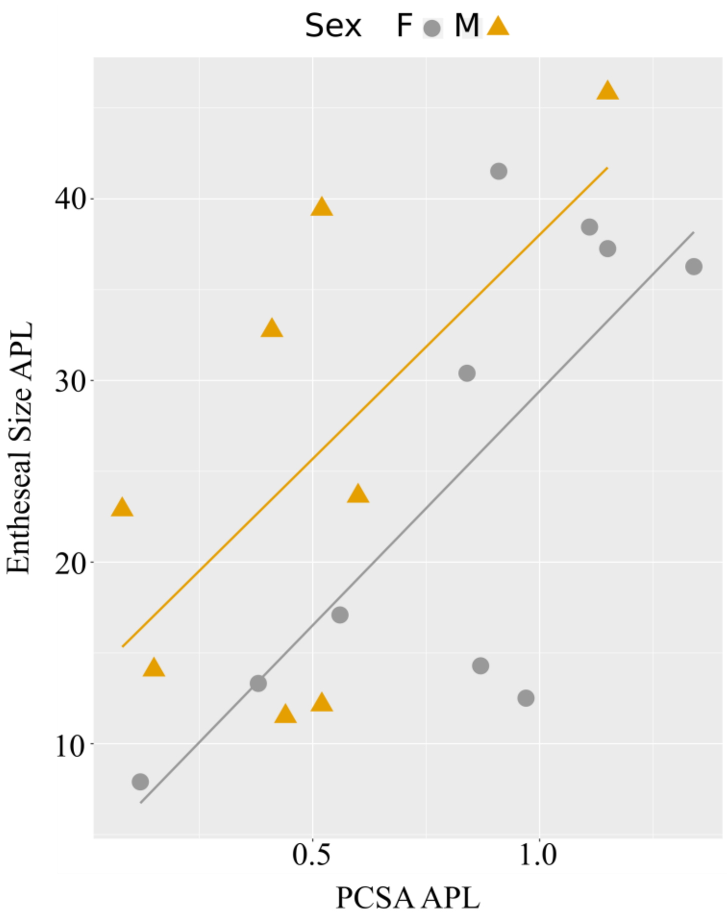

Fig. 2: Scatter plot of the entheseal area (mm^2) and the physiological cross-sectional area (cm^2) of the APL. Regression line is shown for males and females separately.

DISCUSSION AND CONCLUSION

These results mean that in the case of APL, muscular strength can be inferred from the size of the enthesis alone (and vice versa), in a relatively strong manner (Pearson's r between both variables was 0.61, p<0.01), validating a useful, simple way to infer muscular strength in paleoanthropological record. However, our results also indicate that strength of the muscles is dependent on the body size of individuals and their age, which is in line with previous studies showing a positive relationship with body size (Nedeljkovic et al. 2008) and a decrease in this muscular property with aging (for a review see Doherty 2003); R-squared raised from 37% to 45% when this last variable was added to the regression analysis.

Even so, there is a considerable proportion of the variance that is not explained by the biological profile of the individuals (sex, age and body size), which indicates that other relevant predictors were not studied here. We believe that it is reasonable to expect that activity patterns may have a potentially large influence on muscular properties and entheseal size as suggested in previous studies (e.g. Villotte et al. 2010; Karakostis et al. 2017), but this proposition remains to be further tested on material in which soft tissue is present. Sadly, no information about activity was available for the individuals dissected in this work, and therefore, it was not possible to evaluate its effect on muscle strength and entheseal size.

For OP, we found an analogous result than Williams-Hatala et al. (2016), who in a methodologically similar study found that entheseal size does not reflect architectural measurements (including PCSA) of the OP and *opponens digiti minimi* muscles.

The different results we obtain between APL and OP may be due to the histological composition of the tissue in the bone-tendon interface; APL has a fibrocartilaginous insertion, while OP has a fibrous attachment. Fibrous attachments dissipate stress over a relatively greater, but less-defined, area (Benjamin et al. 2006; Zumwalt 2006). Previous studies also proposed that fibrocartilaginous attachments are better indicators of general level of activities (Villotte et al. 2010).

There are few studies using dissected material with the aim of relating soft and hard tissue of hands (Shrewsbury et al. 2003; Marzke et al. 2007; Williams-Hatala et al. 2016) and, to our knowledge, ours provides the first promising results on the ability of bone features to provide information on muscular properties of this anatomical segment using this type of material. Further studies on other muscles of the hand would serve as corroborative data on this problem and may improve our knowledge on activity patterns and human hand evolution.

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