ANTHROPOLOGICAL REVIEW

WYDAWNICTWO
UNIWERSYTETU
ŁÓDZKIEGO

ANTHROPOLOGICAL REVIEW

The Official Publication of
the Polish Anthropological Society

Volume 86/2023
Issue 1

POLSKIE TOWARZYSTWO
ANTROPOLOGICZNE

WYDAWNICTWO
UNIWERSYTETU
ŁÓDZKIEGO
Łódź 2023

Published by Łódź University Press
Publisher's sheets 10.0; printing sheets 7.125
W.11030.23.0.C
ISSN 1898-6773
e-ISSN 2083-4594

Contents

Anthropological Review • Vol. 86(1), 1–15 (2023)

ANTHROPOLOGICAL REVIEW

Available online at: https://doi.org/10.18778/1898-6773.86.1.01

Craniofacial pathologies in an early adolescent from the Funnel Beaker site of Modřice, Czechia

Frank L'Engle Williams[1], *Zdeněk Tvrdý*[2], *David Parma*[3]

[1] Department of Anthropology, College of Arts and Sciences, Georgia State University, Atlanta, GA, United States
[2] Anthropos Institute, Moravian Museum, Brno, Czech Republic
[3] Institute for Archaeological Heritage, Brno, Czech Republic

Abstract: Several craniofacial pathologies are present in an early adolescent from a cemetery (n = 22) associated with a Neolithic Funnel Beaker culture in Modřice, Czechia.

The objective of the study was to document anomalies on the Modřice 3871 cranium, with an emphasis on investigating whether the mid-sagittal suture exhibited synostosis or bridging to account for the visible scaphocephaly.

All available cranial and postcranial elements of the Modřice 3871 early adolescent were examined macroscopically. The cranial vault was subjected to radiography and compared to macroscopic views.

Modřice 3871 is estimated to age to 12–14 years. Macroscopic examination and radiography support a diagnosis of mid-sagittal bridging rather than synostosis for this slender and anteroposteriorly elongated cranium. In comparison, the anterior sagittal, coronal and lambdoidal sutures are completely unfused. Craniofacial asymmetry, cribra orbitalia, porotic hyperostosis of the temporal and the presence of multiple wormian bones indicate additional maturational disruptions.

The scaphocephaly observed in Modřice 3871 is not severe compared to modern clinical manifestations of craniosynostosis. Radiocarbon dated to 3,700–3,600 years BCE, Modřice 3871 presents one of the oldest recorded cases of scaphocephaly. The elongated vault is probably not the result of head-binding given the dearth of anthropogenic cranial reshaping in the Neolithic of Europe. This study adds to the growing recognition of prehistoric and historic craniofacial anomalies which will likely continue as additional human remains are excavated. In addition, the study increases the understanding of the lived experience of prehistoric individuals experiencing visible craniofacial pathologies such as cranial asymmetry and scaphocephaly.

Key words: scaphocephaly, cribra orbitalia, wormian bones, craniosynostosis.

Original article

Received: 9.01.2023; Revised: 1.03.2023; Accepted: 2.03.2023

Introduction

Suture closure ages are notoriously variable in humans (Meindl and Lovejoy 1985; Buikstra and Ubelaker 1994; Hershkovitz et al. 1997). When the premature ossification of suture mesenchyme occurs in prenatal or early postnatal development, the cranium continues to grow, but largely within those neurocranial regions unconstrained by premature suture closure, resulting in an abnormal vault morphology (Marsh et al. 1991; Cohen 2005; DeLeon and Richtsmeier 2009; Ursitti et al. 2011; Kajdic et al. 2018; Eisová et al. 2021). Partial or complete ossification of the sagittal mesenchyme during early cranial development results in a visibly narrow head shape or scaphocephaly, often including elevation of the fused suture (Weber et al. 2008; Ursitti et al. 2011; Soficaru et al. 2018).

Scaphocephaly is often the result of sagittal synostosis although the converse is not necessarily true (Cohen 2005; Padmalayam et al. 2013; Groza et al. 2014). Sagittal synostosis is detectable by the third trimester and is the most common form of craniosynostosis, affecting approximately 1 in 5,000 births (Constantine et al. 2000), and is 3.5 times as common in males compared to females (Cohen 2005; Ursitti et al. 2011; Kajdic et al. 2018). Partial synostosis of the sagittal suture occurs in about a third of cases among infants around one year (Boyajian et al. 2020). As infants age, the partial closure of the sagittal sutures often proceeds to full fusion.

Scaphocephaly has been found in several Neolithic contexts across Europe. The earliest of these include the Eneolithic of Spain and the Neolithic cultures of central Europe (Table 1). The paucity of individuals noted to exhibit scaphocephaly point to the lack of evidence of head binding in comparison to other prehistoric contexts, such as the Neolithic Near East and Pre-Columbian Mesoamerican, Hopi and Andean cultures (Antón 1989; Meiklejohn et al. 1992; Kohn et al. 1994; Gerszten et al. 1998). Here we report a case of scaphocephaly, possibly from sagittal synostosis or partial fusion (bridging), found in an early adolescent cranium from the Neolithic cemetery of Modřice. Scaphocephaly in Modřice 3871 is coupled with other craniofacial pathologies, including facial asymmetry, the presence of wormian bones, cribra orbitalia and porotic hyperostosis of the temporal bone.

Table 1. Scaphocephaly in prehistoric Europe

Site	Location	Identifier	Dating	Sex	Age in years
Kóny[a]	Hungary	SNR 247/1	Linear Pottery Culture	?	6–7
Kóny[a]	Hungary	SNR 247/2	Linear Pottery Culture	?	7
West Kennet Barrow[b]	UK	EU 1.5.148	Neolithic	F	17–25
Zengövárkony[c]	Hungary	Grave Nr. 7	Lengyel	F	20–25
Náměšť na Hané[d]	Czechia	Feature Nr. 7	Funnel Beaker	F	30–50
Cova del Palanques[e]	Spain	Skull Nr. 6	Eneolithic	?	?

[a]Tőth et al. (2009); [b]Cuthbert (2018); [c]Smrčka et al. (2018); [d]Pankowská et al. (2010); [e]Campillo (1993)

Materials and Methods

Modřice cemetery

Modřice is located in the southern Moravia region of Czechia (Fig. 1). Extensive excavations recovered a rich prehistoric settlement and burial ground associated with the Funnel Beaker culture. The graves include skeletal remains, mostly without artifacts, and are radiocarbon dated to 3,800–3,600 years BCE (Šmíd et al. 2018, 2021a; Drtikolová Kaupová et al. 2023), corresponding to the late Neolithic or Early Eneolithic in Czech archaeology (Jarošová et al. 2022). The Funnel Beaker culture is associated with a further Neolithization of the incipient agricultural economy that rapidly spread into parts of northwest and northcentral Europe. The Funnel Beaker culture of Modřice was an agrarian community that included domesticated animals, wheat and vegetable cultivation as well as wild foods in the diet.

At Modřice, there were 22 individuals buried in two main groups of single graves, each apparently comprising members of the same household (Šmíd et al. 2018, 2021a); two of the burials were in a settlement pit and no commingled graves were found. Individuals of both sexes were distributed across the two groups, about a half of whom were immature, including an early adolescent, Modřice 3871. In total there were five children 3–6 years-old, four older children 7–14 years, two adolescent females, six adult males and five adult females. Most of skeletons (including 3871) were deposited in an outstretched position, which was a common burial practice in this phase of the Funnel Beaker culture, although only recently recognized in Moravian archaeology (Šmíd et al. 2021b). The rectangular grave pit of 3871 was oriented NW-SE, and the burial was directly dated to 4880±33 years uncalBP (Drtikolová Kaupová et al. 2023). A subsequent Bronze Age pit located in the lower part of the legs disturbed the grave of Modřice 3871, and the bones were partially scattered, probably by animals (rodents). Some of the skeletal remains were partly fractured and many smaller bones of the hands and feet were missing (Fig. 2).

There are multiple paleopathologies found at Modřice, including spina bifida, spondylolysis and ankylosis of the lumbar

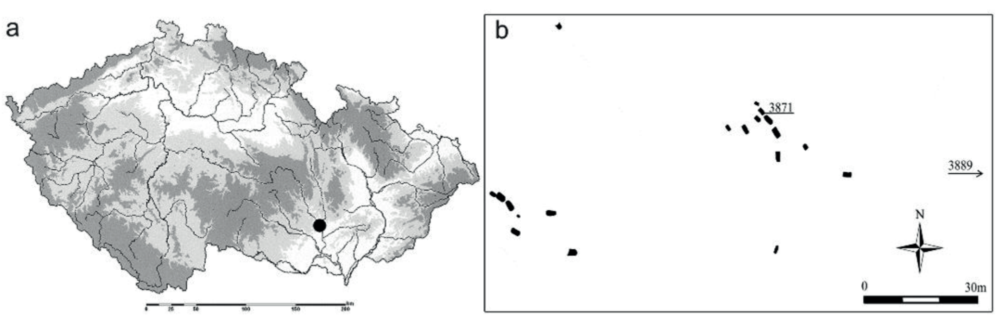


Fig. 1. Map of (a) Czechia showing the location of the Neolithic cemetery of Modřice indicated by the black circle; and (b) the cemetery showing the two main groups of graves and the position of Modřice 3871 vis-à-vis the other graves

vertebrae, entheses, clavicle and cervical asymmetry, healed and perimortem fractures, osteophytosis, osteoporosis, periosteal reactions and other skeletal abnormalities (Šmíd et al. 2021a, Table V). The dental health noted at the Modřice cemetery was rather poor with a relatively greater prevalence of caries compared to other Neolithic population from Moravia and East Bohemia (Jarošová et al. 2022).

Methods

Modřice 3871 was examined at the Moravian Museum in Brno, Czechia (Inv. nr. A25632) using macroscopic investigation to estimate the age and describe the preservation and morphology. Dental wear scores following Smith (1984) were used to characterize molar attrition to corroborate the age estimate. Radiographic images of Modřice 3871 were obtained at Fakultní nemocnice U sv. Anny v Brně (St. Anne's University Hospital in Brno), and these were compared to the macroscopic examination of the cranial vault.

Results

Inventory

The grave of Modřice 3871 consists of a single incomplete early adolescent skeleton. The cortical surface is slightly eroded in places, and covered with calcareous debris. The bones are brownish-yellow in color (Fig. 2).

Cranial vault

The cranium of Modřice 3871 is relatively well preserved and partially reconstructed (Fig. 3). The cranial vault base is slightly deformed by the position of the basi-occipital bone, which is conjoined with the two lateral occipitals and slightly rotated to the left. The foramen magnum is nearly intact excepting a posterior margin with possible rodent gnaw marks.

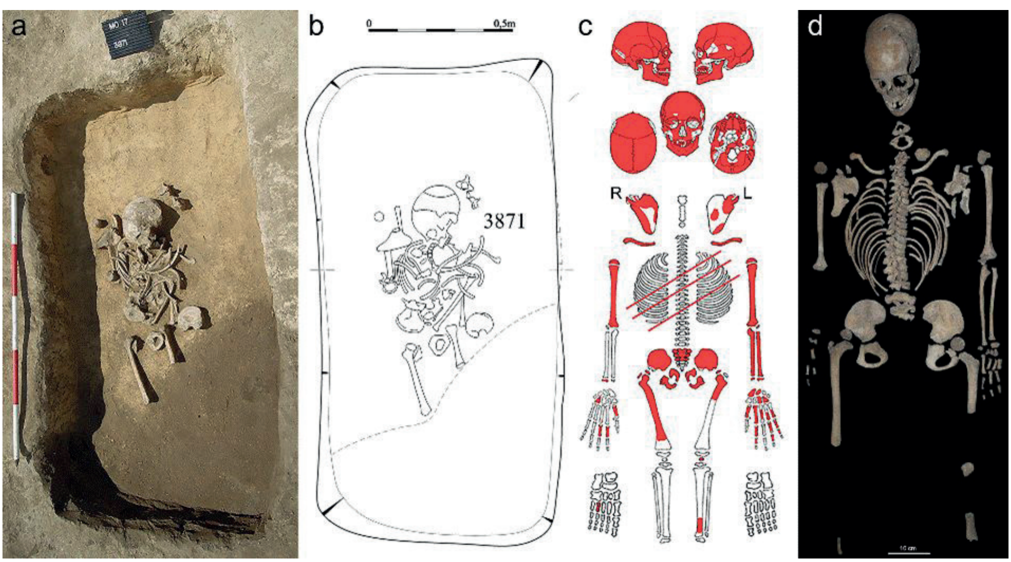


Fig. 2. Modřice 3871 (a) photograph and (b) drawing showing the skeleton *in situ*; (c) scheme of preservation, R = right, L = left; and (d) skeletal elements in anatomical position

The frontal and occipital bones are complete, whereas the parietal bones are reconstructed after recent fracturing in the area of the parietal tubercles. The damage is confined mostly along the parietal-occipital margin, and extends to the right occipitomastoid region. The right temporal bone is almost complete, whereas the left is damaged. The sphenoid body and greater wings are partly preserved.

The cranial vault is markedly expanded anteroposteriorly from a maximum cranial length (gonion to opistocranion = 185 mm) much greater than the maximum cranial breadth (euryon to euryon = 124 mm). The occipital extends posteriorly forming a relatively concave inferior contour in which the inferior squama abruptly tapers anteriorly forming a small occiput, with a sigmoid curvature extending further inferiorly to opisthion (Fig. 3).

Face and dentition

The relatively vertical frontal squama exhibits slight but palpable superciliary arch development. Much of the splanchocranium is missing, although the palate connects to the mid-face (Fig. 3). The posterior mid-face is partly damaged owing to the destruction of the inferior left and right palatine bones and the adjoining maxillary palatal border, while the mandible is complete.

The permanent dentition is mostly preserved *in situ*. On the maxilla, only the right canine and left I^2 are missing postmortem, while the unerupted M^3 is visible on both sides. On the mandible, only I_1 on both sides and left I_2 are lost postmortem.

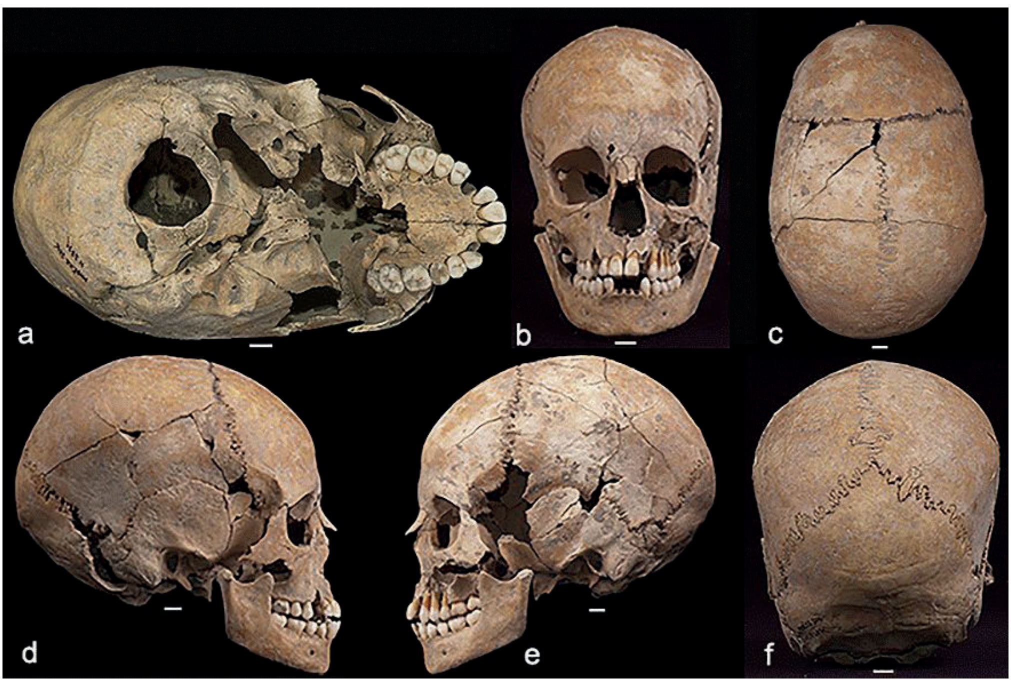


Fig. 3. Modřice 3871, (a) inferior view showing the elongated cranial vault; as well as (b) anterior; (c) superior; (d) lateral right; (e) lateral left; and (f) posterior planes; scale bars = 1 cm

Postcranial skeleton

The vertebrae ribs, scapulae and clavicle are well preserved. The humeri are also nearly complete and include separated proximal epiphyses without any fusion evident. From the right forearm, only the distal epiphysis of the radius is preserved. The forearm bones of the left are intact except for the proximal epiphyses. Five carpal bones, 5 metacarpals and 9 phalanges are preserved (Fig. 2).

The ischium and pubis are fused but are separated from the ilium. The right femur is largely preserved but misses the distal end of the shaft and epiphysis, although the greater and lesser trochanter and head epiphyses are present. There are gnaw marks on the diaphysis of the right femur. On the left femur, only the proximal third of the diaphysis is preserved, as is the distal diaphysis of the left tibia and the right fifth metatarsal (Fig. 2).

Age and sex estimation of Modřice 3871

Based on visual examination of the size of the cranium, the small and orthogonal face, and lack of coronal and lambdoial ossification (Fig. 3), the individual is aged as an early adolescent (Scheuer and Black 2000; Scheuer 2002). All of the permanent teeth have erupted with the exception of the third molars, which are deeply embedded within the crypts, although the crowns are fully formed and the growth of roots has commenced. The permanent teeth, and in particular M_2 and M^2 show minimal attrition or Stage 2, whereas M^1 is consistent with Stage 3 (Smith 1984).

The lack of fusion of epiphyses of the preserved appendicular skeleton provide additional corroboration of an immature age (Scheuer and Black 2000). These include the femoral head, the greater and lesser trochanters and distal tibial epiphysis, the fused ischiopubis and ilium articulation, the humeral head and distal trochlear end of the humerus, the proximal head and distal styloid processes of the radius and the proximal olecranon and distal styloid processes of the ulna (Fig. 2). Many of these epiphyses fuse during the late teens. However, the superior ischial and inferior pubic rami fuse at 6–9 years (Steele and Bramblett 1988), while the lesser trochanter of the femur and proximal radius commence fusion at 15–16 and 16 years respectively (Steele and Bramblett 1988), suggesting Modřice 3871 can be confidently aged between these extremes. The fact that the ischiopubic fusion site is still visible could suggests an individual not much older than 9 years. The triradiate cartilage joining the three innominate bones of Modřice 3871 is unfused (Fig. 2). The triratiate commences from multiple epiphyses, including a posterior one forming around 10–11 years, which eventually joins an anterior epiphysis around 12–14 years and these fuse with the epiphysis of the anterior inferior iliac spine, which forms at 14 years (Scheuer and Black 2004). The *os coxa* is completely ossified by 19 years (Scheuer and Black 2004). Modřice 3871 does not present any notable fusion of these triradiate epiphyses and lacks an anterior inferior iliac spine suggesting an age younger than 14 years. The unfused distal humerus which commences ossification at 14 years (Steele and Bramblett 1988) further corroborates an early adolescent attribution. There are no instances of the skeletal remains showing epiphyseal fusion that would be unusual for an early adolescent. The length of the long bones and state of fusion of all the epiphyses taken together indicate an age 10–13 years (Scheuer and Black 2000) while tooth eruption, including the slight wear on the fully erupted second molar, indicates an age closer to 14 years (Al Qhatani et al. 2010). The lack of sexually diagnostic features on the pelvis, cranium and mandible and the immature age of the individual prevented an estimation of sex membership.

