Effects of occupation-related physical activity on limb bone shaft strength among contemporary people in the United States

A thesis presented by

Amaya Abeyta-Brown

To the Department of Anthropology

in partial fulfillment of the requirements

for the degree with honors

of Bachelor of Science

University of New Mexico

Albuquerque, New Mexico

December 2023

Abstract

Compelling evidence indicates that physical activity can enhance human limb bone shaft strength. Much of this evidence, however, comes from studies of people who engage in exceptionally high levels of activity, such as competitive and professional athletes. Less is known about how more subtle sources of variation in activity might affect bone shaft strength, including the effects of a person’s occupation. Here, we investigate the influence of occupation-related physical activity on bone shaft strength among young men (aged 18-35 years) in the New Mexico Decedent Image Database, a collection of full-body CT scans of 21st-century individuals with documented occupations. Bone shaft strength was quantified in the humerus and tibia from CT scans. Physical activity intensity of each person's job was categorized based on an established classification scheme as either (1) sedentary or requiring light amounts of activity, or (2) involving moderate to large amounts of activity. Results suggest that humeral and tibial shaft strength properties (e.g., cortical bone area, second moments of area) do not differ significantly between people with and without jobs requiring moderate to large amounts of activity. This may suggest that most jobs today are not physically demanding enough to provide substantial benefits for bone shaft strength. If so, activities outside the workplace may be critical for developing and maintaining strong limb bones.

Introduction

It is well established that bones adjust their strength to the mechanical loads imposed upon them (Ruff, 2006; Hart et al., 2017). Increased mechanical loading typically results in bone strengthening, whereas decreased mechanical loading typically leads to bone weakening. In standard biomechanical analyses of bones, strength is measured from the amount of cortical bone tissue and its distribution about the long axis of the bone shaft. Positive associations between mechanical loading and bone strength have been documented in experiments with animal models (Burr et al., 2002; Forwood, 2008) and in studies of competitive and professional human athletes (Shaw and Stock, 2009a, 2009b; Korht et al., 2004; Wilks et al., 2009). Much of this prior evidence, however, comes from studies of animals and people who engage in exceptionally high levels of activity. Less is known about how more subtle sources of variation in activity might affect bone strength, including the effects of a person's occupation.

Most adults spend a large proportion of their daily time in the workplace (Kirk & Rhodes, 2011), where many people are exposed only to low- to moderate-intensity, repetitive activities (Church et al., 2011). However, very few studies have analyzed the impact of occupational physical activity intensity on bone strength from a biomechanical basis. One study found a positive association between occupation-dependent loading and bone strength in men (Biver et al., 2016), while other studies found no consistent relationship (Vehmas et al., 2005; Barbe & Popoff, 2020). Similarly, conflicting results have been obtained from studies that focused only on bone mineral density (BMD), which is related to bone strength but does not take into account the size and structure of bones like biomechanical analyses do (Choksi et al., 2018). Two studies (Weiss et al., 1997; Coupland et al., 2000) documented a positive correlation between occupational activity intensity and BMD. Conversely, others obtained more ambiguous results. For example, in sawmill workers, there was no strong relationship between workload and BMD, but rather other lifestyle practices like smoking had a greater effect (Cvijetić et al., 2021). A study in a Swedish sample also showed no correlation between occupational activity intensity and BMD (Brahm et al., 1998).

Biomechanical analyses of bone strength have been popular in archaeological and paleontological research that aims to interpret patterns of past physical activity from skeletal remains. Such analyses have provided much insight into the mobility patterns of early humans, for example, by demonstrating that factors like terrain have a major effect on bone strength (Holt & Whittey, 2019). Other popular areas of research look at subsistence strategies and the transition from a hunter-gatherer to an agricultural way of life (Bridges, 1985), lifestyle characteristics like occupation or tool use (Maggiano et al., 2008; Mays, 2001, 2002; Wanner et al., 2007), as well as behavioral reconstruction of early hominins (Sawyer & Maley, 2005). This work has also become increasingly popular in epidemiological studies. Bone strength analyses have provided a more comprehensive understanding of musculoskeletal diseases, most commonly osteoporosis (Egloff et al., 2012; Ferretti et al., 2003), nutritional intake (Rizzoli, 2008), and sports-related injuries (Taunton et al., 1988).