Diagnosis

Although taphonomic processes have fractured and slightly distorted the cranium, the unusual elongated shape of the vault is unambiguous (Fig. 3). Weber et al. (2008) calculate a mean cranial length/breadth index for untreated scaphocephalic adult crania from historical and archaeological collections to be 63.4 (n = 18). The mean length/breadth index for adult crania without stenostosis is 78.9 (n = 40) (Weber et al. 2008). The length/breadth index for Modřice 3871 is 67.0, which is lower than then mean of 74.3 for the six complete adolescent and adult crania from Modřice (Šmíd et al. 2021a). The cranial index of the other adolescent from Modřice excavated from grave 3858 (female, 15–19 years) is 80.3.

The superior surface of the orbital wall exhibits cribra orbitalia (Fig. 4) indicative of nutritional stress. The superior ceiling of both orbits presents cribra orbitalia Grade 1–2 (Rivera and Lahr 2017) or Type 2–3 in the antero-intermediate sector following Stuart-Macadam (1991) (Fig. 4). Porosity is also evident in the area of *porus accusticus externus*.

In addition, the upper facial skeleton also appears slightly deformed. The right supraorbital rim is higher and more bulbous than the left in inferior view (Fig. 3 and Fig. 4). This difference is likely not the result of taphonomic processes since the bony table is mostly uninterrupted across the supraorbital margin. The right orbit is also shaped differently than the left. Whereas the left is relatively circular, the right orbit is wider, shorter, and more trapezoidal in shape (Fig. 4). There is also asymmetry in the partly preserved superior portions of the nasal bones in which the right is broader than the left.

Additional asymmetry exists in the superior shape of the cranial vault, such that the right lateral parietal arch bulges slightly laterally compared to the left (Fig. 3). In addition, the sagittal suture veers slightly to the left approaching the coronal suture about 10 to 15 degrees from the sagittal plane (Fig. 3). Although some of this distortion could possibly be from taphonomic factors, the slight but visible asymmetry at multiple locations on the upper face and vault, combined with mid-sagittal partial fusion could signal the presence of a syndromic synostosis involving multiple deformities (Ursitti et al. 2011; Kajdic et al. 2018). Howev-

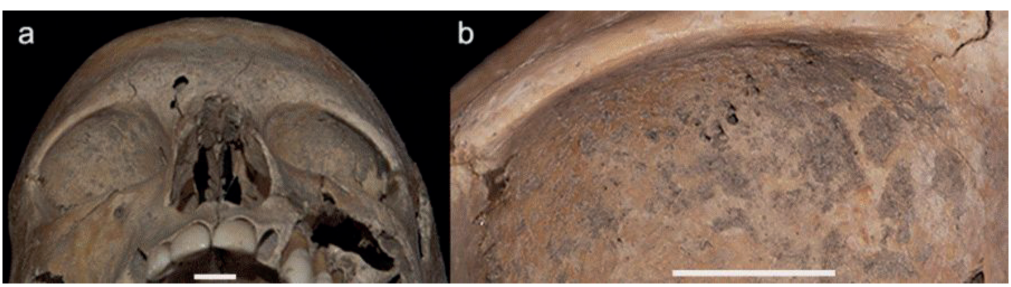


Fig. 4. Cribra orbital (a) viewed inferior on the orbital ceiling of the frontal bones; (b) the right orbital ceiling at a higher objective shows the lesions appear to be healing; both scale bars = 1 cm

er, the coronal and lambdoidal sutures lack any evidence of closure, suggesting nonsyndromic synostosis (Giuffra et al. 2013) (Fig. 3).

The suture morphology is rugged and continuous, with the exception of an intervening wormian ossicle in the posterior sagittal suture (Fig. 3). Two additional wormian bones are located in the occipitomastoid sutures of the right and left sides (Fig. 3). Another double ancillary ossicle is found in the right lambdoidal suture (*ossiculum suturae lambdoideae*).

Radiography of Modřice 3871 corroborates the mid-sagittal partial closure endocranially (Fig. 5). Like the ectocranial surface, the endocranium features an unfused coronal, anterior sagittal and lambdoidal suture. The mid- and posterior sagittal suture areas are represented by a faint line that demarcates the fusion site and the lack of two independent parietal bones in Modřice 3871 (Fig. 5). The radiological and macroscopic analyses confirm that the mid-sagittal suture exhibits partial fusion endocranially and ectocranially, while the coronal and lambdoidal are open. Rather than the classic definition of sagittal synostosis (White 1996), it appear that the formation of bone spicules that cross the suture, or bridging, could be present (Fig. 5). The ectocranial surface presents a suture partly filled with matrix, suggesting an opening sufficient to collect debris (Fig. 5). Therefore, a diagnosis of bone bridging rather than synostosis is advanced to characterize the partial fusion of the sagittal suture.

It is possible that Modřice 3871 suffered from Klippel-Feil syndrome given the asymmetry of the face and bridging of the mid-sagittal suture (Herrerín et al. 2022). Basilar impression is also

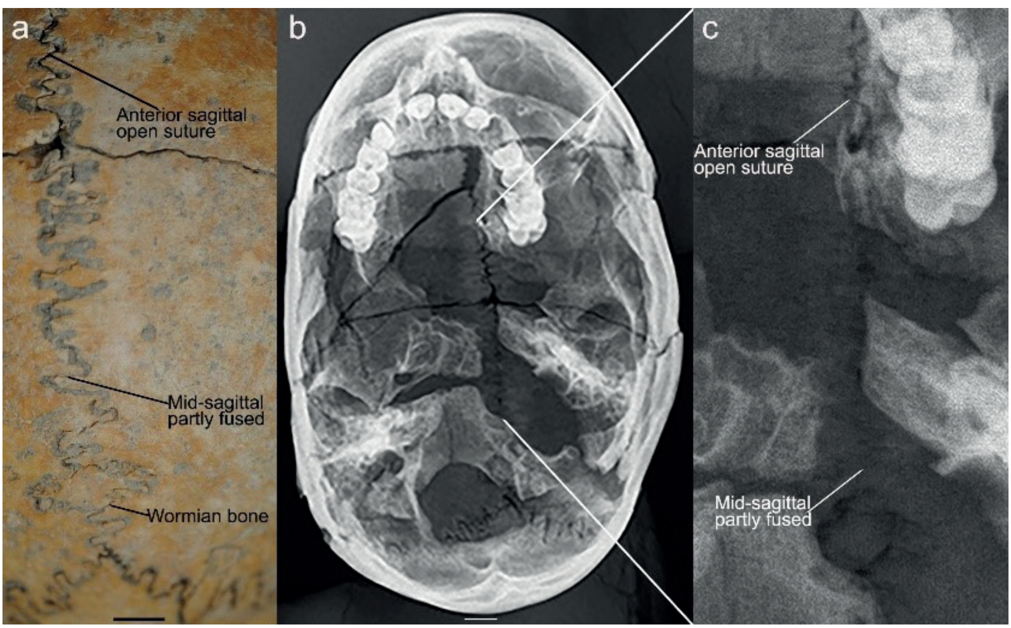


Fig. 5. Modřice 3871 cranial vault (a) superior view, showing the mid-sagittal suture ectocranially and a sagittal wormian bone; (b) radiograph of the cranium; and (c) enlarged area on the radiograph showing the mid-sagittal suture; scale bars = 1 cm

associated with Klippel-Feil syndrome. The basilar region of Modřice 3871 is slightly displaced inferiorly. Yet Modřice 3871 lacks the concavity of the posterior occipital squama, sphenoid and petrous portion of the temporal surrounding the foramen magnum that characterizes basilar impression (Chamberlain 1939; Herrerín et al. 2022; Fig. 3). In addition, the cervical vertebrae do not show ankylosis, severe osteophytosis or any notable ossification (Fig. 2); the sagittal suture is not ossified along its entire length; and no large parietal foramina are present (Herrerín et al. 2022). Although craniofacial asymmetry and sagittal suture bridging exist, Klippel-Feil syndrome, which is not associated with the formation of wormian ossicles, is an unlikely diagnosis for Modřice 3871.

Discussion

Scaphocephaly is often the result of untreated sagittal synostosis, which is most common in the posterior and middle portion of the suture (Marsh et al. 1991; Cohen 2005; Ursitti et al. 2011). Constriction of the fetal neurocranium, including the base, during the third trimester does seem to correlate with sagittal synostosis, which may explain a greater prevalence in males who have larger skulls, even during gestation (White 1996). Constriction or mechanical stress results in a close alignment of cranial ossification centers during the sensitive periods of prenatal dura development that could influence the expression of sagittal synostosis (DeLeon and Richtsmeier 2009; Padmalayum et al. 2013).

Sagittal synostosis is one of the most common human craniofacial anomalies, and is usually apparent to external observers by the end of the first year (Gracia et al. 2009). By the second year of life, most cases of sagittal synostosis exhibit complete fusion of the sagittal suture (Kohn et al. 1994), although early closure of a sagittal suture does not necessarily result in scaphocephaly (Cohen 2005; Padmalayam et al. 2013; Groza et al. 2014). The degree of cranial elongation would depend on the timing of the closure.

Prehistory of scaphocephaly

Scaphocephaly has been noted since antiquity (Padmalayum et al. 2013), and was present at least as early as the Middle Pleistocene (Garcia et al. 2009). Modřice 3871 presents one of the most ancient examples of scaphocephaly although there are others. Three from Hungary are earlier. Two of these are from the latter half of the 6th millennium BCE (Tóth et al. 2009), and another is dated to 4,500–4,300 BCE (Smrčka et al. 2018). At Náměšť na Hané, a cranium dated to a slightly earlier time period but also from a Funnel Beaker culture settlement in Moravia, exhibits sagittal synostosis and is associated with a cranial index of 55 (Pankowská et al. 2010). Relative to the female from Náměšť na Hané, Modřice 3871 may have presented mild scaphocephaly that probably arose from postnatal bridging of the sagittal suture.

Although head binding causes significant closure to the sagittal suture (White 1996), only one individual, Modřice 3871, out of both cemetery plots (Fig. 1) exhibits this elongated cranial form. Head binding was widely practiced in the Americas to denote status and identity (Antón et al. 1992; Meiklejohn et al. 1992; White 1996). Eurasian head binding has also been documented although more rarely and is often associated with cultures characterized by stricter hierarchies and greater contact among diverse peoples than would be typical for a small-scale Neolithic society like Modřice (Meiklejohn et al. 1992; Fernandes et al. 2019).

Wormian bones

Both tensile and compressive forces act to prematurely fuse the suture in affected individuals (White 1996). These forces also tend to be implicated in the formation of wormian bones (White 1996; Sanchez-Lara et al. 2007). Their presence is consistent with other studies noting wormian bones in individuals exhibiting premature sagittal fusion (White 1996). Sagittal and other synostoses as well as wormian bones, have been considered by some to be adaptive responses to prenatal constraints on the developing cranium (Moss 1959; White 1996; Pedersen and Antón 1998; Cohen 2005). Whether these ancillary ossicles are related to the presentation of partial fusion of the mid-sagittal suture is unknown. However, the presence of wormian bones do suggest some irregularities of sutural development during early embryogenesis.

However, one of the wormian bones of Modřice 3871 is found in the sagittal suture which is rare (Fig. 5). Most wormian bones occur in the lambdoidal suture or at lambda and less often in the occipitomastoid (Safak et al. 2020) and coronal sutures (Bellary et al. 2013). Some studies report an absence of sagittal sutural bones (Safak et al. 2020) whereas others demonstrate its presence albeit in small numbers (Vijay et al. 2017). Pryles and Khan (1979) suggest wormian bones to be a marker of central nervous system abnormality, craniosynostosis and other anomalies although its presence in 61% of individuals in one study (Vijay et al. 2017) and 59% in another (Cirpan et al. 2015) may indicate a lack of concordance between sutural ossicles and other disorders. However, the presence of several wormian bones may signal the existence of other anomalies (Cremin et al. 1982). This is the case for Modřice 3871 in which 5+ are found at multiple locations. Given the bridging of the mid-sagittal suture (Fig. 5), the presence of a sagittal wormian bone offers greater support for linking these anomalies to dural mechanical stress during maturation, either pre- or postnatally, that adversely affected cranial development. The placement of the sagittal wormian bone observed in Modřice 3871, approximately 2 cm superior to lambda, also approximates the position of the third fontanelle, which is associated with other birth defects (Chemke and Robinson 1969). It is possible that the sagittal wormian bone formed to compensate for a third fontanelle, although it remains unknown.

Cribra orbitalia and nutrition

The nutritional stress indicated by the presence of cribra orbitalia is also noteworthy. In addition to its manifestation on Modřice 3871, cribra orbitalia affected another 4 individuals from the cemetery, and nearly all are children (4 of 5). Altogether, cribra orbitalia was present in 38.5% of available individuals (5 of 13) indicating nutritional and/or disease stress broadly affected this Neolithic farming community, particularly its youngest members (Šmíd et al. 2021a). Other indices of nutritional stress include porosity of the temporal and asymmetry of the face. Furthermore, wormian bones were present in 8 out of 15 individuals (53.3 %) (Šmíd et al. 2021a), suggesting a possible genetic or behavioral influence on cranial suture formation in the community. Although the presentation of skeletal abnormalities at this cemetery is widespread (Šmíd et al. 2021a), the combination of paleopathologies in Modřice 3871 is unique.

The analysis of stable isotopes of individuals from Modřice shows that this community did not differ from other Funnel Beaker populations in the region, whose diet was of a terrestrial origin with a dominant C3-plant component supplemented with animal products (Drtikolová Kaupová et al. 2023). The isotope values for Modřice 3871 (δ15N = 9.5, δ13C = -19.8) fall close to the average of the Modřice population (δ15N = 9.5; δ13C = -19.6). Cribra orbitalia could have been the result of any number of processes, acting alone or in combination, including nutritional stress, anemia, infections and parasites, all of which are connected to a Neolithic agrarian lifestyle. The lack of agreement between older dental and younger epiphyseal age estimates may also point to nutritional stress.

Asymmetry of the basicranium

In Modřice 3871, the basicranium is titled to the left (Fig. 2). Although the possibility remains that taphonomic processes distorted the basicranium, it is unlikely given the corroborating evidence of asymmetry in the facial skeleton and superior cranial vault. Furthermore, the observed basicranial deformation may be associated with mid-sagittal bridging given the intertwined ontogenetic processes governing the formation of the vault and the base (Moss 1959; Antón 1989; DeLeon and Richtsmeier 2009; Ursitti et al. 2011). Asymmetry of the face and vault favoring the right side is consistent with the directionality of the foramen magnum and basion pointing to the smaller left side of the basicranium (Fig. 2). The combination of cranial asymmetry, scaphocephaly, multiple wormian bones, cribra orbitalia and porosity of the temporal are suggestive of multiple stressors during development, potentially including epigenetic and nutritional constraints.

Conclusion

The long narrow cranial shape, caused by endo- and ectocranial mid-sagittal bone bridging, indicates Modřice 3871 represents one of the oldest recorded instances of scaphocephaly in human history (Weber et al. 2008; Tóth et al. 2009; Pankowská et al. 2010; Smrčka et al. 2018). With respect to the lived experience, Modřice 3871 may have had an unusual head shape and slight facial asymmetry. The cribra orbitalia and porosity in the temporal bone indicates nutritional deficiencies or disease-related complications (Armelagos et al. 2014), which could have compromised the life expectancy of Modřice 3871. Nevertheless, Modřice 3871 was buried similarly to the others in the cemetery as has been reported for other prehistoric adolescents with visible congenital cranial anomalies (Pedersen and Antón 1998; Garcia and Santos 2020).

Acknowledgments

Research funding for Frank Williams was provided by the Department of Anthropology at Georgia State University. Zdeněk Tvrdý was funded through the institutional support of long-term conceptual development of research institutions provided by the Ministry of Culture (ref. MK000094862). We are grateful to Valerie DeLeon for valuable insights and the five anonymous reviewers whose comments improved the rigor of the paper.

Conflict of interests

The authors have no conflicts of interest to declare.

Authors' contribution

The concept for the paper was developed by FLW and ZT in consultation with DP. The analysis, description and figures were prepared by FLW and ZT. The radiography was coordinated by ZT.

Corresponding author

Frank L'Engle Williams, Ph.D., Department of Anthropology, College of Arts and Sciences, Georgia State University, P.O. Box 3998, Atlanta, GA, 30302-3998 USA; e-mail: frankwilliams@gsu.edu

References

Al Qahtani SJ, Hector MP, Liversidge HM. 2010. The London atlas of human tooth development and eruption. Am J Phys Anthopol 142:481–90. https://doi.org/10.1002/ajpa.21258

Antón SC. 1989. Intentional cranial vault deformation and induced changes in the cranial base and face. Am J Phys Anthropol 79:253–67.

Antón SC, Jaslow CR, Swartz SM. 1992. Sutural complexity in artificially deformed human (*Homo sapiens*) crania. J Morphol 24:321–32.

Armelagos GJ, Sirak K, Werkema T, Turner BL. 2014. Analysis of nutritional disease in prehistory: the search for scurvy in antiquity and today. Int J Paleopath 5:9–17. https://doi.org/10.1016/j.ijpp.2013.09.007

Bellary SS, Steinberg A, Mirzayan N, Shirak M, Tubbs RS, Cohen-Gadol AA, Loukas M. 2013. Wormian bones: a review. Clin Anat 26:922–27. https://doi.org/10.1002/ca.22262

Boyajian MK, Al-Samkari H, Nguyen DC, Naidoo S, Woo AS. 2020. Partial suture fusion in nonsyndromic single-suture craniosynostosis. Cleft Palate-Craniofacial J 57:499–505. https://doi.org/10.1177/1055665620902299

Buikstra JE, Ubelaker DH. 1994. Standards for Data Collection from Human Skeletal Remains: Proceedings of a Seminar at the Field Museum of Natural History. Fayetteville, AR: Arkansas Archeological Survey Research Series No 44.

Chamberlain WE. 1939. Basilar impression (platybasia). A bizarre developmental anomaly of the occipital bone and upper cervical spine with striking and misleading neurologic manifestations. Yale J Biol Med 11:487–96.

Chemke J, Robinson A. 1969. The third fontanelle. J Pediatrics 75:617–22.

Cirpan S, Aksu F, Mas N. 2015. The incidence and topographic distribution of sutures including wormian bones in human skulls. J Craniofac Surg 26:1687–90. https://doi.org/10.1097/SCS.0000000000001933

Cohen MM, Jr. 2005. Editorial: perspectives on craniosynostosis. Am J Med Genet 136A:313–26. https://doi.org/10.1002/ajmg.a.30757

Constanine S, Kiermeier A, Anderson P. 2020. Sonographic indicators of isolated fetal sagittal craniosynostosis during pregnancy. J Med Imaging Radiation Oncology 64:626–33. https://doi.org/10.1111/1754-9485.13068

Cremin B, Goodman H, Spranger J, Beighton P. 1982. Wormian bones in osteogenesis imperfecta and other disorders. Skeletal Radiol 8:35–38. https://doi.org/10.1007/BF00361366

Cuthbert GS. 2018. Enriching the Neolithic: the forgotten people of the barrows. PhD Thesis, University of Exeter.