Here, I adopt a biomechanical approach to investigate the influence of occupation-related physical activity intensity on bone shaft strength among men aged 18-35 years in the New Mexico Decedent Image Database (NMDID), a collection of full-body CT scans of 21st-century individuals with documented occupations (Edgar et al., 2020). Bone strength among people with sedentary and more physically demanding jobs were compared. I hypothesized that bone strength would differ between the groups with greater bone strength in those with more physically demanding jobs and lower bone strength in the sedentary group of individuals.

Materials and Methods

Sample from NMDID

For this study, full-body CT scans were obtained from a total of 179 men with known occupations. Only individuals aged 18 to 35 years were included in the analysis because this is the age range between when longitudinal bone growth typically ceases and before peak bone mass is typically obtained. All individuals with fractured limb bones in the upper and lower extremities were eliminated from the study. Individuals were also excluded if their body weight, stature, and/or body mass index were not documented in the NMDID. Females were not considered in the study because of the small number of females available in the NMDID with documented occupations requiring more than light amounts of physical activity.

For each individual, the level of intensity of occupational physical activity was assigned based on documented metabolic equivalents (METs) of occupations. A previously established classification scheme (Deyaert et al., 2017) was used to categorize an occupation as either sedentary or requiring light amounts of physical activity (hereafter, called "inactive") or involving moderate to large amounts of activity (hereafter, called "active"). Examples of inactive occupations included retail/wholesale, cashiers, business employees, and truck drivers, whereas examples of active occupations included construction, mining, agriculture/farming, manufacturing, and factory work (Figure 1). Among individuals with inactive occupations, those documented in the NMDID as frequently engaging in exercise outside of work were also excluded. The final sample size included 40 men in the inactive group and 61 men in the active group.

Measurements of CT scans

Bone strength was measured from the CT scans following the protocol of Wallace and colleagues (2023). For each person, their full-body CT image stack was imported into Amira software, and a 3D rendering of their full-body skeleton was generated to locate the left and right humeri and the right tibia. These limb bones were then digitally cropped out from the full-body skeleton, and the cropped-out bones were saved as separate CT image stacks (Figure 2). Next, the CT image stacks were imported into ImageJ software, and 3D digital renderings of the bones were aligned longitudinally using the BoneJ plugin (Doube et al., 2010). On the aligned humeri, the transverse CT image slices of the shafts corresponding to the 35% bone length from the distal ends of the bones were selected, and cortical area (bone quantity) and polar moment of area (average bending strength) were calculated using BoneJ. These properties were similarly calculated at the midshaft in the tibia. In addition, for each individual, ImageJ was used to measure waist size from transverse CT slices corresponding to the level of umbilicus (Figure 3).

Statistical Analysis

Comparisons of body size and bone strength properties between men with inactive and active occupations were made using *t*-tests. All analyses were performed using JMP Pro software. Statistical significance was judged using a 95% criterion ($p \leq 0.05$).

Results

Stature, body weight, body mass index, and waist size did not differ significantly between people with inactive and active jobs (*t*-tests: $p > 0.1$ for all variables) (Figure 4).

Cortical area in the left and right humerus did not differ significantly between people with inactive and active jobs (*t*-tests: $p = 0.53$ and 0.21, respectively), nor did polar moment of area (*t*-tests: $p = 0.62$ and 0.35, respectively) (Figure 5).

Among people with both inactive and active jobs, cortical area was significantly greater in the right than left humerus (paired *t*-tests: $p < 0.001$ for both groups), as was polar moment of area (paired *t*-tests: $p < 0.001$ for both groups). Limb asymmetry in cortical area and polar moment of area did not differ significantly between groups (*t*-tests: $p = 0.54$ and 0.39, respectively) (Figure 5).