DeLeon VB, Richtsmeier JT. 2009. Fluctuating asymmetry and developmental instability in sagittal craniosynostosis. Cleft Palate Craniofac J 46:187–96. https://doi.org/10.1597/08-001.1

Drtikolová Kaupová S, Jarošová I, Bíšková J, Hrnčíř V, Květina P, Neugebauer-Maresch C, Pokutta DA, Řídký J, Tvrdý Z, Vytlačil Z, Trampota F. 2023. The diet of settled Neolithic farmers of east-central Europe: isotopic and dental microwear evidence. Archaeol Anthropol Sci 15:21. https://doi.org/10.1007/s12520-023-01720-9

Eisová S, Naňka O, Velemínský P, Bruner E. 2021. Craniovascular traits and braincase morphology in craniosynostotic human skulls. J Anat 239:1050–65. https://doi.org/10.1111/joa.13506

Fernandes D, Sirak K, Cheronet O, Howcroft R, Čavka M, Los D, Burmaz J, Pinhasi R, Novak M. 2019. Cranial deformation and genetic diversity in three adolescent male individuals from the Great Migration Period from Osijek, eastern Croatia. PLoS ONE 14(8):e0216366. https://doi.org/10.1371/journal.pone.0216366

Garcia SJ, Santos AL. 2020. Osteological evidence of short stature and parieto-squamosal arch craniosynostosis in a non-adult male from the 13th century Leiria, Portugal. Int J Osteoarch 30:145–54. https://doi.org/10.1002/oa.2842

Gerszten PC, Gerszten E, Allison MJ. 1998. Diseases of the skull in Pre-Colombian South American mummies. Neurosurgery 42:1145–51. https://doi.org/10.1097/00006123-199805000-00114

Giuffra V, Bianucci R, Milanese M, Fornaciari G. 2013. A probable case of non-syndromic brachycephaly from 16th century Sardinia (Italy). Int J Paleopath 3:134–37. https://doi.org/10.1016/j.ijpp.2013.05.005

Gracia A, Arsuaga JL, Martínez I, Lorenzo C, Carretero JM, de Castro JMB, et al. 2009. Craniosynostosis in the Middle Pleistocene human Cranium 14 from the Sima de los Huesos, Atapuerca, Spain. Proc Natl Acad Sci USA 106:6573–78. https://doi.org/10.1073/pnas.0900965106

Groza V-M, Simalcsik A, Bejenaru L, Simalcsik R-D. 2014. Osteopathies in the population of old Iasi City (Romania): the necropolis of the "Banu" church, 16th–19th centuries. Analele Științifice ale Universității „Alexandru Ioan Cuza" din Iași, s. Biologie animală, Tom LX:91–104.

Herrerín J, Dorado E, Galassi FM, Varoto E, Dinarès Solà R. 2022. Klippel-Feil Syndrome: morphological findings in a 19th-century musealized skull from Viana del Bollo (Orense, Spain). Anthropol Rev 85:63–78. https://doi.org/10.18778/1898-6773.85.2.03

Hershkovitz I, Latimer B, Dutour O, Jellema LM, Wish-Baratz S, Rothschild C, Rothschild BM. 1997. Why do we fail in aging the skull from the sagittal suture? Am J Phys Anthropol 103:393–99. https://doi.org/10.1002/(SICI)1096-8644(199707)103:3<393::AID-AJPA8>3.0.CO;2-R

Jarošová I, Fojtová M, Tvrdý Z, Kala J, Beran-Cimbůrková P, Brzobohatá H, Trampota F. 2022. Dental health and diet in the middle and late Neolithic (4900–3400 BC): a study of selected microregions in the Czech Republic. Anthropologie LX:351–78.

Kajdic N, Spazzapan P, Velnar T. 2018. Craniosynostosis – recognition, clinical characteristics, and treatment. Bosn J Basic Med Sci 18:110–16. https://doi.org/10.17305/bjbms.2017.2083

Kohn LAP, Vannier MW, Marsh JL, Cheverud JM. 1994. Effect of premature sagittal suture closure on craniofacial morphology in a prehistoric male Hopi. Cleft Palate-Craniofacial J 31:385–96. https://doi.org/10.1597/1545-1569_1994_031_0385_eopssc_2.3.co_2

Marsh JL, Jenny A, Galic M, Picker S, Vannier W. 1991. Surgical management of sagittal synostosis: a qualitative evaluation of two techniques. Neurosurg Clin N Am 2:629–40.

Meiklejohn C, Agelarakis A, Akkermans PMMG, Smith PEL, Solecki R. 1992. Artificial cranial deformation in the proto-Neolithic and Neolithic Near East and its possible origin: evidence from four sites. Paléorient 18:83–97.

Meindl RS, Lovejoy CO. 1985. Ectocranial suture closure: a revised method for the determination of skeletal age at death based on the lateral anterior sutures. Am J Phys Anthropol 68:57–66.

Moss ML. 1959. The pathogenesis of premature cranial synostosis in man. Acta Anat. (Basel), 37:351–70.

Padmalayam D, Tubbs RS, Loukas M, Cohen-Gadol AA. 2013. Absence of the sagittal suture does not result in scaphocephaly. Childs Nerv Syst 29:673–77. https://doi.org/10.1007/s00381-012-2005-4

Pankowská A, Peška J, Vrána J. 2010. Congenital cranial defect in a female from a Funnel Beaker Culture settlement burial in Náměšť na Hané (Czech Republic) – a case report. Interdisciplinaria Archaeologica 1:77–89. https://doi.org/10.24916/IANSA.2010.1-2.8

Pedersen SC, Antón SC. 1998. Bicoronal synostosis in a child from historic Omaha cemetery 25DK10. Am J Phys Anthropol 105:369–78. https://doi.org/10.1002/(SICI)1096-8644(199803)105:3<369::AID-AJPA6>3.0.CO;2-M

Pryles CV, Khan AJ. 1979. Wormian bones. A marker of CNS abnormality? Am J Dis Child 133:380–82.

Rivera F, Mirazón Lahr M. 2017. New evidence suggesting a dissociated etiology for cribra orbitalia and porotic hyperostosis. Am J Phys Anthropol 164:76–96. https://doi.org/10.1002/ajpa.23258

Safak NK, Taskin RG, Yücel AH. 2020. Morphologic and morphometric evaluation of the wormian bones. Int J Morphol 38:69–73.

Sanchez-Lara PA, Graham JM Jr, Hing AV, Lee J, Cunningham M. 2007. The morphogenesis of Wormian bones: a study of craniosynostosis and purposeful cranial deformation. Am J Med Genet Part A 143A:3243–51. https://doi.org/10.1002/ajmg.a.32073

Scheuer L. 2002. Application of osteology to forensic medicine. Clin Anat 15:297–312. https://doi.org/10.1002/ca.10028

Scheuer L, Black S. 2000. Developmental Juvenile Osteology. London: Elsevier Academic Press.

Scheuer L, Black S. 2004. The Juvenile Skeleton. London: Elsevier Academic Press.

Šmíd M, Tvrdý Z, Parma D, Kos P. 2018. Pohřebiště kultury nálevkovitých pohárů s pohřby v natažené poloze z Modřic, okr. Brno-venkov. Acta Musei Moraviae 103:101–40.

Šmíd M, Kos P, Parma D, Prichystal A, Tvrdý Z. 2021a. Eneolitické osídlení lokality Modřice-Rybníky (okr. Brno.venkov). Pravěk Supplementum 36. Ústav archeologické památkové péče Brno, v. v. i., Brno (ISBN 978-80-86399-71-3; ISSN 1804-5731).

Šmíd M, Lečbych M, Šmerda J, Kala J, Limburský P. 2021b. Sídliště a pohřebiště kultury nálevkovitých pohárů v Dambořicích, okr. Hodonín. Příspěvek k poznání pohřebišť s pohřby v natažené poloze. Archeologické rozhledy LXXIII: 3–47. https://archeologickerozhledy.cz/index.php/ar/article/view/30/29

Smrčka V, Kuželka V, Musilová Z, Gábor O. 2018. Bone diseases at the Lengyel culture burial site in Zengövárkony, Hungary. Anthropologie LVI:53–62. https://doi.org/10.26720/anthro.17.12.12.1

Soficaru AD, Ionică C, Constaninescu M, Enyedi M. 2018. Altered shapes, same people: scaphocephaly in the early modern Bucharest. Homo 69:176–87. https://doi.org/10.1016/j.jchb.2018.08.001

Steele DG, Bramblett CA. 1988. The Anatomy and Biology of the Human Skeleton. College Station: Texas A&M University Press.

Stuart-Macadam P. 1991. Anaemia in Roman Britain: Poundbury Camp. In: H Bush and M Zvelebil, editors. Health in Past Societies: Bioculutural Interpretations of Human Skeletal Remains in Archaeological Contexts. Oxford: Tempvs Reparatvm. 101–13.

Tóth GA, Puskás T, Buda BL. 2009. Co-existence of scaphocephaly and Hand-Schüller-Christian syndrome on the remains of two Neolithic children. Ind J Phys Anthropol & Hum Genet 28:141–47.

Ursitti F, Fadda T, Papetti L, Pagnoni M, Nicita F, Iannetti G, Spalice A. 2011. Evaluation and management of nonsyndromic craniosynostosis. Acta Paediatrica 100:1185–94. https://doi.org/10.1111/j.1651-2227.2011.02299

Vijay VG, Avadhani R, Jacob M. 2017. Incidence of wormian bones in dry human skulls in south Indian population. Int J Anat Res 5:4349–55. https://doi.org/10.16965/ijar.2017.331

Weber J, Collmann H, Czarnetzki A, Spring A, Pusch CM. 2008. Morphometric analysis of untreated adult skulls in syndromic and nonsyndromic craniosynostosis. Neurosurgical Rev 31:179–88. https://doi.org/10.1007/s10143-007-0100

White C. 1996. Sutural effects of fronto-occipital cranial modification. Am J Phys Anthropol 100:397–410.

Anthropological Review • Vol. 86(1), 17–22 (2023)

ANTHROPOLOGICAL REVIEW

Available online at: https://doi.org/10.18778/1898-6773.86.1.02

POLSKIE TOWARZYSTWO ANTROPOLOGICZNE

Osteoporosis and vertebral trabecular bone health: an historico-anthropological perspective

Francesco M. Galassi[1,2], *Elena Varotto*[2,3]

[1] Department of Anthropology, Faculty of Biology and Environmental Protection, University of Lodz, 90-136 Lodz, Poland
[2] FAPAB Research Center, Avola (SR), Sicily, Italy
[3]Archaeology, College of Humanities, Arts and Social Sciences, Flinders University, Adelaide, SA 5001, Australia

ABSTRACT: This brief review article aims to recapitulate the history of osteoporosis from the most ancient observations to the current clinical definition, by offering a perspective on trabecular bone health and degeneration, which has become of paramount important both in clinical, radiological and biological anthropological studies.

KEY WORDS: osteoporosis, trabecular bone, endocrinology, history of anthropology, biological anthropology, palaeopathology.

Original article

Received: 9.01.2023; Revised: 2.03.2023; Accepted: 2.03.2023

The first identification of a link between a structural abnormality in bones and subsequent fractures is to be ascribed to the British surgeon and anatomist Sir Astley Paston Cooper (1768–1841) (Lorentzon and Cummings 2015), while the technical term naming this condition, 'osteoporosis' (Fr.: *ostéoporose*), dates back to 1833, when the German-born French pathologist and surgeon Jean G.C.F.M. Lobstein (1777–1835) was able to describe an expansion of the marrow spaces at the expense of the trabecular bone in osteological specimens (Brand 2011).

Nowadays it is known that trabecular bone has a characteristic network of lamellar bony plates and rods which shows less density, homogeneity and lower degree of parallel orientation. It shows a wide variability in strength and stiffness to be related with this type of bone's apparent density (Osterhoff et al. 2016). Osteoporotic loss occurs as a result of an imbalance of the remodelling process governing bone homeostasis, noting that this remodelling activity is higher in the central skeleton, which explains bone loss-related vertebral fractures (Osterhoff et al. 2016). Although trabecular bone accounts only for approximately 20% of the total skeletal bone mass, it is responsible for most of a skeleton's turnover, which is particularly apparent in individuals younger than 65 years of age (Osterhoff et al. 2016).

Lobstein wrote that osteoporosis implies a reduction of internal cohesion between the molecules of the bones (*elle suppose une diminution de cohésion entre les molecules de l'os*), a diminution which he thought was caused by a certain 'expansive force' (*force expansive*). Concurring with previous similar observation by the Italian anatomist Antonio Scarpa (1751–1831), he defined this force as responsible for the softening, swelling and rarefaction (*le rammollissment, le goflement et la rarefaction*) of the bone the result of the activity of excited nerves (*l'activité exaltée de nerfs*), possibly activated by special pathological principles connected with some of the major diseases such as the venereal, the arthritic, the variolar, morbillar, etc. (Lobstein 1833; Schapira & Schapira 1993), since at the time he was not aware of the currently known aetiology of osteoporosis.

While it is now believed that, in fact, what Lobstein commented on may have been osteogenesis imperfecta type I, yet this appears to be the earliest known mention of trabecular bone pathology (Lorentzon and Cummings 2015). Consequently, the word osteoporosis became rapidly popular in medical circles by the late 19th century (Brand 2011).

While still unable to name a precise cause for this disease, in the 1850 edition of German pathologist August Förster's (1822–1865) anatomical pathology textbook, a description closer to the current one is to be found: 'This condition of macerated bone [*des macerierten Knochens*], called Lobstein's osteoporosis [*diese von Lobstein Osteoporose*], is caused by various processes, some of which are still unknown to us [*ist durch verschiedene, und zum Theil noch unbekannte Vorgänge bedingt*]. Most frequently, inflamed or rachitic bones, when macerated at certain periods, i.e. after healing but before complete ossification, take on the shape described; older and newer authors also assume hypertrophy of the medulla as a condition for expansion of the medullary spaces and inflation of the bone [*eine Hypertrophie des Markes als Bedingung der Ausdehnung* *der Markräume und Aufblähung des Knochens*]' (Förster 1850).

By the late 19th century, the general pattern of age (advanced) and sex (female) distribution for this disease had become known, particularly with reference to fractures (at the time the principal factor leading to a diagnosis), while the manifestation of osteoporosis in males and its lower frequency were not yet completely understood (Brand 2011).

Growing knowledge on bone physiology owing to the work of Albert von Kölliker (1817–1905), who named osteoclasts in 1873, and of Carl Gegenbauer (1826–1903), who described osteoblasts, together with more information being gradually available on the impact of parathyroid hormone and estrogen on bone (resorption vs new production) would make a better understanding of osteoporosis possible (Grob 2014).

During WW2, in 1941, Albright and colleagues examined clinical data of 42 cases of what they called 'generalized osteoporosis', *a priori* excluding patients aged over 65 years because senescence could then become a primary factor in the pathophysiological process: 40/42 patients were female individuals who had passed the menopause and they had not developed osteoporosis before it, while 2/40 were males for whom no apparent causal explanation was identified (Albright et al. 1941). This analysis stressed the fact that osteoporosis was caused by deficient osteoblastic activity, hence it was a deficit of formation rather than mineralization (Albright et al. 1941; Forbes 1991).

It was precisely this study, which saw the implementation of X-ray imaging, that determined the predilection for the spine and pelvis by osteoporosis and that showed how long bones became affected merely in instances of more severe involvement. It also highlighted how osteoporosis typically does not affect the skull, unlike hyperparathyroidism (Albright et al. 1941). Albright and colleagues' study also presented the main radiological characteristics of spinal involvement in osteoporosis: fractured/crushed vertebrae, 'fish vertebrae' (i.e. biconcave vertebral bodies due to the expansion of intervertebral disks), Schmorl's nodes (herniation of the nucleus pulposus) (Albright et al. 1941).

This research additionally indicated how, while an osteoporotic vertebral lesion can be revealed by X-ray imaging after a patient's report of back pain, it can also be an incidental finding because the vertebral changes can develop completely asymptomatically (Albright et al. 1941). With reference to vertebral damage, one of the key merits of the Albright et al. study was also to show that the administration of long-term therapy was capable of arresting it, including statural loss, in postmenopausal women affected by osteoporosis or prevented them altogether if started in the early stages of the disease (Forbes 1991).

In 1973 Gallagher and colleagues examined the nature and presentation of osteoporosis-induced vertebral fractures in 58 postmenopausal women, a condition which they named 'The Crush Fracture Syndrome', combining radiological, histological and metabolic data (Gallagher et al. 1973). This study proved that osteoporotic fractures included patients with various clinical pictures, irrespective of their mineralization rates, and that fractures had to be related to a severe reduction in the amount of trabecular bone. This reduction of bone in vertebral bodies was reflected by a similar loss of trabecular bone in biopsies from patients' iliac crests which were subjected to histological analysis (Gallagher et al. 1973). This study also pointed out that, while loss of trabecular bone is of the primary relevance in the pathogenesis of osteoporotic fractures, also cortical bone is affected by the pathological process, in that it is lost 'at a faster rate than normally occurs in postmenopausal women', and this becomes ever more apparent if the patient manages to survive long enough and the disease chronicizes (Gallagher et al. 1973). The authors concluded that osteoporosis-related crush fracture syndrome could be seen to be a self-limiting disease only at the spinal level, whereas such an attribute could not be given to its metacarpal manifestation (Gallagher et al. 1973).

Following in the footsteps of the Albright et al. study and the Gallagher et al. one, the continued implementation of lateral thoracic radiographs in subsequent research indicated that 'in some cases, vertebral fractures may be the result of a gradual loss of vertebral height rather than sudden vertebral collapse' (Hedlund et al. 1989), which could explain the asymptomatic nature of some of the vertebral changes first described by Albright et al. Hedlund et al.'s study demonstrated how the first stage of non-traumatic spinal fractures involved an initial wedging of 1–2 mid-thoracic or thoracic-lumbar vertebrae, which would then likely involve ≥ 4 vertebrae, hence ultimately making a final posterior vertebral collapse much more frequent (Hedlund et al. 1989). The final stage of the process presents with an even distribution between T6 and L2 manifesting with anterior and posterior collapse (Hedlund et al. 1989). In this study it was also shown that vertebral fractures did not only reduce vertebral height but also explained wider vertebrae (Hedlund et al. 1989).

This research also highlighted that anterior vertebral fractures were found to be more frequent in the mid-thoracic spine, while a more lumbar distribution was to be described for posterior fractures, a difference that could be explained with the direction of compressive forces according to the natural kyphotic (thoracic) and lordotic (lumbar) curvatures of the spine (Hedlund et al. 1989). Hedlund et al.'s paper finally concluded that an individual's body mass seemed to be more related to spinal vertebral fractures than vertebral size but did not exclude the possibility that density of nonfractured vertebrae could be less in osteoporotic patients (Hedlund et al. 1989).

As research on osteoporosis continued to progress a new radiological methodology was implemented, that is dual-energy X-ray absorptiometry which allowed for the assessment of bone mineral density (BMD), the current diagnostic gold standard as it is considered a surrogate marker of bone strength, although it only accounts for 60% of bony fragility variation (McDonnell et al. 2007).

However, BMD does not fully explain changes in trabecular architecture, tissue properties and accumulation of microdamage, as it has been shown in subsequent studies that a patient's risk of fracture is influenced by bone quality as defined by the aforementioned aspects (Osterhoff et al. 2016), especially when one considers that a parameter like loss of strength is more affected by perforation of the trabeculae than by their general thinning (McDonnell et al. 2007).

Further advances were made possible by the application of microCT analysis, which is nonetheless not allowed on living patients' due to the high radiation exposure, but proved excellent for *in vitro* studies, cadaver or anthropological studies (McDonnell et al. 2007). In particular it permits scientists to produce detailed and accurate 3D reconstructions of trabecular volumes (McDonnell et al. 2007).

With a special focus on vertebral changes the following characteristics are to be considered:

a. microstructure and density are not uniform in the vertebral centrum;
b. the regions of the centrum closest to the endplates and in the posterio-lateral regions show the highest volume fraction and BMD;
c. the middle and anterior regions of the centrum show the highest trabecular separation and degree of anisotropy;
d. the high percentage of anterior wedge vertebral fractures can be explained by the the anterior region's relatively low density and high degree of anisotropy in the anterior region (Osterhoff et al. 2016).