Cortical area in the tibia did not differ significantly between people with inactive and active jobs (*t*-test: $p = 0.88$), nor did polar moment of area (*t*-test: $p = 0.85$) (Figure 5).

Discussion

The results show that humeral and tibial shaft strength properties do not differ significantly between people with active and inactive jobs. It is perhaps surprising that limb bone shaft strength was not found to be associated with occupation-related physical activity levels, given substantial prior evidence that exercise is generally anabolic to bone. One explanation might be due to the fact that occupations documented for individuals at the time of CT scanning do not accurately reflect the strenuousness of their entire work history. Considering that the job descriptions from NMDID stemmed mostly from interviews with close relatives, it is possible error in recall could under- or over-estimate the duration and type of occupational activity.

However, another reasonable interpretation might be that most jobs today in our modern post-industrial economy are not physically demanding enough to provide substantial benefits for limb bone shaft strength. With increasing technological advances in the workplace, occupational activities are less labor intensive and, consequently, more sedentary. This shift towards a more automized work environment has had a noticeable impact. In the mid-20th century, nearly half of the private sector jobs in the United States demanded moderate to large amounts of physical activity. Today, less than 20% of jobs require this same level of activity (Church et al., 2011). It is well-researched that a sedentary lifestyle increases the risk of osteoporosis leading to greater bone fragility and fracture risk. This implies that exercise outside the workplace may be critical for developing and maintaining strong, healthy bones.

The reduction in long bone shaft strength can be explored from an evolutionary perspective as contemporary humans shift towards greater sedentary behavior. Humans evolved from a physically demanding lifestyle derived from a hunter-gatherer way of life and would partake in rigorous activities like long-distance walking and running and weapon use. The skeletal structure of early hominins reflects this intense level of physical activity where early humans had a robust skeletal structure compared to modern-day humans, who are much more gracile. This shift in bone morphology demonstrates the reduction in bone strength due to the lowered levels of physical activity prevalent in today's sedentary society. The reliance on technology and reduced physical activity patterns goes at odds with our evolutionary adaptations, underlining the importance of exercise for bone health.

There were several limitations to this study. In the sample criteria, alternative factors influencing bone adaptation, such as genetics, hormones, diet, substance abuse, and environment, were not considered (Turner, 2001; Ruff et al., 2006). The main focus of this paper was to control for active and inactive occupations, thus the other factors were not deemed relevant, but it is important to acknowledge that bone adaptation is not solely from mechanical loads but intertwined with various complex systems. Additionally, the subjects and occupations described here were from the United States and biased toward Western technology and cultural norms. However, labor intensity may vary worldwide, and what might be considered heavy labor here may not necessarily be the same in other countries. In developing countries, jobs are more labor intensive and subject to greater physically demanding activities and manual tasks. Thus, gathering data from other countries where manual labor is more prevalent can provide greater insight into the strengthening of bones influenced by occupational physical activity.

Another potential limitation was that the measurement of occupational activity was derived from MET values which is a systematic approach to estimate energy usage but MET scores do not take into account individual variation. Alternative measurements of levels of physical activity should be considered to reflect types of occupational activity. Further research needs to be done to better understand the influence of moderate forms of activity on bone strength.

References

Barbe, M. F., & Popoff, S. N. (2020). Occupational activities: Factors that tip the balance from bone accrual to bone loss. *Exercise and Sport Sciences Reviews*, *48*(2), 59–66. https://doi.org/10.1249/JES.0000000000000217.

Biver, E., Perréard Lopreno, G., Hars, M., van Rietbergen, B., Vallée, J. P., Ferrari, S., Besse, M., & Rizzoli, R. (2016). Occupation-dependent loading increases bone strength in men. *Osteoporosis International, 27*(3), 1169–1179. https://doi.org/10.1007/s00198-015-3409-2.

Brahm, H., Mallmin, H., Michaëlsson, K., Ström, H., & Ljunghall, S. (1998). Relationships between bone mass measurements and lifetime physical activity in a Swedish population. *Calcified Tissue International*, *62*(5), 400–412. https://doi.org/10.1007/s002239900452.

Bridges, P. S. (1985). *Changes in long bone structure with the transition to agriculture: Implications for prehistoric activities* (Publication No. 8520876) [Doctoral Dissertation, University of Michigan]. University Microfilms International.

Burr, D. B., Robling, A. G., & Turner, C. H. (2002). Effects of biomechanical stress on bones in animals. *Bone*, *30*(5), 781–786. https://doi.org/10.1016/s8756-3282(02)00707-x.

Choksi, P., Jepsen, K. J., & Clines, G. A. (2018). The challenges of diagnosing osteoporosis and the limitations of currently available tools. *Clinical Diabetes and Endocrinology,* 4(12). https://doi.org/10.1186/s40842-018-0062-7.

Church, T. S., Thomas, D. M., Tudor-Locke, C., Katzmarzyk, P. T., Earnest, C. P., Rodarte, R. Q., Martin, C. K., Blair, S. N., & Bouchard, C. (2011). Trends over 5 decades in U.S. occupation-related physical activity and their associations with obesity. *PloS one*, *6*(5), e19657. https://doi.org/10.1371/journal.pone.0019657.

Coupland, C. A., Grainge, M. J., Cliffe, S. J., Hosking, D. J., & Chilvers, C. E. (2000). Occupational activity and bone mineral density in postmenopausal women in England. *Osteoporosis International*, *11*(4), 310–315. https://doi.org/10.1007/s001980070119.

Cvijetić, S., & Kovacic, J. (2019). Association between quantitative bone ultrasound and self-reported physical activity in nursing homes residents. *Sigurnost*, *10*(4), 659–666. https://doi.org/10.1007/s41999-019-00183-3.

Deyaert, J., Harms, T., Weenas, D., Gershuny, J., & Glorieux, I. (2017). Attaching metabolic expenditures to standard occupational classification systems: Perspectives from time-use research. *BMC Public Health*, *17*(1), 620. https://doi.org/10.1186/s12889-017-4546-7.

Doube, M., Kłosowski, M. M., Arganda-Carreras, I., Cordelières, F. P., Dougherty, R. P., Jackson, J. S., Schmid, B., Hutchinson, J. R., & Shefelbine, S. J. (2010). BoneJ: Free and extensible bone image analysis in ImageJ. *Bone*, *47*(6), 1076–1079. https://doi.org/10.1016/j.bone.2010.08.023.

Edgar, H. J. H., Daneshvari Berry, S., Moes, E, Adolphi, N. L., Bridges, P., & Nolte, K. B. (2020). New Mexico Decedent Image Database. Office of the Medical Investigator, University of New Mexico. doi.org/10.25827/5s8c-n515.

Egloff, C., Hügle, T., & Valderrabano, V. (2012). Biomechanics and pathomechanisms of osteoarthritis. *Swiss Medical Weekly*, 142:w13583. doi:10.4414/smw.2012.13583.

Ferretti, J. L., Cointry, G. R., Capozza, R. F., & Frost, H. M. (2003). Bone mass, bone strength, muscle-bone interactions, osteopenias and osteoporosis. *Mechanisms of Ageing and Development, 124*(3), 269-279. https://doi.org/10.1016/s0047-6374(02)00194-x.

Forwood, M. R. (2008). Physical activity and bone development during childhood: insights from animal models. *Journal of Applied Physiology*, *105*(1), 334–341. https://doi.org/10.1152/japplphysiol.00040.2008.

Hart, N. H., Nimphius, S., Rantalainen, T., Ireland, A., Siafarikas, A., & Newton, R. U. (2017). Mechanical basis of bone strength: Influence of bone material, bone structure and muscle action. *Journal of Musculoskeletal & Neuronal Interactions*, *17*(3), 114–139.