Additional studies have shown that vertebral trabecular architecture increasingly becomes anisotropic with the progress of bone loss, which can be a significant factor in fracture risk due to the fact that trabecular architecture tries to adapt to compensate for the loss of bone (Osterhoff et al. 2016).

A study on population sample of 541 women and 490 men aged 17 to 88 years, trabecular vBMD in both sexes decreased from the T1 to L3 in all age categories, L3 showing the lowest vBMD of all other thoracic and lumbar vertebrae (Chen et al. 2013).

A cadaveric study on 56 L4 vertebrae from Asian donors aged between 57 and 98 years showed, at microCT scan and scanning electron microscopic analysis, that trabecular bone volume fraction (BV/TV) and trabecular number (Tb.N) significantly decreased with advancing age, with a similar pattern in males and females. Additionally, trabecular separation augmented with increasing age, while decrease in trabecular thickness (Tb.Th) was not found to be statistically significant (Chen et al. 2013).

Moreover, some studies suggest that the loss of horizontal trabeculae is the only one occurring while other studies indicate that both horizontal and vertical trabeculae are lost with age (Chen et al. 2013).

Future studies investigating trabecular health will likely show a pattern of deterioration of such structures fundamental for bone strength and their assessment in past populations, thanks to the analysis of large skeletal populations, could provide an evolutionary perspective on this condition.

Acknowledgments

The authors would like to thank Prof. dr. hab. Elżbieta Żądzińska for reading an earlier version of this paper.

Conflict of interests

We have no competing interests.

Authors' contribution

Both authors contributed equally to this paper.

Corresponding author

Francesco M. Galassi, MD PhD, Department of Anthropology, Faculty of Biology and Environmental Protection, University of Lodz, 90-136 Lodz, Poland, e-mail: francesco.galassi@biol.uni.lodz.pl

References

Albright F, Smith PH, Richardson AM. 1941. Postmenopausal Osteoporosis: Its Clinical Features. JAMA 116(22):2465–74. https://doi.org/10.1001/jama.1941.02820220007002

Brand RA. 2011. 50 Years ago in CORR: The appearance of osteoporosis in ambulatory institutionalized males Paul J. Vincent MD and Marshall R. Urist MD CORR 1961;19:245–252. Clin Orthop Relat Res 469(7):2076–7. https://doi.org/10.1007/s11999-011-1876-0

Chen H, Zhou X, Fujita H, Onozuka M, Kubo KY. 2013. Age-related changes in trabecular and cortical bone microstructure. Int J Endocrinol 2013:213234. https://doi.org/10.1155/2013/213234

Forbes AP. 1991. Fuller Albright. His concept of postmenopausal osteoporosis and what came of it. Clin Orthop Relat Res (269):128–41.

Förster A.1850. Lehrbuch der pathologischen Anatomie. Jena: F. Mauke. 541.

Grob GD. 2014. Aging bones. A Short History of Osteoporosis. Baltimore: Johns Hopkins University Press. 24–26.

Lobstein J-F. 1833. Traité d'anatomie pathologique, Vol. 2, Paris: Levrault. 120.

Lorentzon M, Cummings SR. 2015. Osteoporosis: the evolution of a diagnosis. J Intern Med 277(6):650–61. https://doi.org/10.1111/joim.12369

McDonnell P, McHugh PE, O'Mahoney D. 2007. Vertebral osteoporosis and trabecular bone quality. Ann Biomed Eng 35(2):170–89. https://doi.org/10.1007/s10439-006-9239-9

Osterhoff G, Morgan EF, Shefelbine SJ, Karim L, McNamara LM, Augat P. 2016. Bone mechanical properties and changes with osteoporosis. Injury 47 Suppl 2(Suppl 2):S11–20. https://doi.org/10.1016/S0020-1383(16)47003-8

Schapira D, Schapira C. 1992. Osteoporosis: the evolution of a scientific term. Osteoporos Int 2(4):164–7. https://doi.org/10.1007/BF01623921

Anthropological Review • Vol. 86(1), 23–36 (2023)

ANTHROPOLOGICAL REVIEW

Available online at: https://doi.org/10.18778/1898-6773.86.1.03

POLSKIE TOWARZYSTWO ANTROPOLOGICZNE

Case study of Legg-Calvé-Perthes disease observed in Radom (Poland, 18th–19th century) with literature review

Anna Myszka[1], *Hanna Mańkowska-Pliszka*[2], *Ewa Rzeźnicka*[2], *Agnieszka Dąbkowska*[3], *Jacek Tomczyk*[1]

[1] Institute of Biological Sciences, Cardinal Stefan Wyszynski University, Poland
[2] Department of Descriptive and Clinical Anatomy, Warsaw Medical University, Poland
[3] Forensic Medicine Department of Medical University of Warsaw, Poland

Abstract: The aim of this study is to present the pathological lesions observed in a skeleton (male, about 35–38 years old) from Radom (Poland), dated to the 18th–19th century. Bone changes were observed in both femurs and both pelvic bones. The head of the femur is enlarged and deformed, described as "mushroom-shaped", with areas of smooth cortex and cavities, or possible cystic residues. The neck of femur is short and thick. The bone shaft and distal epiphysis do not show any changes. The changes were also observed in both acetabularies of the hip joint (marginal bone formation, subchondral bone remodelling). Radiographic images show bilateral necrosis of the femoral head. There is a significant sclerotization of the femoral head, with a discrete visible crescent sign. These macroscopic and radiological changes match the symptoms associated with Legg-Calvé-Perthes disease. This is the first case of the disease described in bioarchaeological materials from Poland.

Key words: Perthes disease, skeletal material, radiology, osteology, palaeopathology.

Original article

Received: 31.01.2023; Revised: 6.03.2023; Accepted: 7.03.2023

Introduction

Assessing health condition, level of hygiene and dietary habits is a fairly common practice in bioarchaeological studies (e.g., Ortner 2008; Yanko et al. 2021). This may allow researchers to draw conclusions about the lifestyle and socio-economic status of individuals or populations in certain historical periods. In this context, palaeopathological studies are interesting, because they show history of medical conditions and help us to better understand the aetiology of a disease. However, the diagnosis of pathology from bioarchaeological material is burdened with many limitations. This is because skeletal material is often destroyed and incomplete, knowledge about the life and health of a given individual/population is usually poor, and because many diseases have similar symptoms. As a result, it is rather difficult to recognise a specific disease, and thus indicating only potential causes of the destruction of bone material (Smith 2002; Ortner 2008). In this respect, case reports are informative by providing information regarding a presence of specific diseases in the past.

The aim of this study is to present the pathological lesions observed in a skeleton from Radom (Poland), dated to the 18th–19th century.

Materials and methods

The described skeleton comes from the Radom site, a medium-sized city located in central Poland, about 80 km from Warsaw (Fig. 1). The early medieval settlement complex in Radom consists of the 'Piotrówka' stronghold, the burial ground, and five open settlements. This complex was explored and partially examined in the second half of the 20th century by the Institute of the History of Material Culture of the Polish Academy of Sciences (now: Institute of Archaeology and Ethnology of the Polish Academy of Sciences) (Skubicha 2010). The results of these excavations have never been fully processed (Gąssowski 1951; Kierzkowska-Kalinowska 1970; 1979; Kurasiński and Skóra 2016; Baranowski et al. 2020).

Human remains were obtained during an excavation conducted in 2010–2013. The skeleton was found in the first urban municipal cemetery, which was founded at the stronghold in 1791. Due to the lack of space for new burials, the cemetery was closed and abandoned in 1811 (Zapłata 2011).

Fig. 1. The map of Poland with the location of Radom (black arrow)

The described human remains (No. 317/13) contained a fragment of splanchnocranium, with a fragment of right maxillary bone and the mandible. From the postcranial skeleton, the following parts were preserved: left and right forearms, both femurs, cervical and lumbar vertebrae and sacrum, both iliac and sciatic bones, and elements of ribs (Fig. 2).

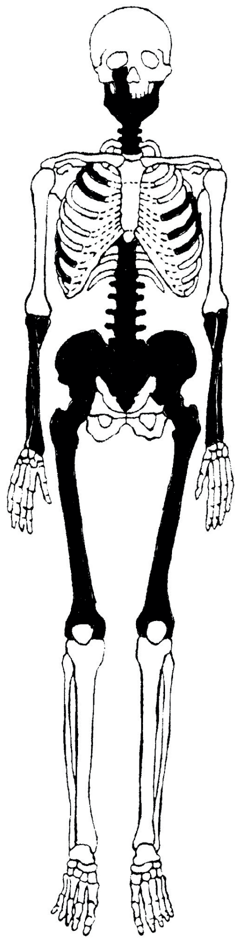


Fig. 2. Representation of the bones of individual No. 317/13 (present bones shown in grey)

The age-at-death of the individual was estimated on the basis of changes in the topography of the auricular surface (Buikstra and Ubelaker 1994; White and Folkens 2000). Moreover, it was possible to estimate the dental age-at-death using radiographic images of selected teeth (Drusini 2008). Age categories considered in the study were applied according to the following standards set by Buikstra and Ubelaker (1994): Young Adult (20–34 years), Middle Adult (35–49 years), and Old Adult (50+ years).

The referential sex of the individuals was estimated using the Phenice (1969) method. In addition, some mandibular features (expression of the mental eminence and gonion regions) were used in sex estimation (Buikstra and Ubelaker 1994; Konigsberg and Hens 1998; Walker 2008). Bone measurements were conducted according to the standards introduced by Buikstra and Ubelaker (1994), using a slide caliper and an anthropometric board.

Radiographical examinations were performed at the Forensic Medicine Department of the Medical University of Warsaw (Poland) using the Toshiba 16-slice computed tomography (CT) scanner and the X-ray Canon Radrex (Philips Medical System IEC 60601 X-ray, image – distance of 1 meter, in two perpendicular projections, 180-degree viewing angle used, horizontal frequency 47 kHz). The atypical juxtaposition of the femur with the hip joint on radiographs was used intentionally to better visualize the characteristic appearance of the femoral head with remodeling in necrotic lesions.

Results

The estimations of age-at-death and sex suggested that the individual being assessed was a male of about 35–38 years old.

Bone changes were observed in both femurs and both pelvic bones. The head of the femur is enlarged in a characteristic way (*coxa magna*); this deformation can be described as "mushroom-shaped", with areas of smooth cortex, cavities, cystic residues. Subchondral cysts and porosity are present. Bony formations (osteophytes) on the femoral head margin are observed (Fig. 5–7).

Fig. 3. An anterior (photo above) and posterior view (phote below) of the femoral and coxa bones of individual No. 317/13 from Radom

Fig. 4. An anterior (left photo) and posterior view (right photo) of the femoral bones of individual No. 317/13 from Radom

Fig. 5. An anterior (left photo) and posterior view (right photo) of the proximal end of femoral bones of individual No. 317/13 from Radom. Photographs show a markedly flattened, "mushroom-shaped" femoral head, with areas of smooth cortex, cavities, cystic residues, porosity (white arrows), and osteophytes (black arrows)

Fig. 6. A posterior view of the proximals end of femoral bones of individual No. 317/13. Photographs show "mushroom-shaped" femoral heads, marginal osteophytes of femoral heads (black arrows)

Fig. 7. The deformities of femoral heads. Osteophytes (black arrows), the areas of smooth cortex, cavities, cystic residues, and porosities (areas in white circles) (No. 317/13)

Fig. 8. Femoral heads deformities; cavities, cystic residues, and porosities (No. 317/13). Left (left photo) and right (right photo) femoral bones; a porous surface is observed and the fovea capitis is disappeared (No. 317/13)

Both femoral heads are deformed, strongly flattened, and both are at a lower position than the greater trochanter (Fig. 3–6, 10). Length measurements of left femoral bone: measurement from the highest point of the greater trochanter to the lowest point of the medial condyle – 435 mm, measurement from the highest point of the femoral head to the lowest point of the medial condyle – 427 mm. The medial condyle damage made the adequate length measurements of the right femur was not possible. On both femoral heads the fovea capitis for the insertion of ligament teres were not observed (Fig. 7, 8). The neck of the femur is short and thick (upper-lower neck dimension: right bone – 35 mm, left bone – 40 mm; anterior-posterior neck dimension: right bone – 28 mm, left bone – 31 mm) (Fig. 3–6, 10). The femoral neck is almost nonexistent on the superior aspect (6 mm length on the left bone, 7 mm length on the right one) and greatly shortened inferiorly (18 mm length on the left bone, 17 mm length on the right one). Head center dislocated toward neck axis was not observed here. The rest of the bone (shaft and distal epiphysis) does not show any changes (Fig. 4).

The changes were also observed in both acetabularies of the hip joint. Right and left acetabulum is shallow, with marginal osteophytes and porosity on articular surfaces (Fig. 9). They also show subchondral bone remodelling (Fig. 10). Radiographic images show bilateral necrosis of the femoral head (Fig. 10). There is a significant sclerotization of the femoral head, with a discrete visible crescent sign.

Fig. 9. Left (left photo) and right (right photo) acetabulum with osteophytes (black arrows), cystic residues, and porosities (areas in white circles); the fovea capitis is disappeared (No. 317/13)

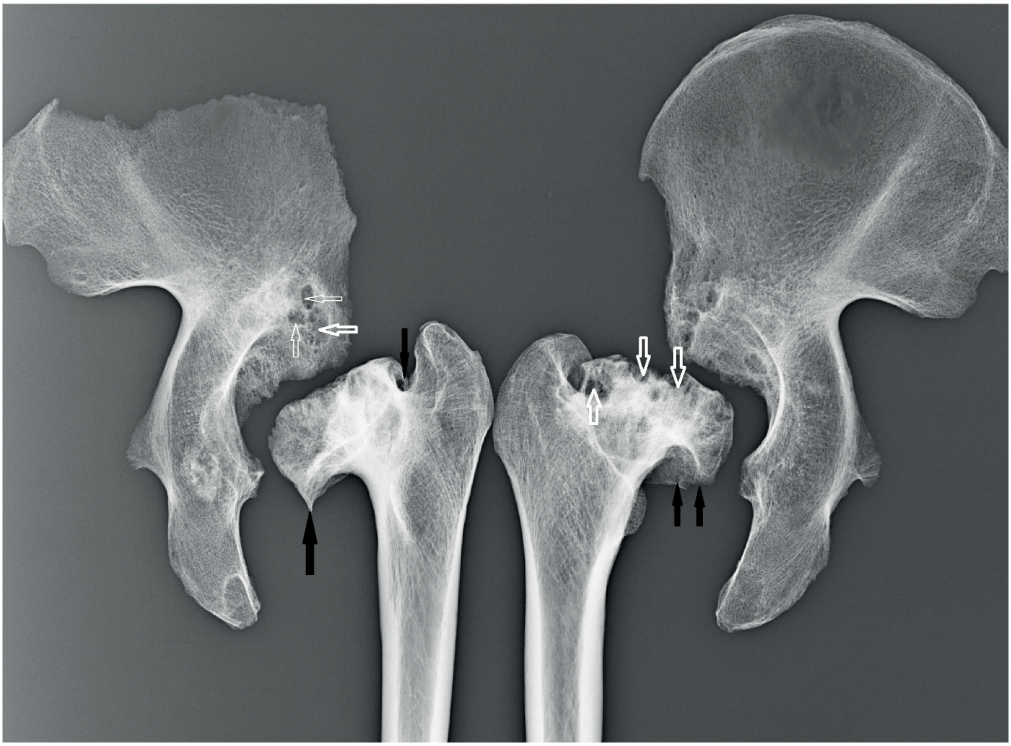


Fig. 10. Radiographs the femurs (proximal end) and pelvic bones with observable necrosis (white arrows) and osteophytes (black arrows) (No. 317/13)

Discussion and conclusions

The observed bilateral femoral head necrosis is idiopathic, and results from ischemic changes and bone remodelling. In patients, a symptom confirming the diagnosis of the vacuum phenomenon, caused by the release of nitrogen into the fissures in the head of the femur, which in turn accelerates the process of cyst formation in the area of the epiphyses. The macroscopic and radiological changes described match the symptoms associated with Legg-Calvé-Perthes disease (LCPD).

In the vast majority of reported cases, the disorder was found to be unilateral. For example, in less than 10% of cases, both hips are affected, and the joints are involved not simultaneously, but successively (Ortner and Putchar 1981; Leroux et al. 2018). In our case, necrotic changes are present in both femoral heads and both hips.

Generally, boys are affected about four times as often as girls. The condition is bilateral in between 10 and 20% of cases, although bilaterality is more frequently observed in girls (Guille et al. 1998; Pavone et al. 2019). This information is important for this case, as we are dealing with an adult male individual.

There is no consensus regarding the treatment of the disease, which is usually more focused on the prevention of femoral head collapse, progressive femoral head deformity and secondary degenerative arthritis, with restoring the range of motion and improving the functional recovery (Larson et al. 2012; Shah 2014).

Generally, the paleopathological evidence of LCPD are scarce. The disease has been previously described in: Peru (Ortner and Putchar 1981; Ortner 2003), Majorca (Marques and Cunha 2001), Serbia (Đurić et al. 2004), Czech Republic (Smrcka et al. 2009), Portugal (Ferreira et al. 2013), Argentina (Ponce and Novellino 2014), Egypt (Fritsch et al. 2015), China (Berger et al. 2017) and Spain (Manzon et al. 2017). Our study provides the first case of LCPD described in bioarchaeological materials from Poland.

A possible example of LCPD was diagnosed in the right femur of an adult female, which came from a miscellaneous group of femora accessioned as NMNH 265331 from the Valley of Chicama in Peru (National Museum of Natural History, Washington, D.C). The pathological changes observed on the femoral head were as follows: an obliterated depression for the ligamentum teres, a large circumscribed porous lesion covering more than half of the joint surface of the femoral head, bony overgrowth at the margins of the joint surface (a mushroom-like appearance), a depressed groove at the boundary with normal bone, a reduction in the mediolateral diameter of the head, bony outgrowths on the superior portion of the neck (Ortner and Putchar 1981; Ortner 2003). The pathological changes observed in the skeleton from Poland seem to be similar to the skeletal changes obtained from NMNH 265331 from Peru.

LCPD was found by Đurić et al. (2004) in a 30–40-year-old male skeleton from the medieval church of St. Ilija in the village of Ba, near Valjevo in western Serbia. In spite of some doubts, authors claimed that characteristics such as enlarged, malformed femoral head, thickening and shortening of the femoral neck, cyst-like destruction in the subarticular part of femoral head, irregular femoral head and acetabular surfaces, acetabular flattening, osteophyte formation on the upper margin of acetabulum suggest Perthes disease as the most likely diagnosis in this case (Đurić et al. 2004). The observed in our sample skeletal changes are similar to the described above. Although Đurić et al. (2004) found LCPD symptoms on one femur only (right bone was not affected), it is known that in 10% of cases LCPD can affect both sides (Manzon et al. 2017).

Smrcka et al. (2009), discussing the differential diagnosis of LCPD versus unilateral and bilateral osteochondroses of the femoral head in archaeological material and clinical situations, described two cases of archaeological LCPD from the Czech Republic. The first was a skeleton of a man older than 50 years, with the left hip affected (Langobard cemetery at Lužice in Moravia, dated to the late 5th century or early 6th century). The second case consists of a skeleton of an adult man from an archaeological investigation in Brandýsek (Bohemia; the 9th–10th century AD). Although authors emphasized that they were unable to exclude other causes of unilateral and/or bilateral osteochondrosis of femoral heads, they suggested these cases reflect Legg-Calvé-Perthes disease according to the criteria provided by Ortner and Putchar (1980). In both examined skeletal cases the following features were observed: mushroom shape of the femoral head, marginal osteophytes of the femoral head and acetabulum, greater trochanter evidently at a higher position than the center of the head, shallow, steep acetabulum, short and thick femoral neck. There was no substantial dislocation of the center of the femoral head from the axis of femoral neck, which also confirms that the authors were dealing with Perthes' disease in the examined case. The head of the right femur was not preserved; therefore, it was not possible to determine whether it is unilateral or bilateral disorder (Smrcka et al. 2009). The pathological changes observed in the male skeleton from Radom are similar to those reported by Smrcka et al. (2004), which further supports our supposition that the male from Radom suffered from the LCPD disease.

LCPD symptoms were also diagnosed and described on the right femur and right hip bone in an adult male (50–60 years old, individual number 12) from Duratón Visigith necropolis in Segovia (Spain) (Herrerín and Garralda 2010). The skeletal characteristics, such as the length of the femoral neck, the radiologically observable trabecular disposition, the flattened and deformed, mushroom-shaped femoral head, and the absence of fovea capitis are described by authors as LCPD symptoms. In addition, the observed changes were supplemented to the attachment sites development on the whole skeleton to describe the individual's mobility. Authors considered the obtained results, such as little muscular developmen on right femur, pronounced bilateral asymmetry observed in this individual's tibiae, strong and deep marks of muscular attachments on the right humerus could indicate a frequent use of the right arm during movement, may suggest the LCPD disorder. Our case reports similar skeletal lesions to those described by Herrerín, Garralda (2010) which suggests the same disorder. In contrast to the Spain sample, however, in male skeleton from Radom muscle attachment sites are not strongly developed and do no differ between left and right bones. Nevertheless, this is not surprising given that in our sample both skeletal sides are affected, muscles are developed, or movement is limited symmetrically.

Lesions observed by Ferreira et al. (2013) in the right femur of an individual (no. 2) from the 15th–17th century cemetery in the Valle da Gafaria (Lagos, Portugal) are also compatible with the LCPD disorder. Initially, the authors diagnosed the observed symptoms as either LCPD or slipped femoral capital but ultimately classified them as Perthes' disease. Slipped femoral capital epiphysis is a condition characterized by an inferior-posterior displacement of the femoral capital epiphysis, fusing with the neck in that position. The Legg-Calvé-Perthes disease do not exhibit such symptoms (Ferreira et al. 2013). The skeletal features observed in our sample are similar to the bone changes seen in an individual from Portugal (Ferreira et al. 2013) which further supports our diagnosis. The lack of inferior-posterior displacement of the femoral capital epiphysis in the Radom sample may also suggest the LCPD condition.

The observed in the Radom skeleton bony lesions, diagnosed as Legg-Calvé-Perthes disease symptoms, are similar to those observed in an individual from the Necropolis of Santa Maria, Sintra (Portugal), dated to the 14th–17th centuries (Wasterlain and Umbelino 2014). In this study, authors reported various macroscopic and radiological aspects as the most probable diagnosis of Legg-Calvé-Perthes disease in one of examined individual.

LCPD symptoms were also diagnosed by Ponce and Novellino (2014) in the well-preserved juvenile skeleton (individual (C 12), aged 14–16 at the time of death) from Argentina (late 16th to 17th

century). Slipped capital femoral epiphysis and developmental dysplasia of the hip were excluded as potential causes of the skeletal condition, and the combined radiological, macroscopic, and osteometric examinations indicated that LCPD was the most likely diagnosis. "Mushroom-shaped", deformed femoral head, its lower position according to the greater trochanter, the absence of the fovea capitis, short and wide femoral neck, wider, flattered, and irregular acetabulum these are the traits which authors to diagnose them as Perthes' disease. The above characteristics were also observed in the skeleton from Radom.

Similar to our sample pathologies has also been identified in ancient Egyptian mummies from the Museum of Antiquities in Cairo by Fritsch et al. (2015), who examined orthopaedic diseases in Ancient Egypt, and by Manzon et al. (2017) who reported on morphometric and radiological analyses of a skeleton from the Etruscan necropolis of Spina (Ferrara, Italy, 6th–3rd century BCE). Similarly, Berger et al. (2017) examined skeletal remains of an individual from the Warring States period in Shaanxi Province (China), and observed a "mushroom head" deformity of the proximal right femur, an enlarged acetabulum, along with a contralateral tibia, talus as well as enlarged navicular with periosteal new bone formation. These conditions were also connected with LCPD.

As highlighted above, LCPD has been rarely reported in ancient populations, and its differentiation from other pathological changes in dry bones (aseptic necrosis in Gaucher's disease, slipped femoral epiphysis) may be difficult (Wasterlain and Umbelino 2014) as all these conditions can produce similar lesions on the femoral head, making diagnosis difficult. Waldron (2009) suggested that the morphological changes associated with LCPD in human skeletal remains can include: a flattened mushroom-shaped femoral head with overhanging margins, thickening and shortening of the femoral neck along with a wide and shallow acetabulum, a normal position of the femoral head in relation to the axis. These femoral changes can be considered distinctive features of LCPD in palaeopathology.

As Waldron (2009) described, the LCPD condition passes through four stages: i/ the onset of avascular necrosis; ii/ femoral head fragmentation; iii/ revascularisation and regeneration; and iv/ healing. Late changes occurred in LCPD include: a shallow acetabulum and a smooth flattening of the femoral head, enlargement of the femoral neck and head, widening and shortening of the femoral neck with a varus deformity, mushroom deformity of the femoral head, shortening of the limb on the affected side, secondary osteoarthritis (Waldron 2009). We also observed such advanced changes in the examined individual from Radom.

LCPD is a complex disease affecting the epiphysis of the femoral head in the paediatric population. The disease occurs as avascular necrosis of the proximal femoral head that is a result of the tenuous blood supply to this area. The disorder is usually observed in boys at the age from 4 to 10 years (Loder and Skopelja 2011; Perry and Hall 2011; Pavone et al. 2019). Despite the aetiology of the disease having been widely discussed, it is still not fully understood (Hosalkar and Mulpuri 2012; Berger et al. 2017). The best supported theory involves an influence of repetitive mechanical stress on blood supply to the epiphysis (Guerado and Caso 2016; Leo et al. 2018).

At this stage of the analysis, it is not possible to determine the cause of LCPD in the Radom sample. Firstly, despite the aetiology of the disease having been widely discussed, it is still not fully understood (Hosalkar and Mulpuri 2012). The major hypothesis relies on a multifactorial genesis, involving genetic, mechanical, traumatic, metabolic, nutritional, environmental, hormonal, and hematologic conditions (Thompson and Salter 1986). Secondly, the archaeological and historical data concerning the examined individual are poor. Therefore, it is not possible to form a hypothesis about the aetiology of the disease. Archaeological and historical data about Radom and its population are available (e.g., Bogucka and Samsonowicz 1986; Kusiński 1991; Kozak 1997; Piątkowski 2000), but they cannot be directly related to a single individual. Although the sample provides some information about the health and biological condition of skeleton No. 317/13, it does not provide any data about this person's individual lifestyle, which limits the possibility of formulating any hypotheses.

In conclusion, all the macroscopic and radiological changes observed and described in the examined male skeleton (No. 317/13) from Radom match the symptoms associated with Legg-Calvé-Perthes disease.

Acknowledgements

This research was funded by the National Science Centre (Poland) from 2013–2017 (Grant No 2013/11/B/HS3/04117).

Conflict of interests

Authors do not have any conflict of interest.

Authors' contribution

AM: carrying out skeletal analyses, preparation and description of the manuscript; HM-P: carrying out skeletal analyses, preparation and description of the manuscript; ER: carrying out skeletal analyses, preparation and description of the manuscript; AD: carrying out skeletal analyses, preparation and description of the manuscript; JT: planning and supervision of the research, setting a goal, substantive supervision.

Corresponding author

Anna Myszka, Institute of Biological Sciences, Cardinal Stefan Wyszynski University, Wóycickiego 1/3, building 23, 01-938 Warsaw; e-mail: a.myszka@uksw.edu.pl

References

Baranowski T, Skóra K, Skrzyńska K. 2020. Stanowisko 4. Badania interdyscyplinarne. Przestrzeń osadnicza wczesnośredniowiecznego Radomia 3. Warszawa: Instytut Archeologii i Etnologii PAN.

Berger E, Chen L, Sun Z, Sun Z. 2017. A probable case of Legg-Calvé-Perthes disease in Warring States-era China. Int J Paleopathol 16:27–30. https://doi.org/10.1016/j.ijpp.2016.11.001

Bogucka M, Samsonowicz H. 1986. Dzieje miast i mieszczaństwa w Polsce przedrozbiorowej. Wrocław: Wyd. Ossolineum.

Buikstra JE, Ubelaker DH. 1994. Standards for data collection from human skeletal remains. Arkansas Archeological Survey Research Series, No. 44: Fayetteville.

Drusini AG. 2008. The coronal pulp cavity index: A forensic tool for age determination in human adults. Cuad. de Medicina Forense 14(53–54):235–2.

Đurić M, Rakočević Z, Bumbaširević M, Lešić A, Kelečević J. 2004. Two cases of joint disease in post-Medieval church cemetery of St. Ilija. Coll Antropol 28 Suppl. 2:273–82.

Ferreira MT, Neves MJ, Wasterlain SN. 2013. Lagos leprosarium (Portugal): direct and indirect evidence of disease. J Archaeol Sci 40(5):2298–307. https://doi.org/10.1016/j.jas.2012.12.039

Fritsch KO, Hamoud H, Allam AH, Grossmann A, Nur El-Din AH, Abdel-Maksoud G, Soliman MA, Badr I, Sutherland JD, Sutherland ML, Akl M, Finch CE, Thomas GS, Wann LS, Thompson RC. 2015. The orthopedic diseases of ancient Egypt. Anat Rec 298(6):1036–46. https://doi.org/10.1002/ar.23136

Gąssowski J. 1951. Wczesnohistoryczne cmentarzysko szkieletowe w Radomiu. Wiadomości Archeologiczne 18(4):305–326.

Guerado E, Caso E. 2016. The physiopathology of avascular necrosis of the femoral head: an update. Injury. 47 Suppl 6:16–26. https://doi.org/10.1016/S0020-1383(16)30835-X

Guille JT, Lipton GE, Szöke G, Bowen JR, Harcke HT, Glutting JJ. 1998. Legg-Calvé-Perthes disease in girls. A comparison of the results with those seen in boys. J Bone Joint Surg. 80(9):1256–63. https://doi.org/10.2106/00004623-199809000-00002

Herrerín J, Garralda M. 2010. Legg-Calvé-Perthes disease and unifocal eosinophilic granuloma in a Visigoth from Duratón Necropolis (Segovia Spain). Int J Osteoarchaeol 22:86–97. https://doi.org/10.1002/oa.1189

Hosalkar HS, Mulpuri K. 2012. Legg-Calvé-Perthes disease: where do we stand after 100 years? Clin Orthop Relat Res 470(9):2345–6. https://doi.org/10.1007/s11999-012-2418-0

Kierzkowska-Kalinowska E. 1970. Dziesięć lat badań Ekspedycji Wykopaliskowej w Radomiu Instytutu Historii Kultury Materialnej PAN. Biuletyn Kwartalny Radomskiego Towarzystwa Naukowego 7:39–68.

Kierzkowska-Kalinowska E. 1979. Rozwój procesów osadniczych na obszarze Radomia przed lokacją miasta. In: Kalinowski W, editor. Urbanistyka i architektura Radomia. Lublin: Wydawnictwo Lubelskie, 9–44.

Konigsberg LW, Hens SM. 1998. Use of ordinal categorical variables in skeletal assessment of sex from the cranium. Am J Phys Anthropol 107:97–112. https://doi.org/10.1002/(SICI)1096-8644(199809)107:1<97::AID-AJPA8>3.0.CO;2-A

Kozak J. 1997. Mortality structure of adult individuals in Poland in the feudal period. Variability and Evolution 6:81–91.

Kurasiński T, Skóra K. 2016. Cmentarzysko w Radomiu, stanowisko 4. Przestrzeń osadnicza wczesnośredniowiecznego Radomia. Łódź: Instytut Archeologii i Etnologii PAN.

Kusiński W. 1991. Stadia rozwoju urbanizacji w Polsce. Przegląd Geograficzny 63:271–81.

Larson AN, Sucato DJ, Herring JA, Adolfsen SE, Kelly DM, Martus JE, Lovejoy JF, Browne R, Delarocha A. 2012. A prospective multicenter study of Legg-Calvé-Perthes disease: functional and radiographic outcomes of nonoperative treatment at a mean follow-up of twenty years. J Bone Joint Surg 94:584–92. https://doi.org/10.2106/JBJS.J.01073

Leo DG, Leong WY, Gambling T, Long A, Murphy R, Jones H, Perry DC. 2018. The outcomes of Perthes' disease of the hip: a study protocol for the development of a core outcome set. Trials 19:374–481.

Leroux J, Abu Amara S, Lechevallier J. 2018. Legg-Calvé-Perthes disease. Orthop Traumatol Surg Res 104(1S):107–12.

Loder RT, Skopelja EN. 2011. The epidemiology and demographics of Legg-Calvé-Perthes' disease. ISRN Orthop 504393. https://doi.org/10.5402/2011/504393

Manzon VS, Ferrante Z, Giganti M, Gualdi--Russo E. 2017. On the antiquity of Legg-Calvé-Perthes disease: Skeletal evidence in Iron Age Italy. HOMO 68(1):10–17. https://doi.org/10.1016/j.jchb.2016.11.002

Marques C, Cunha E. 2001. A paleopathological evidence of Perthes disease. In: Sanchez-Sanchez JA, editor. Actas del V Congreso Nacional de Paleopatologia. Alcalá la Real, Asociación Española de Paleopatología, 311–313.

Ortner DJ. 2003. Identification of pathological conditions in human skeletal remains. London: Academic Press.

Ortner DJ. 2008. Differential diagnosis of skeletal lesions in infectious disease. In: Pinhasi R, Mays S, editors. Advances in human palaeopathology. Chichester: John Wiley&Sons, 191–214.

Ortner DJ, Putschar WGJ. 1981. Identification of Pathological Conditions in Human Skeletal Remains. Washington, DC: Smithsonian Institution Press.

Pavone V, Chisari E, Vescio A, Lizzio C, Sessa G, Testa G. 2019. Aetiology of Legg-Calvé-Perthes disease: A systematic review. World J Orthop 10(3):145–165. https://doi.org/10.5312/wjo.v10.i3.145

Perry DC, Hall AJ. 2011. The epidemiology and etiology of Perthes disease. Orthop Clin North Am 42: 279–283. https://doi.org/10.1016/j.ocl.2011.03.002

Piątkowski S. 2000. Radom – zarys dziejów miasta. Wyd. Radom: Radom.

Phenice WT. 1969. A newly developed visual method of sexing the os pubis. Am J Biol Anthropol 30/2:297–301. https://doi.org/10.1002/ajpa.1330300214

Ponce P, Novellino P. 2014. A palaeopathological example of Legg-Calvé-Perthes disease from Argentina. Int J Paleopathol 6:30–33. https://doi.org/10.1016/j.ijpp.2014.03.004

Shah H. 2014. Perthes disease: evaluation and management. Orthop Clin North Am 45:87–97. https://doi.org/10.1016/j.ocl.2013.08.005

Skubicha E. 2010. Archeologia Radomia – dzieje badań. In: Buko A, Główka D, editors. Radom: korzenie miasta i regionu. Badania 2009. Warszawa: Instytut Archeologii i Etnologii PAN, 105–113.

Smith MO. 2002. A Probable case of metastatic carcinoma from the late prehistoric eastern Tennessee River valley. Int J Osteoarchaeol 12:235–47. https://doi.org/10.1002/oa.618

Smrčka V, Marik I, Svenssonova M, Likovsky J. 2009. Legg-Calvé-Perthes disease in Czech archaeological material. Clin Orthop Relat Res 467:293–97. https://doi.org/10.1007/s11999-008-0527-6

Thompson GH, Salter RB. 1986. Legg–Calve–Perthes Disease. Clinical Symposia. 38:2.

Waldron T. 2009. Palaeopathology. Cambridge: Cambridge University Press.

Walker PL. 2008. Sexing skulls using discriminant function analysis of visually assessed traits. Am J Biol Anthropol 136(1):39–50. https://doi.org/10.1002/ajpa.20776

Wasterlain SN, Umbelino C. 2014. Legg-Calvé-Perthes disease and slipped femoral capital epiphysis in the skeletal remains of the Mediaeval Necropolis of Santa Maria (Sintra, Portugal). Cadernos do DEEvH. 2(2):27–39.

White TD, Folkens PA. 2000. Human osteology. (2nd ed.). San Diego: Accademic Press.

Zapłata R. 2011. Wstępne wyniki badań archeologicznych w wykopie 1/2010 na stanowisku 1 „Majdan" i w wykopie I-2/2010 na stanowisku 2 „osada" w Radomiu. In: Buko A, Główka D, Trzeciecki, editors. Radom: korzenie miasta i regionu. Tom 2. Warszawa: Wyd. Instytutu Archeologii i Etnologii PAN, 89–112.

Yanko NV, Artemyev AV, Kaskova LF. 2021. Dental health indicators of the Chernyakhov population from Shyshaki (Ukraine). Anthropol Rev 84(1):17–28. https://doi.org/10.2478/anre-2021-0002

Anthropological Review • Vol. 86(1), 37–49 (2023)

ANTHROPOLOGICAL REVIEW

Available online at: https://doi.org/10.18778/1898-6773.86.1.04

Sex estimation using measurements of the proximal femur in a historical population from Poland

Joanna Wysocka, Agata I. Cieślik, Dariusz P. Danel

Department of Anthropology, Hirszfeld Institute of Immunology and Experimental Therapy, Polish Academy of Sciences, Wrocław, Poland

Abstract: Sex estimation is one of the most important components in assessing the biological profile of an individual. In an archaeological context, the pelvis, which is the most dimorphic part of the skeleton, is often poorly preserved, which can cause an inability to use morphological sex estimation methods. Therefore, alternative methods are required in such cases. Because the utility of the metric methods based on the femur measurement has been confirmed, and the bone is usually available for examination due to its good preservation, developing methods using the landmarks of the femur could have important implications in sex estimation.

This study aimed to derive a discriminant function equation for a Polish archaeological population based on measurements of the proximal end of the femur.

The study sample included individuals from a medieval cemetery in Milicz (n = 62) and an early modern necropolis at Czysty Square in Wrocław, Poland (n = 162). The analysis included seven measurements collected from the right and left proximal femora. To estimate the reproducibility of the measurements, intra-and interobserver errors and reliability coefficients were calculated. Subsequently, univariate and stepwise discriminant analyses were performed, and the sex sectioning points and equations were proposed.

No differences were observed between measurements of the right and left femora. The results indicated a high utility and reproducibility of the FHD measurement (regardless whether left or right femur was measured). The discriminant equations for sex estimation reached an accuracy of 83.0–92.3%, which implies the utility of the function on Polish historical populations when the other methods for sex estimation cannot be used.

Key words: sex assessment, morphometrics, sexual dimorphism, discriminant function, the Polish population.

Original article

Received: 23.01.2023; Revised: 2.03.2023; Accepted: 6.03.2023

Introduction

Estimating biological sex of an individual is one of the most important elements in the forensic anthropological examination of skeletal remains of unknown identity as well as historical material. Moreover, the assessment of other biological parameters, such as age at death and stature, often depends on the sex of the individual (Brůžek 2002; Byers 2016).