Holt, B., & Whittey, E. (2019). The impact of terrain on lower limb bone structure. *American Journal of Physical Anthropology*, *168*(4), 729–743. https://doi.org/10.1002/ajpa.23790.

Kirk, M. A., & Rhodes, R. E. (2011). Occupation correlates of adults' participation in leisure-time physical activity: A systematic review. *American Journal of Preventive Medicine*, *40*(4), 476–485. https://doi.org/10.1016/j.amepre.2010.12.015.

Kohrt, W.M., Bloomfield, S.A., Little, K.D., Nelson, M.E., & Yingling, V.R. (2004). Physical activity and bone health. *Medicine and Science in Sports and Exercise*, 36, 1985-1996. DOI: 10.1249/01.MSS.0000142662.21767.58.

Maggiano, I. S., Schultz, M., Kierdorf, H., Sosa, T. S., Maggiano, C. M., & Tiesler Blos, V. (2008). Cross-sectional analysis of long bones, occupational activities and long-distance trade of the Classic Maya from Xcambó - Archaeological and osteological evidence. *American Journal of Physical Anthropology*, *136*(4), 470–477. https://doi.org/10.1002/ajpa.20830.

Mays, S. A. (2001). Effects of age and occupation on cortical bone in a group of 18th-19th century British men. *American Journal of Physical Anthropology*, *116*(1), 34–44. https://doi.org/10.1002/ajpa.1099.

Mays, S. A. (2002). Asymmetry in metacarpal cortical bone in a collection of British post-medieval human skeletons. *Journal of Archaeological Science, 29*(4), 435-441. https://doi.org/10.1006/jasc.2002.0729.

Rizzoli, R. (2008). Nutrition: Its role in bone health. *Best Practice & Research Clinical Endocrinology & Metabolism*, *22*(5), 813–829. https://doi.org/10.1016/j.beem.2008.08.005.

Ruff, C., Holt, B., & Trinkaus, E. (2006). Who's afraid of the big bad Wolff?: "Wolff's law" and bone functional adaptation. *American Journal of Physical Anthropology*, *129*(4), 484–498. https://doi.org/10.1002/ajpa.20371.

Sawyer, G. J., & Maley, B. (2005). Neanderthal reconstructed. *Anatomical Record, 283*(1), 23–31. https://doi.org/10.1002/ar.b.20057.

Shaw, C. N., & Stock, J. T. (2009a). Habitual throwing and swimming correspond with upper limb diaphyseal strength and shape in modern human athletes. *American Journal of Physical Anthropology*, *140*(1), 160–172. https://doi.org/10.1002/ajpa.21063.

Shaw, C. N., & Stock, J. T. (2009b). Intensity, repetitiveness, and directionality of habitual adolescent mobility patterns influence the tibial diaphysis morphology of athletes. *American Journal of Physical Anthropology*, *140*(1), 149–159. https://doi.org/10.1002/ajpa.21064.

Taunton, J. E., McKenzie, D. C., & Clement, D. B. (1988). The role of biomechanics in the epidemiology of injuries. *Sports Medicine, 6,* 107–120. https://doi.org/10.2165/00007256-198806020-00005.

Turner, R. T. (2001). Skeletal adaptation to external loads optimizes mechanical properties: Fact or fiction. *Current Opinion in Orthopaedics*, *12*(5), 384–388. https://doi.org/10.1097/00001433-200110000-00004.

Vehmas, T., Solovieva, S., Riihimäki, H., Luoma, K., & Leino-Arjas, P. (2005). Hand workload and the metacarpal cortical index. A study of middle-aged teachers and dentists. *Osteoporosis International, 16*(6), 672–680. https://doi.org/10.1007/s00198-004-1742-y.

Wallace, I. J., Toya, C., Peña Muñoz, M. A., Meyer, J. V., Busby, T., Reynolds, A. Z., Martinez, J., Thompson, T. T., Miller-Moore, M., Harris, A. R, Rios, R., Martinez, A., Jashashvili, T., & Ruff, C. B. (2023). Effects of the energy balance transition on bone mass and strength. *Scientific Reports, 13*(1), 15204. https://doi.org/10.1038/s41598-023-42467-6.