There are two main approaches to estimating sex based on skeletal features: morphological and metric. The first set of methods is based on the macroscopic evaluation of morphological features of the skull and pelvis, while the latter uses selected bone measurements and statistical analysis (e.g., regression equations, discriminant functions) (Byers 2016; Bidmos et al. 2021). Both approaches are not error-free. For example, in qualitative methods, incorrect sex estimation may be related to subjectivity and insufficient level of relevant research experience. However, such methods are relatively easy to apply and do not require the use of anthropological equipment. Although metric methods are more time-consuming and require specialized instrumentation, they substantially reduce the risk of subjectivity and allow for determining measurement differences that cannot be detected using the macroscopic methods (Christensen et al. 2015; Krishan et al. 2016).

Most dimorphic bones (such as pelvi girlde bones) are often not available for examination due to bad preservation, incomplete or highly fragmented skeletal material. For instance, according to Walker (2005), incomplete preservation occurs in 80–90% of the individuals excavated from historical cemeteries. Thus, in such cases metric methods can be used for biological sex assessment as an alternative. Results obtained by using metric methods can be further processed by applying discriminant functions, regression analysis, and sectioning points methods (Krishan et al. 2016; Ubelaker and DeGaglia 2017). Apart from bones exhibiting the highest degree of sexual dimorphism, such as pelvic and skull bones (İşcan 2005; Walker 2005; Byers 2016), attempts have been also made to evaluate sex based on metric characteristics of other elements of the postcranial skeleton. For example, discriminative equations have been designed by using measurements of the shoulder girdle bones, e.g. scapula (Tormitsu et al. 2016), clavicle (Albanese 2013), upper limbs (Bidmos and Mazengenya 2021), lower limbs, e.g. femur (Kim et al. 2013), as well as chest bones, e.g. sternum (Macaluso 2010), ribs (Macaluso et al. 2012; Kubicka and Piontek 2016), or smaller limb bones such as calcaneus (Dimichele and Spradley 2012), metacarpals, metatarsals and phalanges (Case and Ross 2007; Bidmos et al. 2021).

The femur is one of the skeletal elements used to construct discriminant equations. Not only it is the most massive and least sensitive to mechanical damage and taphonomic changes, but it is often the best-preserved bone in skeletal material excavated from historical cemeteries. Due to the direct contact in the hip joint with the most dimorphic part of the skeleton – the pelvis and the location of the muscle attachments that are crucial in locomotion, sex estimation based on the femur is characterized by high accuracy (86.4–95%.) (Mall et al. 2000; Purkait 2005; Albanese et al. 2008; Kim et al. 2013; Djorojević et al. 2015; Colman et al. 2018).

Metric methods for estimating sex are common, widely applied, and created for different populations. However, there have been only two attempts to obtain population-specific formulae for the Polish population, based on modern samples with a known biological profile and utilizing CT imaging (Tomaszewska et al. 2014; Kubicka and Piontek 2016). Some studies have proposed sectioning points data for archaeological material derived from Poland (e.g. Tomczyk et al. 2017). However, there are no discriminant functions designed for historical Polish population that utilize the measurements of the proximal femur. Some studies have highlighted an important limitation of the metric methods (e.g. Albanese et al. 2008; Anastopoulou et al. 2014; Colman et al. 2018), such as a low accuracy of the discriminant function or regression equations when applied to other than the original population (i.e., the one for which the function was originally designed), mainly due to the high inter-population variability. This limitation is especially important when assessing the biological sex of individuals of unknown identity whose skeletons were excavated from various historical necropolises. Thus, the specific-population equation is needed for the historical Polish populations. However, there are also limitations in deriving sex estimation equations for Polish populations mainly due to the lack of a large skeletal series that provide information regarding sex, age, health, stature, and other physical characteristics that are critical in comparative analysis.

The main purpose of this study is to derive discriminant function equations for the historical Polish population represented by individuals excavated from two historical Polish cemeteries located in Milicz (12^{th}–14^{th} centuries) and Czysty Square (Plac Czysty) in Wrocław (16^{th}–19^{th} centuries), using the measurements of the proximal end of the femur, in order to propose an alternative method for sex estimation.

Materials and methods

The right and left femora of 223 adult individuals from two Polish archaeological sites were examined. The skeletal material is a part of the osteological collection stored at the Department of Anthropology, Hirszfeld Institute of Immunology and Experimental Therapy, Polish Academy of Sciences, in Wroclaw. The data were collected from a) 144 right and 154 left femora from Czysty Square (in Wroclaw), b) 53 right and 53 left femora from Milicz. The sex of the individuals from both sites was unknown.

The Orthodox cemetery near Czysty Square was adjacent to the Salvator Church, situated on the perimeter of Wroclaw (Lower Silesia voivodeship, Poland), which was built in 1568. The cemetery was in use from the year 1541 until the first half of the 19^{th} century. According to Wojtucki (2015) and Sawicki (2015), the majority of people buried at the cemetery came from the nearby poor communities.

The cemetery in Milicz, which was in use between the 12^{th}–14^{th} century, contains remains of an early medieval town community. The cemetery was located on the southwestern part of a farmed hill near the Barycz Valley, 500 m from the buildings of the modern town of Milicz (Wachowski 1969; Kiarszysz and Kolenda 2017).

Femora with visible pathological lesions or in a poor state of preservation were excluded from the study because any form of alteration (e.g., degenerative) might influence the measurements. Another criterion of sample selection was based on the possibility of establishing at least three landmarks. If possible, the measurements were taken both from the right and left femur of an individual.

Ability to estimate the sex of an individual based on pelvic morphology was also a critical criterion in sample selection. An individual was excluded from the study if there was not at least one pelvic bone in a state of good preservation available to examine or if the dimorphic features were ambiguous.

The sex of an individual was estimated by JW based on the morphological features of the pelvis, using standard anthropological criteria (Phenice 1969; Buikstra and Ubelaker 1994; Brickley 2004). During the sex evaluation, the following traits were taken into consideration: ventral arc, ischiopubic ramus ridge, subpubic concavity (Phenice 1969), sciatic notch (Buikstra and Ubelaker 1994; Walker 2005), and subpubic angle (Brickley 2004). During the next step, the outcome of the estimation of sex, based on morphological criteria, was also verified with the results of the sex assessment established previously by other authors (Wachowski 1969; Wachowski 1970; Łubocka and Gronkiewicz 2015).

Every bone was measured twice using an electronic caliper by JW. All anthropometric landmarks included in this research were located on the proximal part of the femur (Table 1, Figure 1).

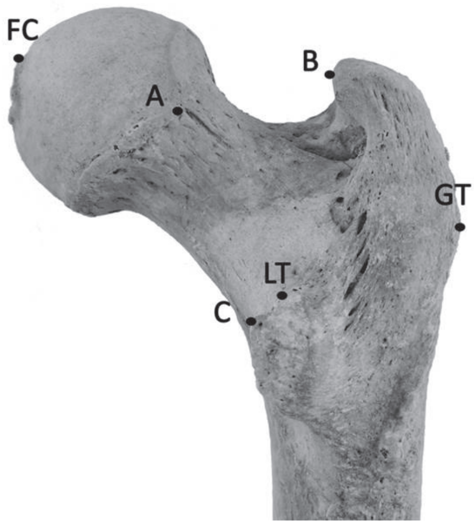


Fig. 1. The landmarks of the proximal femur used in equations (according to Purkait 2005; Albanese et al. 2008)

Table 1. Definitions of the measurements of the proximal femur according to Purkait (2005)[a], Albanese et al. (2008)[b] and Bass (1987 cited in Djorojević et al. 2015:247)[c]

Measurement	Definition
AB [a]	The straight distance between the point on the articular margin of head dipping most laterally and the point projecting most medially on the greater trochanter.
BC [a]	The straight distance between the point projecting most medially on the greater trochanter and the highest point on the lesser trochanter.
AC [a]	The straight distance between the point on the articular margin of head dipping most laterally and the point projecting most medially on the highest point on the lesser trochanter.
GT-LT [b]	The straight distance between the most lateral apex on the greater trochanter and the most proximal point on the lesser trochanter.
GT-FC [b]	The straight distance between the most lateral apex on the greater trochanter and the superior margin on the fovea capitis.
LT-FC [b]	The straight distance between the most proximal point on the lesser trochanter and the superior margin on the fovea capitis.
FHD [c]	The maximum diameter of the head of the femur

Statistical analyses were conducted using SPSS v.25, STATISTICA 13.1, and Microsoft Office Excel 2007. The sexual dimorphism index (SDI) was calculated according to the formula used by Tobias (after Ricklan and Tobias 1986), where Xm is the mean value for males and Xf is for the females:

$$SDI = \frac{Xm - Xf}{Xm} \times 100\%$$

Inspection of the normal probability (i.e., Q-Q) plots for each of the femur measurements, for males and females, was conducted. The Mann-Whitney U-test was used for the comparison of the measurements of the femora between the Czysty square and Milicz collection. For symmetry examination between the right and left femora, paired-sample t-tests were performed. For the inter-observer error evaluation, the measurements of the two authors were compared. The author, AC, measured 41 femora twice from the original sample. The technical error of measurements (TEM), the relative technical error of measurements (%TEM), and the reliability coefficient (*R*) were calculated (Ulijaszek and Kerr 1999). For the comparison with the inter-observer error calculated by Albanese et al. (2008), the equation mentioned below was used as well:

$$\%Error = \frac{|m1 - m2| \times 100}{m1}$$

Two sample t-tests, as well as simple univariate discriminant analysis and multivariate backward stepwise discriminant function analyses, were conducted to analyze possible sex differences in the proximal femur measurements. Inspection of the normal probability revealed that the data were distributed normally. Results for homogeneity of variances Levene's test are presented in table 2. For multiple testing (t-tests for determination of sexual dimorphism in n=7 measurements) the significance level was Bonferroni corrected to $\alpha = 0.05/7 = 0.007$. The sex demarcation points for univariate discriminants analyses were calculated as the grand average of the means for both sexes for each measurement. The sex sectioning point (SP) for the backward stepwise multivariate function analysis was calculated as the average between mean canonical scores for males and females. The Box's M test showed that the assumption of homogeneity of variance–covariance matrices for the predictor variables in multivariate discriminant analysis were only marginally violated (Box's M = 44.81; $\chi 2$(df:28) = 42.28; p = 0.04). The Czysty square (Wrocław) collection was used as an original sample and the Milicz series as a cross-validation sample. Statistical significance was set at $\alpha = 0.05$.

Results

In total, there were 81 male and 71 female skeletons from the Czysty Square, and 56 male and 44 female skeletons from the Milicz collection. No significant differences between the average measurement values of femora from the early modern (Czysty square, Wrocław) and medieval (Milicz) anthropological series were found (see Supporting Information Table S1).

The variability of measurements was moderately high (Table 2). The highest reliability coefficient was observed in the case of GT-FC and FHD measurements (*R* = 0.99). All of the lengths of Purkait's Triangle (AB, BC, AC) obtained lower reliability (below 0.90). Out of the 14 used measurements (seven on the right and seven on the left femur), six obtained moderately high values of inter- and intra-observer error (four dimensions of the right and two of the left femur).

A series of t-tests showed that except for AC (right and left), all measurements were sexually dimorphic at Bonferroni corrected level $\alpha = 0.007$. All traits were significantly larger in males. The highest SDI value was calculated for FHD, whereas the lowest was for AC measurement. (Table S3).

Table 2. Evaluation of inter- and intra- observer error and the coefficient of reliability of taken measurements

Measurements	Observer 1					Observer 2						
	N	Mean	SD	TEM intra	%Error	Mean	SD	TEM intra	%Error	TEM inter	%TEM	R
AB R	30	29.26	4.94	31.47	4.16	29.50	4.14	32.84	4.17	2.14	7.12	0.78
AB L	34	30.29	4.82	23.61	2.85	32.97	4.62	34.35	3.89	1.73	5.48	0.87
AC R	30	50.39	5.76	32.91	2.45	44.04	4.63	30.47	2.68	2.11	4.48	0.83
AC L	34	51.41	5.65	41.39	2.14	43.15	5.79	32.65	2.43	2.19	4.64	0.85
BC R	31	57.67	4.66	26.39	2.08	52.22	3.85	44.73	2.72	2.37	4.31	0.69
BC L	35	58.89	5.52	31.29	1.88	51.68	4.56	28.15	1.81	1.70	3.08	0.89
LT-GT R	40	54.50	5.42	35.48	1.84	54.22	4.76	49.87	2.67	2.16	3.98	0.82
LT-GT L	41	53.88	8.88	38.88	1.78	55.45	5.06	36.01	1.91	1.83	3.34	0.93
GT-FC R	41	90.28	7.25	20.67	0.67	91.69	7.58	14.70	0.41	0.87	0.96	0.99
GT-FC L	41	89.43	9.54	18.72	0.56	92.26	7.78	17.61	0.44	0.89	0.98	0.99
FC-LT R	40	66.15	6.77	24.43	1.11	69.90	6.54	32.68	1.22	1.44	2.12	0.95
FC-LT L	41	66.27	7.40	62.89	1.95	67.62	7.20	40.38	1.63	2.58	3.82	0.88
FHD R	40	44.77	3.86	10.02	0.43	45.58	4.62	7.77	0.49	0.45	0.98	0.99
FHD L	41	44.89	3.90	9.39	0.72	45.24	4.51	6.67	0.44	0.40	0.87	0.99

R- right femur; L-left femur

Table 3. Descriptive statistics and assessment of sexual dimorphism for all measurements for the Czysty square collection – the original sample

	Female			Male			t-test		Levene's test			
	Mean	SD	n	Mean	SD	n	t-value(df)	p*	F(1.df)	p	df	SDI
AB R	29.56	4.603	51	32.30	4.811	50	-2.93	0.004	0.08	0.775	99	8.48
AB L	30.94	4.484	52	34.26	5.779	57	-3.32	0.001	2.11	0.150	107	9.69
AC R	43.28	4.961	57	45.38	6.595	60	-1.93	0.056	8.55	0.004	115	4.63
AC L	42.20	4.825	57	44.53	6.500	70	-2.24	0.027	6.73	0.011	125	5.23
BC R	49.90	4.652	52	54.30	4.790	50	-4.71	<0.007	0.01	0.906	100	8.10
BC L	49.39	4.414	52	54.18	5.560	56	-4.93	<0.007	2.36	0.127	106	8.84
LT-GT R	51.85	3.870	62	56.86	4.023	70	-7.27	<0.007	0.03	0.867	130	8.81
LT-GT L	52.70	4.240	63	58.36	4.371	77	-7.72	<0.007	0.04	0.841	138	9.70
GT-FC R	87.96	5.796	62	98.24	6.348	70	-9.67	<0.007	0.75	0.388	130	10.46
GT-FC L	88.23	5.609	63	98.33	6.336	77	-9.88	<0.007	0.59	0.444	138	10.27
FC-LT R	67.18	5.204	62	73.44	6.854	70	-5.85	<0.007	6.86	0.010	130	8.52
FC-LT L	64.95	4.964	63	71.16	6.649	77	-6.15	<0.007	7.66	0.006	138	8.73
FHD R	42.86	2.774	63	48.99	3.378	81	-11.67	<0.007	1.02	0.313	142	12.51
FHD L	42.63	2.480	66	48.82	3.321	88	-12.72	<0.007	3.24	0.074	152	12.68

p* – refers to Bonferroni-corrected significance level; Levene's test for homogeneity of variances in the compared groups; note that in two cases the assumption is violated.

The means of the measurements were significantly different in four out of seven cases (measurements: GT-FC, LT-FC, AB, and AC) between the right and left bones (Table 4). For this reason, the samples were not combined, and the measurements of each side were analyzed separately. GT-LT and AB measurements took on average higher values on the left side, while LT-FC and AC on the right side.

In order to determine whether males and females differed with respect to the proximal femur measurements, the discriminant function analysis was conducted. Results for the univariate discriminant analyses are presented in Table 5. For the original data, the accuracy for the sex discrimination (combined for males and females) was the highest for FHD R – 83.33%, and FHD L – 85.71%. For the cross-validation data (Milicz collection) the highest accuracy for the sex discrimination (combined for both sexes) was observed also for FHD R – 88.68, FHD L – 86.79%. The multivariate backward stepwise method showed that only FHD (right and left) was a statistically significant measurement that can be included in the discriminant function. The results of the stepwise discriminant function analysis showed a high accuracy in estimating sex when using FHD measurement of both sides and in the case of both: original and cross-validation sample (FHD R: 83.0; 92.3%; FHD L: 88.0; 89.3% respectively) (Table 6).

Table 4. A comparison of right and left femoral measurements. The results of paired-samples t-test

		Right		Left				95% *CI*		
	n	$\bar{X}$	*SD*	$\bar{X}$	*SD*	*t*	*p*	*LL*	*UL*	*d* Cohena
AB	86	30.77	4.37	32.69	5.03	-4.73	<0.001	-2.73	-1.11	0.51
AC	119	44.73	5.76	43.75	6.04	2.88	0.004	0.31	1.66	0.26
BC	89	51.74	5.67	51.94	5.70	-0.76	0.449	-0.74	0.33	0.08
LT-GT	149	54.73	4.86	55.85	5.20	-5.31	<0.001	-1.54	-0.70	0.43
GT-FC	149	93.55	7.46	93.59	7.40	-0.27	0.784	-0.38	0.29	0.02
FC-LT	150	70.73	6.68	68.65	6.68	8.14	<0.001	1.58	2.59	0.66
FHD	183	46.36	4.60	46.30	4.65	0.92	0.356	-0.07	0.19	0.07

Table 5. Results of the univariate discriminant analyses

	Original accuracy (%)			Cross-validation accuracy (%)			
	male	female	total	male	female	total	Demarcation points (mm)
AB R	64.00	60,78	62.38	55.00	57.14	55.56	1<30,92<0
AC R	58.33	54.39	56.41	61.54	57.14	60.61	1<44.36<0
BC R	62.00	67.31	64.71	57.14	85.71	64.29	1<52.05<0
LT-GT R	77.14	69.35	73.48	82.35	69.23	78.72	1<54.50<0
GT-FC R	80.00	75.81	78.03	97.06	84.62	93.62	1<93.41<0
FC-LT R	68.57	69.35	68.94	71.43	61.54	68.75	1<70.50<0
FHD R	86.42	79.37	83.33	87.18	92.86	88.68	1<46.31<0
AB L	61.40	59.62	60.55	65.22	37.50	58.06	1<32.68<0
AC L	74.29	31.58	55.12	74.07	12.50	60.0	1<43.48<0
BC L	64.29	63.46	63.89	57.14	88.89	66.67	1<51.87<0
LT-GT L	80.52	71.43	76.43	80.00	76.92	79.07	1<55.81<0
GT-FC L	83.12	74.60	79.29	90.00	76.92	86.05	1<93.79<0
FC-LT L	72.73	68.25	70.71	76.67	46.15	67.44	1<68.36<0
FHD L	85.23	86.36	85.71	89.19	81.25	86.79	1<46.16<0

0 – male; 1 – female; R -right; L – left

Table 6. Stepwise discriminant function analysis of the proximal femur measurements (accuracies both for original and cross-validation sample)

							Original accuracy (%)			Cross-validation accuracy (%)		
Variable entered	Exact *F*	df	*p*	Wilks' λ	χ2	Raw coefficient	male	female	total	male	female	total
FHD R	98.74	1, 98	< 0.001	0.50	67.95	0.3276	82.0	84.0	83.0	90.0	100.0	92.3
Constant						-14.9832						
FHD L	125.04	1, 106	< 0.001	0.46	82.20	0.3467	83.9	92.3	88.0	90.5	85.7	89.3
Constant						-15.8345						

The sectioning point equals zero. Standard coefficient equals on

The final forms of the discriminant functions were:

For the right measurement:

$$y = -14.9832 + (\text{FHD R} \times 0.3276)$$

Since the sectioning point equals SP = 0 (canonical means: males = 0,994; females = -0,994) positive y-values indicate a male and negative values indicate a female.
and for the left measurement:

$$y = -15.8345 + (\text{FHD L} \times 0.3467)$$

Since the sectioning point equals SP= -0.04 (canonical means: 0 = 1.037; 1 = -1,117) y-values greater than SP indicate a male femur and values lower than SP indicate a female femur.

Discussion

The mean values of the selected proximal femoral measurements did not differ between the medieval and early modern collections. This denotes a similarity between individuals from the two historical periods (medieval and early modern) living in the same geographical area (the distance between cemeteries was approximately 60 km).

Although metric methods of sex assessment developed in other studies (e.g. Purkait 2005; Anastopoulou et al. 2014; Djorojević et al. 2015; Djorojević et al. 2019) had common assumptions and goals, they differed significantly in terms of methodology. For example, because Purkait (2005) and Djorojević et al. (2015) assumed that there were no differences in right-left measurements of the femora, they measured only one femur from each individual without recording which bone was measured. Similarly, in another study Djorojević et al. (2019) originally measured femora from both sides using CT scans, but, having established the symmetry of the femora, the authors decided to use measurements from only one side without reporting which one was measured. In contrast, Anastopoulou et al. (2014) used the metric features of both femora of measured individuals, despite the lack of differences between the average bone measurements, and yielded comparable effectiveness of sex estimation for the right and left bones (77.8%, 75.9%).

In the present study, four out of seven measurements of the right and left femora differed significantly from one another. However, it is not possible to unambiguously determine whether the right or left bone dimensions were on average larger because two of the measurements (LT-FC, AC) point to the right femoral proximal end being larger and two (GT-FC, AB) to the left femoral proximal end being larger. It is also worth noting that LT-FC and AC, as well as GT-FC and AB, are equivalent in Purkait (2005) and Albanese et al. (2008) methods. LT-FC and AC are the distance from the fovea capitis (LT-FC) or posterior margin of the head (AC) to the point located on the lesser trochanter, whereas GT-FC and AB are the distance between the head (fovea capitis – GT-FC, posterior margin of a head – AB) and the most lateral point situated on the greater trochanter. This may suggest that the development of the greater trochanter on the left side was more prominent and the lesser trochanter was strongly marked on the right side. The FHD measurement did not differ between the sides, which contradicts the observations of Plochocki (2004) and Auerbach and Ruff (2006), who recorded higher values of the femoral head measurements of the left limb.

The discriminant function results indicate that using the femoral head diameter measurement (FHD) in a discriminant equation alone has a high accuracy and no additional measurements of the proximal part of the femur are needed. A high SDI value of 12.7–12.9 and a large size effect obtained by the sex comparison test (Table 2) suggest that the FHD measurement is a highly dimorphic feature. In addition, the FHD measurement is easy to perform, thus its precision is higher (the lowest inter- and intra-observer error values) compared to other measurements. As Albanese et al. (2008) suggested that a miscalculation may occur when the % error margin exceeds 2-2.5%, and in this study, the majority of Purkait's Triangle (AB, BC, AC) dimensions (all measurements of the right femora and two out of three from the left femora) exceed the 2% error margin (Table 3). The lengths proposed by Albanese et al. (2008), only LT-GT was associated with a high risk of measurement inaccuracies (%error = 2.67). Similarly, Albanese et al. (2008) observed the lowest precision of LT-GT (%error = 1.99). Relatively high inter- and intra-observer error values of the measurements reported in the above studies (besides GT-FC and FHD) may indicate difficulties in a precise assessment of some landmarks on the femur and in their reproducibility. The results of the discriminant function and inter- and intra- observer error suggest that a more efficient approach in estimating sex could be one measurement as oppose to applying multiple measurements with more complicated formulae.

The results of the stepwise discriminant function did not support the results of Purkait (2004) and Albanese et al. (2008), whose measurements did not meet the criteria in the stepwise discriminant function when applied to the Polish population. Though, the six measurements (AB, AC, BC, GT-LT, LT-FC, GT-FC) were not included in the deriving functions for the sex estimation. The single measurement FHD used in the discriminant function reached high accuracy of the sex estimation (83.0–92.3%).

In Poland, there is no reference collection that would allow for deriving methods based on known sex. Regarding the historical osteological materials, information on the biological profile of the individuals is usually unknown and the only source of substantial data is a skeleton. Therefore, the sex needs to be estimated using morphological and morphometrical methods. There are no studies on the accuracy of the sex estimation methods based on the morphology of the pelvis regarding historical Polish populations. However, the accuracy of those methods was estimated at 94.5–95.7% (Klales et al. 2012; Inskip et al. 2019).

Deriving the discriminant function based on the measurements of individuals whose sex was estimated using anthropological methods is prone to error. However, this approach is not new and skeletons with unknown sex were used e.g., for the creation of the first sex discrimination function for the Iron Age population from Iran, using dental measurements (Kazzazi and Kranioti 2018) or for calculating formula for late antique East Adriatic coast population (Jerković et al. 2016). The need for metric methods for sex estimation is strong. However, the above-mentioned limitations regarding archaeological material, are often inherent.

When the standard morphologic methods for sex estimation are not available due to the poor preservation of the material (absent or damaged pelvis and skull) and the head of the femur is well preserved, the use of presented equations is recommended for both medieval and early-modern Polish populations.

The methodological approach applied in this study requires further discussion. Some authors recommend using logistic regression over a discriminant function when formulating sex estimating equations, pointing out to the continuity of sex dimorphic features and fewer required assumptions of logistic regression (Bartholdy et al. 2020). Although the overlapping variability of female and male features when investigating data from historical populations, a dichotomic approach for sex assessment, with clearly defined cut-off points, could still be preferred. Considering the popularity of this procedure, the discriminant function was utilized in this study. We provide raw data as supplementary materials for further examinations with different statistical analyses (Tab. S2).

Conclusion

To conclude, our results imply the utility of the calculated discriminant function in estimating sex in medieval and early-modern Polish populations. Nevertheless, in order to prove the applicability of the derived discriminant function across the population, a replication of this study, using samples of individuals from other Polish sites and different historical periods, is needed. In addition, moderately high inter- and intra-observer errors pose difficulties regarding the repeatability of some of the applied measurements (AB, AC, BC, LT-GT, FC-LT). It is worth noting that the FHD measurement (not regarding the side) have been found to be the easiest to reproduce and the most accurate in estimating sex.

Conflict of interest

The authors declare no conflict of interest associated with this study. There was no financial support for this study.

Authors' contributions

JW designed the study, formulated the hypothesis, collected the data, conducted the statistical analysis, and wrote the first draft of the manuscript. AC collected the data and supervise the study, DD conducted the statistical analysis. All authors edited the final version of the text.

Corresponding author

Joanna Wysocka, Department of Anthropology, Hirszfeld Institute of Immunology and Experimental Therapy, Polish Academy of Sciences; Weigla 12, 53-114 Wrocław, Poland; e-mail: joanna.wysocka@hirszfeld.pl

References

Albanese J. 2013. A method for estimating sex using the clavicle, humerus, radius, and ulna. J Forensic Sci 58(6):1414–1419. https://doi.org/10.1111/1556-4029.12188

Albanese J, Eklics G, Tuck A. 2008. A Metric Method for Sex Determination Using the Proximal Femur and Fragmentary Hipbone. J Forensic Sci 53(6):1283–1288. https://doi.org/10.1111/j.1556-4029.2008.00855.x

Anastopoulou I, Eliopoulos C, Valakos ED, Manolis SK. 2014. Application of Purkait's triangle method on a skeletal population from southern Europe. Forensic Sci Int 245:203.e1–203.e4. https://doi.org/10.1016/j.forsciint.2014.10.005

Auerbach BM, Ruff CB. 2006. Limb bone bilateral asymmetry: variability and commonality among modern humans. J Hum Evol 50:203–218. https://doi.org/10.1016/j.jhevol.2005.09.004

Bartholdy BP, Sandoval E, Hoogland ML, Schrader SA. 2020. Getting rid of dichotomous sex estimations: Why logistic regression should be preferred over discriminant function analysis. J. Forensic Sci 65(5):1685–1691. https://doi.org/10.1111/1556-4029.14482

Bidmos MA, Adebesin AA, Mazengenya P, Olateju OI, Adegboye O. 2021. Estimation of sex from metatarsals using discriminant function and logistic regression analyses. Aust J Forensic Sci 53(5):543–556.

Bidmos MA, Mazengenya P. 2021. Accuracies of discriminant function equations for sex estimation using long bones of upper extremities. Int J Legal Med 135(3):1095–1102.

Brickley M. 2004. Determination of sex from archaeological skeletal material and assessment of Partutition. In: Brickley M, McKinley JI, editors. Guidelines to the standards for recording human remains. IFA paper. UK: Southampton and Reading, 7:22–25.

Brůžek J. 2002. A method for visual determination of sex, using the human hip bone. Am J Phys Anthropol 117(2):157–168.

Buikstra JE, Ubelaker DH. 1994. Standards for data collection from human skeletal remains. Arkansas Archeological Survey: Fayetteville.

Byers SN. 2016. Introduction to forensic anthropology. Routledge

Case DT, Ross AH. 2007. Sex determination from hand and foot bone lengths. J. Forensic Sci 52(2):264–270. https://doi.org/10.1111/j.1556-4029.2006.00365.x

Christensen MA, Passalacqua VN, Bartelink JE. 2015. Forensic anthropology current methods and practice. Elsevier.

Colman KL, Janssen MCL, Stull KE, Van Rijn RR, Oostra RJ, Boer HH, Van Der Merwe AE. 2018. Dutch population specific sex estimation formulae using the proximal femur. Forensic Sci Int 286:268.e1-268.e8. https://doi.org/10.1016/j.forsciint.2017.12.029

Dimichele DL, Spradley MK. 2012. Sex estimation in a modern American osteological sample using a discriminant function analysis from the calcaneus. Forensic Sci Int 221(1–3):152.e1-152.e5. https://doi.org/10.1016/j.forsciint.2012.03.026

Djorojević M, Roldán C, Botella M, Alemán I. 2019. Sex assessment from the proximal femur in a Spanish population based on three-dimensional computed tomography metric analysis. Vojnosanit Pregl 76(12):1245–1252.

Djorojević M, Roldán C, Botella M, Alemán I. 2015. Estimation of Purkait's triangle method and alternative models for sex assessment from the proximal femur in the Spanish population. Int J Legal Med 130(1):245–251. https://doi.org/10.1007/s00414-015-1201-7

Inskip S, Scheib CL, Wohns AW, Ge X, Kivisild T, Robb J. 2019. Evaluating macroscopic sex estimation methods using genetically sexed archaeological material: The medieval skeletal collection from St John's Divinity School, Cambridge. Am J Phys Anthropol 168(2):340–351. https://doi.org/10.1002/ajpa.23753

İşcan MY. 2005. Forensic anthropology of sex and body size. Forensic Sci Int 147(2–3):107–112. https://doi.org/10.1016/j.forsciint.2004.09.069

Jerković I, Bašić Ž, Kružić I, Anđelinović Š. 2016. Sex determination from femora in late antique sample from Eastern Adriatic coast (Salona necropolis). Anthropol Rev 79(1):59–67. https://doi.org/10.1515/anre-2016-0005

Kazzazi SM, Kranioti EF. 2018. Sex estimation using cervical dental measurements in an archaeological population from Iran. Archaeol Anthropol Sci 10(2):439–448. https://doi.org/10.1007/s12520-016-0363-7

Kiarszysz G, Kolenda J. 2017. Wczesnośredniowieczne Grodziska w Krajobrazie Doliny Baryczy. Przyczynek do Studiów nad Przemianami Osadniczymi. Śląskie Sprawozdania Archeologiczne 59:93–126. https://doi.org10.23734/ssa.2017.59.93.126

Kim D, Kwak D, Han S. 2013. Sex determination using discriminant analysis of the medial and lateral condyles of the femur in Koreans. Forensic Sci Int 233(1–3):121–125. https://doi.org/10.1016/j.forsciint.2013.08.028

Klales AR, Ousley SD, Vollner JM. 2012. A Revised Method of Sexing the Human Innominate Using Phenice' s Nonmetric Traits and Statistical Methods. Am J Phys Anthropol 149(1):104–14. https://doi.org/10.1002/ajpa.22102

Krishan K, Chatterjee PM, Kanchan T, Kaur S, Baryah N, Singh RK. 2016. A review of sex estimation techniques during examination of skeletal remains in forensic anthropology casework. Forensic Sci Int 261,165-e1.

Kubicka AM, Piontek J. 2016. Sex estimation from measurements of the first rib in a contemporary Polish population. Int J Legal Med 130(1):265–272. https://doi.org/10.1007/s00414-015-1247-6

Łubocka Z, Gronkiewicz S. 2015. Analiza zmian patologicznych i wybranych czynników stresów oraz izotopów stabilnych w materiale osteologicznym z wczesnonowożytnego cmentarza Salwatora we Wrocławiu Aneks. Wratislavia Antiqua 21:143–162.

Macaluso PJ. 2010. The efficacy of sternal measurements for sex estimation in South African blacks. Forensic Sci Int 202(1–3):111. https://doi.org/10.1016/j.forsciint.2010.07.019

Macaluso PJ, Rico A, Santos M, Lucena J. 2012. Osteometric sex discrimination from the sternal extremity of the fourth rib in a recent forensic sample from Southwestern Spain. Forensic Sci Int 223(1–3). https://doi.org/10.1016/j.forsciint.2012.09.007

Mall G, Graw M, Gehring KD, Hubig M. 2000. Determination of sex from femora. Forensic Sci Int 113(1–3):315–321. https://doi.org/10.1016/S0379-0738(00)00240-1

Phenice TW. 1969. A newly developed visual method of sexing the os pubis. Am J Phys Anthropol 30(2):297–301. https://doi.org/10.1002/ajpa.1330300214

Plochocki JH. 2004. Bilateral Variation in limb articular surface dimensions. Am J Hum Biol 16:328–333. https://doi.org/10.1002/ajhb.20023

Purkait R. 2005. Triangle identified at the proximal end of femur: a new sex determinant. Forensic Sci Int 147(2–3):135–139. https://doi.org/10.1016/j.forsciint.2004.08.005

Ricklan DE, Tobias PV. 1986. Unusually low sexual dimorphism of endocranial capacity in a Zulu cranial series. Am J Phys Anthropol 71:285–293. https://doi.org/10.1002/ajpa.1330710304

Sawicki J. 2015. Kultura materialna w świetle znalezisk z grobów na cmentarzu Salwatora we Wrocławiu. Wratislavia Antiqua 21:59–137.

Šlaus M, Strinovic D, Skavic J, Petrovecki V. 2003. Discriminant function sexing of fragmentary and complete femora: standards for contemporary Croatia. J. Forensic Sci 48(3):509–512.

Tomaszewska IM, Frączek P, Gomulska M, Pliczko M, Śliwińska A, Sałapa K, Chrzan R, Kowalski P, Nowakowski M, Walocha JA. 2014. Sex determination based on the analysis of a contemporary Polish population's palatine bones: a computed tomography study of 1,200 patients. Folia morphol 73(4):462–468. https://doi.org/10.5603/FM.2014.0069

Tomczyk J, Nieczuja-Dwojacka J, Zalewska M, Niemiro W, Olczyk W. 2017. Sex estimation of upper long bones by selected measurements in a Radom (Poland) population from the 18th and 19th centuries AD. Anthropol Rev 80(3):287–300. https://doi.org/10.1515/anre-2017-0019

Torimitsu S, Makino Y, Saitoh H, Sakuma A, Ishii N, Yajima D, Inokuchi G, Motomura A, Chiba F, Yamaguchi R, Hashimoto M, Hoshioka Y, Iwase H. 2016. Sex estimation based on scapula analysis in a Japanese population using multidetector computed tomography. Forensic Sci Int 262(285):285.e1–285.e5. https://doi.org/10.1016/j.forsciint.2016.02.023

Ubelaker DH, DeGaglia CM. 2017. Population variation in skeletal sexual dimorphism. Forensic Sci Int 278:407.e1–407.e7. https://doi.org/10.1016/j.forsciint.2017.06.012

Ulijaszek SJ, Kerr DA. 1999. Anthropometric measurement error and the assessment of nutritional status. Br J Nutr 82(3):165–177. https://doi.org/10.1017/s0007114599001348

Wachowski K. 1969. Wczesnośredniowieczne cmentarzysko szkieletowe w Miliczu. Silesia Antiqua 11:199–223.

Wachowski K. 1970. Wczesnośredniowieczne cmentarzysko szkieletowe w Miliczu cz. II. Silesia Antiqua 12:123–195.

Walker PL. 2005. Greater sciatic notch morphology: sex, age, and population differences. Am J Phys Anthropol 127(4):385–391.

Wojtucki D. 2015. Cmentarz i kościół Salwatora we Wrocławiu w świetle źródeł pisanych. Wratislavia Antiqua 21:11–18.

Anthropological Review • Vol. 86(1), 51–66 (2023)

ANTHROPOLOGICAL REVIEW

Available online at: https://doi.org/10.18778/1898-6773.86.1.05

Sarcopenia: prevalence and its main risk factors in older women

Aleksandra Bogucka[1], *Anna Kopiczko*[1], *Jadwiga Charzewska*[2]

[1] Department of Human Biology, Faculty of Physical Education, Józef Piłsudski University of Physical Education in Warsaw, Poland

[2] Department of Nutrition and Nutritive Value of Foods, National Institute of Public Health NIH – National Research Institute Warsaw, Poland

Abstract: *Introduction:* Sarcopenia is a major public health concern. It is defined as a progressive and generalized skeletal muscle disorder that is associated with an increased likelihood of falls, fractures, physical disability, and ultimately, premature death.

Objective: The aim of the study was to assess the prevalence and determine the role of physical activity, nutrient intake, and selected risk factors for the development of sarcopenia in older women.

Methods: The study involved 302 women aged ≥65 years (mean age: 72.1± 5.9 years). Bioelectrical impedance analysis of body composition, static muscle strength measurements, Timed Up and Go test, and the assessment of current physical activity using accelerometers were performed. Diets were assessed using the 24-h recall method from two non-consecutive days. The energy and nutrient content of diets was calculated using the computer program DIETA 6.

Results: Sarcopenia was present in 28.8% of the women studied. The most important factor in the decrease in the risk of sarcopenia was protein intake ≥ 0.9 g/kg b.m. (OR=0.08;p<0.001), and physical activity ≥ 4000 steps/day. However, these results were not statistically significant (OR=0.58; p=0.08). Furthermore, the risk of developing sarcopenia increased as BMI (OR=1.36; p<0.001) or percent of body fat (OR=1.29; p<0.001) increased.

Discussion: Implementing sarcopenia risk prevention programs should be a priority in preventing this condition.

Key words: sarcopenia, muscle disease, muscle failure, protein intake, physical activity, body mass index, body fat.

Original article

Received: 8.12.2022; Revised: 28.02.2023; Accepted: 6.03.2023

Introduction

Sarcopenia is a major public health concern. In 1988, Irwin Rosenberg proposed that the term sarcopenia be used to describe the major changes in body composition and function associated with aging. It is defined as a progressive and generalized skeletal muscle disorder that is associated with an increased likelihood of falls, fractures, physical disability, and ultimately, death (Cruz-Jentoft et al. 2019; Chen et al. 2020). It is characterized by progressive muscle failure (Zanker et al. 2019), increased risk of falls and fractures (Schaap et al. 2018; Yeung et al. 2019), and worse functional capacity in older adults (Malmstrom et al. 2016). Ultimately, it leads to reduced quality and length of life (Anker, Morley and von Haehing 2016; Beaudart et al. 2017; Tanaka et al. 2021).