Wanner, I. S., Sosa, T. S., Alt, K. W., & Blos, V. T. (2007). Lifestyle, occupation, and whole bone morphology of the pre-Hispanic Maya coastal population from Xcambó, Yucatan, Mexico. *International Journal of Osteoarcheology*, *17*, 253-268. DOI: 10.1002/oa.873.

Weiss, M., Yogev, R., & Dolev, E. (1997). Occupational sitting and low hip mineral density. *Calcified Tissue International, 62*(1), 47–50. https://doi.org/10.1007/s002239900393.

Wilks, D. C., Winwood, K., Gilliver, S. F., Kwiet, A., Chatfield, M., Michaelis, I., Sun, L. W., Ferretti, J. L., Sargeant, A. J., Felsenberg, D., & Rittweger, J. (2009). Bone mass and geometry of the tibia and the radius of master sprinters, middle and long distance runners, race-walkers and sedentary control participants: A pQCT study. *Bone*, *45*(1), 91–97. https://doi.org/10.1016/j.bone.2009.03.660.

Figures and Figure Captions

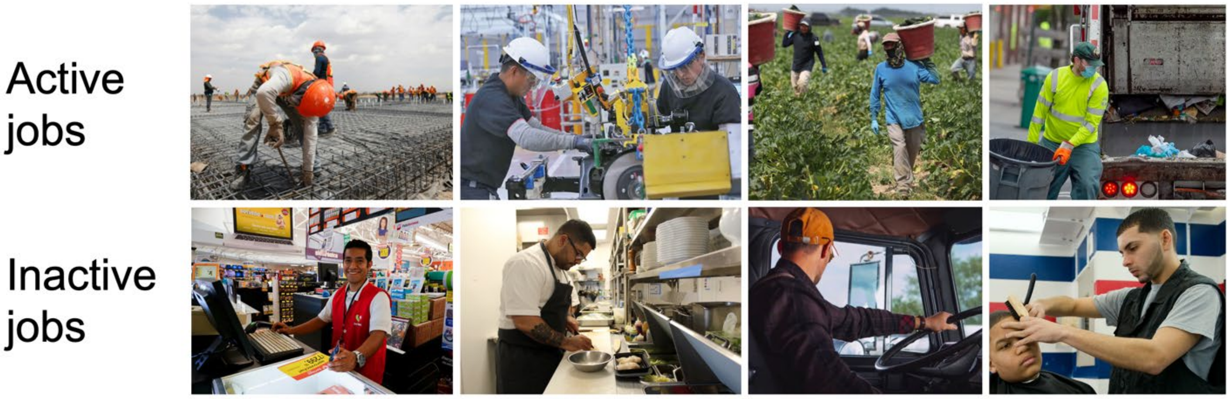

Figure 1: Common types of physically active (top row) and inactive (bottom row) jobs of men in the study.

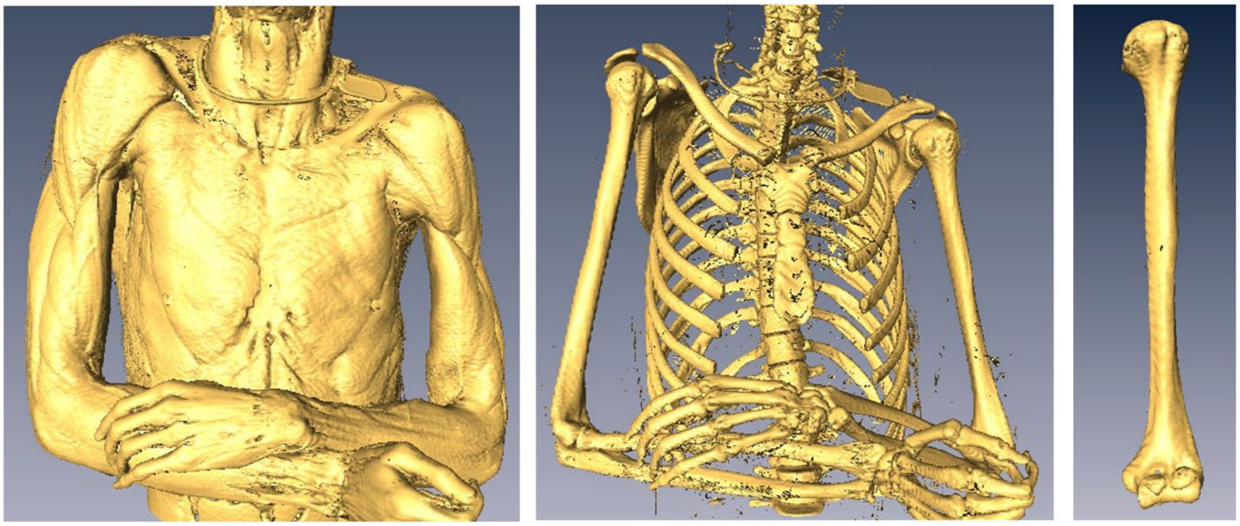

Figure 2: Cropping a limb bone (humerus) from a full-body CT image stack.

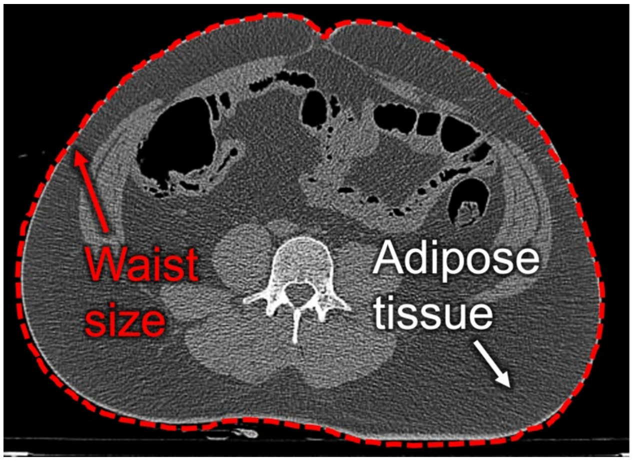

Figure 3: Measurement of waist size from a CT image.

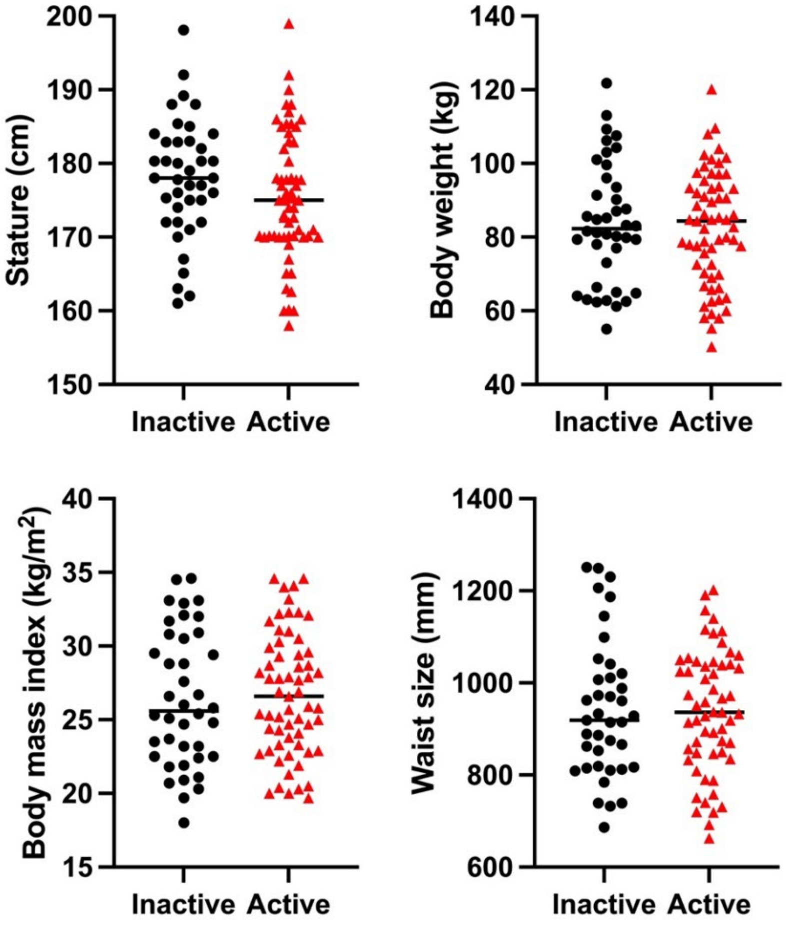

Figure 4: Body size among people with and without physically demanding jobs.

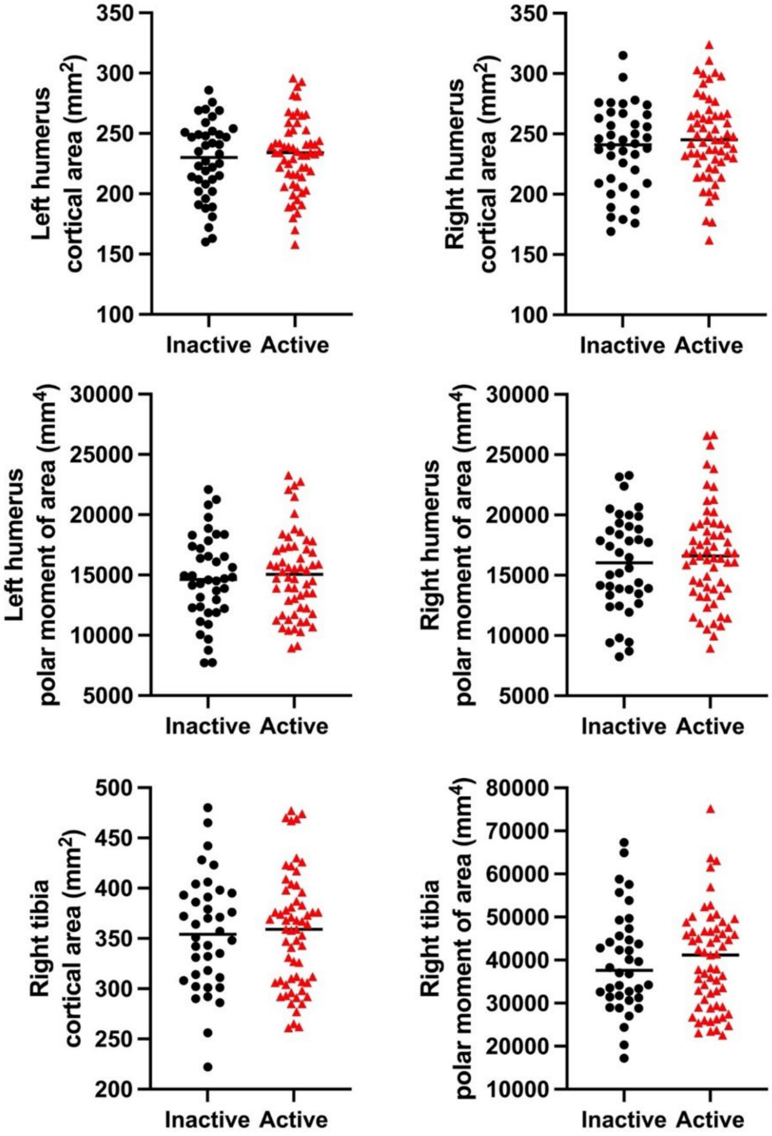

Figure 5: Limb bone shaft properties among people with and without physically demanding jobs.