The term sarcopenia is primarily defined as a low level of muscle mass. However, its definition is often broadened to include the underlying cellular processes involved in skeletal muscle loss as well as their clinical manifestations. In terms of the clinical aspect, sarcopenia is often used to describe both a set of cellular processes (denervation, mitochondrial dysfunction, inflammatory and hormonal changes) and a set of outcomes, such as decreased muscle strength, decreased mobility and function, increased fatigue, increased risk of metabolic disorders, and increased risk of falls and skeletal fractures (Lang et al. 2010).

Numerous studies have shown that sarcopenia is a strong determinant in the development of many other diseases, such as metabolic syndrome, cardiovascular disease, and osteoporosis (Karakelides and Nair 2005; Miyakoshin et al. 2013; Pacifico et al. 2020). For several years, sarcopenia has been recognized as a muscle disease and is numbered in the ICD-10-MC international classification of diseases (Anker, Morley and von Haehing 2016; Cruz-Jentoft et al. 2019).

Sarcopenia is known to be more prevalent in older populations. However, the decline in muscle mass starts from 40 years old. In addition to older-aged adults, underweight people, women, and people with other chronic conditions are more likely to develop sarcopenia and adverse health outcomes associated with this disease. Research has shown that the prevalence of sarcopenia is significantly higher in females than in males (Petermann-Rocha et al. 2022).

Comparability of data on the prevalence of sarcopenia worldwide is ensured by a widely accepted definition, designated cut-off points, and consensus guidelines for the population (Cruz-Jentoft et al. 2019; Chen et al. 2020). It is estimated that the problem of sarcopenia may affect several to tens of percent of the world's older adult population (Cruz-Jentoft et al. 2019).

A meta-analysis of two international studies, Collaborative Research on Aging in Europe and the SAGE study of the World Health Organization, showed that among 18,363 people over 65 years of age, on average, sarcopenia was diagnosed in 15.2% of participants (Tyrovolas et al. 2016). The highest prevalence of sarcopenia in that study was in India (17.7%) and the lowest was in Poland (12.6%) (Tyrovolas et al. 2016).

A study of 542 randomly selected Singaporeans over 60 years of age showed that sarcopenia was present in 32.2% of participants, with 33.7% of men and 30.9% of women (Pang et al. 2021). In China, the prevalence of sarcopenia in people over 50 years of age is 19.31%

(Liu et al. 2020). Furthermore, in South Korea, the prevalence of this problem in a group of 82,221 individuals over 50 years of age was estimated to be 21.5% (Cho et al. 2020).

A recent systematic review and meta-analysis performed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) analyzed studies published between 2019 and 2020. The review included 207 cross-sectional studies and 53 cohort studies, with 3 using both designs. The overall prevalence of sarcopenia ranged from 0.2% to 86.5% according to the classification used (0.3–91.2% in women and 0.4–87.7% in men). Severe sarcopenia was estimated only in 34 studies, with prevalence ranging from 0.2% to 45.0% in women and from 0.2% to 17.1% in men (overall prevalence range: 0.2–34.4%) (Petermann-Rocha et al. 2022).

A meta-analysis conducted by Pacifico et al. (2020) showed an increased prevalence of sarcopenia among men and women diagnosed with various chronic diseases. Among 17,206 participants aged 65±1.6 years, the prevalence of sarcopenia was 31.4% in those with cardiovascular diseases, 26.4% with dementia, 31.1% with diabetes, and 26.8% with respiratory diseases. The meta-analysis showed highly prevalent sarcopenia in individuals with multiple system diseases (Pacifico et al. 2020). Basing on the prospective cohort study of medical inpatients, not only diseases related to malnutrition but especially sarcopenia was associated with poor quality of life, more readmissions, and higher mortality (Ballesteros-Pomar et al. 2021).

The different prevalence of sarcopenia in the world may be due to the different severity of the main risk factors involved in the development of this condition, such as general physical fitness, the level of habitual daily physical activity, different diets, and different population-specific factors. The factors that contribute to the development of sarcopenia in older populations are chronic inflammation, motoneuron atrophy, reduced protein intake, and immobility (Malafarina et al. 2012). Adequate protein intake is important for maintaining muscle mass during aging, although the amount and source of protein necessary for optimal prevention of sarcopenia remains to be determined. One study showed that increasing the proportion of plant-derived at the expense of animal-derived proteins in diet is beneficially linked to lower sarcopenia risk in a cross-cultural sample of older European adults (Montiel-Rojas et al. 2020).

Previous studies suggested that protein synthesis and degradation, autophagy, impaired satellite cell activation, mitochondrial dysfunction, and other factors associated with muscle weakness and muscle degeneration may be potential molecular pathophysiology of sarcopenia. Dietary strategies and exercise represent the interventions that can also alleviate the progression of sarcopenia (Rong et al. 2020).

An adequate level of knowledge about sarcopenia among adults living in society is very important for the effective prevention and treatment of sarcopenia. Unfortunately, as research indicates (Van Ancum et al. 2020), knowledge about sarcopenia is limited and strategies are needed to increase health education among adults about this problem.

The aim of the present study was to evaluate the prevalence of sarcopenia in women and to analyze the role of selected lifestyle risk factors for its development.

The level of physical activity, intake of selected nutrients, body nutritional status, and total body fat were analyzed.

Material and methods

Material

This cross-sectional study involved 302 randomly selected women aged ≥65 years (average age 72.1± 5.9 years) from the Electronic System for Registration of the Population of City Councils living in towns with about 10.000 inhabitants in the eastern part of Poland. The sample size was calculated using the formula proposed by Lwanga (Lwanga et al. 1991). The study was conducted in the summer and early fall of 2018. The response rate was 40.6%. The exclusion criteria were hormone replacement therapy, contraindications to bioelectrical impedance body composition measurement, severe physical or intellectual disabilities, and diseases affecting muscle tissue metabolism such as cancer, anorexia, rheumatoid arthritis, and osteoporosis (Jochum et al. 2019; Tsutsumimoto et al. 2020).

Methods

The face-to-face interview was used to collect data on metric age, age at menopause, level of education, type of past work, and others. Basic body measurements (body height and mass, waist circumference, hip circumference) were performed using standard anthropometric methods (Lohman, Roche and Martorell 1988; Hall et al. 2007). Body height was measured using the GPM anthropometer (Siber Hegner, Zurich, Switzerland) in anthropometric landmarks with a measurement accuracy of 0.1 cm. Waist circumference and hip circumference were measured using the Holtain anthropometric tape (Crymych, UK) with a measurement accuracy of 0.1 cm. All measurements were performed by one person with appropriate qualifications and extensive experience in anthropometric measurements in optimal climatic conditions. The mean of two measurements was used in the analyses. Protein-energy nutritional status disorders were assessed based on body mass index (BMI) whereas the type of body fat was identified based on the waist-to-hip ratio (WHR) using the classification recommended by WHO (WHO 2008). Bioelectrical impedance analysis (BIA) using the Tanita BC-418 four-leg body composition analyzer was used to measure percentage body fat (PBF), lean body mass (LBM), and total body water (TBW).

Methods to assess sarcopenia

Sarcopenia was diagnosed according to the accepted methodology recommended by the European Working Group on Sarcopenia in Older People (EWGSOP) (Cruz-Jentoft et al. 2010) and EWGSOP2 in 2018 (Cruz-Jentoft et al. 2019). However, in a recent publication, more attention has been paid to the assessment of muscle strength as a measure enabling a quick diagnosis (Cruz-Jentoft et al. 2019). Muscle mass was assessed using bioelectrical impedance analysis (BIA) on the Tanita BC-418 four-leg body composition analyzer. Total skeletal muscle mass (SMM) was calculated according to the methodology proposed by Kim et al. (2002). Muscle mass for the diagnosis of sarcopenia was assessed based on the skeletal muscle index (SMI) recommended for the European population (Cruz-Jentoft et al. 2010). An SMI value <28.94% calculated for the Polish population was used as the cut-off point (Krzymińska-Siemaszko 2014).

Assessment of static muscle strength

Static muscle force was measured using the Jamar® Hydraulic Hand dynamometer (Warrenville, IL, USA). The hand grip force of both hands was measured alternately and twice. The mean of the two measurements was used in the assessment of muscle strength. The criteria for assessment of muscle strength were adopted according to the EWSGOP recommendations for women relative to BMI (Cruz-Jentoft et al. 2010).

Assessment of physical fitness and the level of physical activity

Physical fitness was assessed using the standardized Timed Up and Go test. The time of ≥14 s recommended by EWGSOP was used as a cut-off point (Shumway-Cook, Brauer and Woollacotta 2000) for low fitness and risk of sarcopenia. Criteria for the diagnosis of sarcopenia were adopted as recommended by EWGSOP (Cruz-Jentoft et al. 2010). The current level of physical activity was measured over 48 h (2x24h) using the Tanita AM-180 three-axis accelerometer. European Union guidelines for older adults (2008) were used to assess the level of physical activity (high physical activity: >4,000 steps a day, moderate physical activity: 3,500–3,999 steps a day, low physical activity: 2,500–3,499 steps a day, very low physical activity: <2,500 steps a day.

Dietary Assessment

Face-to-face 24-hour dietary recalls for two non-consecutive days preceding the interview were administered in the study. The album of Photographs of Food Products and Dishes (2018/2019) was used to estimate the portion sizes of products and foods consumed. The energy and nutrient content of the women's diets was calculated using the computer program DIETA 6.0. Protein intake, expressed in g/day and g/kg body mass/day, and vitamin D intake in μg/day were included in the analyses. Consumption of proteins was categorized as low <0.73 g/kg/body mass, medium 0.73–0.89 g/kg/body mass, and high ≥0.9 g/kg body mass. Energy consumed from protein was categorized as <15% E, 15%–20% E, and >20% E. In the case of vitamin D, the categorization was: <1.5 μg/day, 1.5–2.2 μg/day, and ≥2.2 μg/day.

Statistical Methods

Statistical analysis was performed using the STATISTICA 13.0 software. The normality of distribution was assessed using the Shapiro-Wilk test. Multivariate logistic regression models were used to identify the determinants of sarcopenia in women. Wald's chi2 was calculated. Odds ratio (OR) with 95% confidence interval (CI) was calculated for independent variables (Hosmer and Lemeshow 1989). The level of statistical significance was set at $^{*}p \le 0.05$, $^{**}p \le 0.01$, and $^{***}p \le 0.001$.

Ethical Considerations

The study was carried out in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans. The project received a positive opinion from the Senate Ethics Committee for Scientific Research of the Józef Piłsudski University of Physical Education in Warsaw (protocol No. SKE 01-14/2017). All study participants gave their informed consent to participate in a research project and were informed about the protocol and test methods.

Results

Selected characteristics of the women studied are shown in Table 1. The mean age of the women was 72.1± 5.9 years, with ages ranging from 65 to 87 years. In general, women had a high mean BMI, indicating excessive body mass (83.4% were overweight or obese). One in two women was obese (49.7%). Based on the WHR index, central body fatness was found in 96.7%. The average intake was 0.75 g/kg/body mass/day for protein and 1.8 μg/day for vitamin D, which can be considered as low (Table 1).

Table 1. Baseline selected characteristics of the studied women

Variables	Females (n=302)
	Mean ± SD
Age [years]	72.1±5.9
Body height [cm]	157.1±5.9
Body mass [kg]	73.9±13.4
BMI [kg/m^2]	30.0±5.3
Waist Circumference [cm]	102.7±13.0
Hip Circumference [cm]	109.0±10.0
WHR	0.94±0.07
PBF [%]	39.3±8.1
LBM [kg]	44.2±5.6
TBW [kg/m2]	33.2±3.9
Total protein intake [g/day]	54.1±14.2
Protein intake [g/kg bm/day]	0.75±0.2
Vitamin D [**µg/da**y]	1.8±1.9
Number of steps/day	4416.1±2618
	Percent
BMI <24.99 [kg/m^2]	16.5
BMI 25.0-29.9 [kg/m^2]	33.8
BMI ≥ 30 [kg/m^2]	49.7
WHR ≥0.8	96.7

BMI – body mass index; WHR – waist-to-hip ratio; PBF – percentage body fat; LBM – lean body mass; TBW – total body water.

Table 2 shows that the incidence of sarcopenia of all types (I, II, and III) was present in 28.8% of all women studied. The state of pre-sarcopenia, characterized by a low muscle mass based on SMI, was found in more than 13% of women, while the severe state, manifested by fulfilling three criteria, i.e., low muscle mass, low muscle strength, and impaired physical fitness, was reported in 4.3% of women (Table 2).

Table 2. The incidence rate of sarcopenia in agreement with diagnostic criteria recommended by EWGSOP (Cruz-Jentoft et al. 2010, 2018) *

Diagnostic criteria	Grades of sarcopenia	Females (n=302)	
		n	%
Low muscle mass (SMI < 28.94%)	Pre-sarcopenia I^0	41	13.6
Low muscle mass (SMI < 28.94%) + low muscle strength (17kg to 21 kg) or low physical fitness (> 14 s)	Sarcopenia II^0	33	10.9
Low muscle mass (SMI < 28.94%) + low muscle strength (17kg to 21 kg) + low physical fitness (> 14 s)	Severe sarcopenia III^0	13	4.3
Sarcopenia I^{o}II^o III^o		87	28.8

*with using the cut-off point for the SMI for the Polish female population (Krzymińska--Siemaszko 2014)

Logistic regression analysis (see Table 3) revealed the most important factors affecting sarcopenia in the group studied. Of the variables analyzed, the most importan factor affecting sarcopenia was high protein intake per kilogram of body mass per day, which significantly reduced the risk of developing sarcopenia by 60%

and 92 %. For intake levels ranging from 0.73 g/kg body mass/day to 0.89 g/kg body mass/day, the odds ratio was OR=0.40 (p=0.003). However, at an intake of ≥0.9 g/body mass/day, the ratio was OR=0.08 (p<0.001). In the case of physical activity (PA), this effect was not significant, but a trend for the decreasing risk of developing sarcopenia with an increase in the level of physical activity was found: OR=0.71 for low-level PA, OR=0.45 for moderate PA, and OR=0,58; p = 0.08 for high levels of PA (≥ 4000 steps/day in our study) (Table 3).

Table 3. Odds ratios (ORs) and 95% confidence interval (95%CI) of sarcopenia by the physical activity, protein, vitamin D intake and the other selected variables

Variable		OR (95%CI)	Wald chi-square	p
Physical activity (PA)	Very low PA (<2500 steps per day)	1	4.22	
	Low PA (2500-3499 steps per day)	0.71 (0.34 – 1.52)	0.77	0.38
	Moderate PA (3500-3999 steps per day)	0.45 (0.13– 1.51)	1.69	0.19
	High PA (≥4000 steps per day)	0.58 (0.31 – 1.07)	3.00	0.08
Intake of total protein (g/day)	< 50g/day	1	20.70	
	50-64 g/day	0.97 (0.55– 1.71)	0.01	0.92
	≥64g/day	0.97 (0.49– 1.90)	0.01	0.93
Intake of protein (g/kg body mass/day)	(< 0.73g/kg bm)	1	3.71	
	(0.73-0.89 g/kg bm)	0.40 (0.21 – 0.74)	8.65	0.003
	(≥0.9 g/kg bm)	0.08 (0.03– 0.24)	20.58	<0.001
Percentage of energy from protein	< 15%	1	13.73	
	15-20%	0.74 (0.43 – 1.26)	1.23	0.26
	>20%	0.79 (0.35 – 1.75)	0.34	0.56
Vitamin D	<1.5 μg/day	1	28.45	
	1.5-2.2 μg/day	1.20 (0.64– 2.23)	0.33	0.56
	≥2.2 μg/day	0.90 (0.48 – 1.68)	0.11	0.74
Age	65-70 years	1	30.00	
	71-75 years	1.65 (0.90– 3.02)	2.67	0.10
	≥76 years	0.99 (0.54 – 1.85)	0.00	0.99

Table 3 (cont.)

Variable		OR (95%CI)	Wald chi-square	p
Education level	Higher/secondary	1	36.31	
	primary	1.14 (0.63 – 2.06)	0.20	0.65
	vocational	1.69 (0.85 – 3.37)	2.24	0.13
Type of work performed in the past	50% sedentary work, 50% standing or moving work	1	18.64	
	>80% sedentary work	0.96 (0.49 – 1.91)	0.008	0.92
	>80% of standing or moving work	1.49 (0.81 – 2.75)	1.64	0.20
Number of births	0	1	4.19	
	1-2	1.03 (0.37 – 2.87)	0.005	0.94
	3-4	1.03 (0.37 – 2.86)	0.003	0.95
	>4	1.52 (0.46 – 4.96)	0.49	0.48
Age of menopause	< 50 years	1	15.0	
	50-55 years	0.98 (0.57 – 1.70)	0.001	0.96
	>55 years	0.70 (0.23 – 2.10)	0.40	0.52

Complementary factors significantly increasing the risk of sarcopenia were BMI and body fat, expressed as % of body weight. A one-unit increase in BMI was associated with the risk of sarcopenia by 36% (OR=1.36; p<0.001). A similar tendency was found for the increase in body fat by 1%. An increase in this variable led to an increase in the prevalence of sarcopenia by 29% (OR=1.29; p<0.001) (Table 4).

Table 4. Odds ratios (ORs) and 95% confidence interval (95%CI) of sarcopenia by the BMI and total fat expressed as % of body mass

Variable	OR (95%CI)	Wald chi-square	p
BMI	1.36 (1.25-1.48)	51.37	<0.001
FAT [%]	1.29 (1.21-1.40)	52.38	<0.001

Discussion

A female group was chosen for the analysis of the sarcopenia because the latter is more commonly diagnosed among women compared to men (Wang et al. 2015; Bianchi et al. 2016; Dodds et al. 2016; Fozouni, Shafiee et al. 2017; Wang and Lai 2019; Kitamura et al. 2020). Differences in the prevalence of sarcopenia between men and women are influenced by hormonal changes that promote the loss of muscle mass with age (Juul and Skakkebeal 2002), serum homocysteine and C-reactive protein (hsCRP) levels (Lee et al. 2020), as well as the fact that women in all countries live longer than men. Differences in life expectancy between females and males in 2019 were 7.9 years in Poland, 6.2 years in Japan, and 3.8 years in Switzerland (Human Development Rep. 2019).

It is also well established that adequate protein intake and high levels of physical activity are required to maintain muscle mass and strength in older adults (Chen et al. 2004; Nilsson et al. 2018; Perna et al. 2020; Montiel-Rojas et al. 2020). This conclusion has been confirmed by several studies (Houston et al. 2017; Nilsson et al. 2018; Montiel-Rojas et al. 2020), including a study of 302 Polish women presented in this paper, where the protective and significant role of dietary protein content was also demonstrated. Protein intake of ≥ 0.9g protein/kg body mass /day significantly reduced the risk of developing sarcopenia by 92% (OR=0.08; $p<0.001$). The intake of at least 0.73–0.89g protein/kg BM/day also reduced the risk of developing sarcopenia by 60% (OR=0.40; $p<0.001$). The threshold value of protein intake in the present study that protected against the risk of developing sarcopenia was 0.73 g/kg BM/day or more, i.e. above the Estimated Average Requirement of Polish Dietary Reference Intakes (DRI). Dorhout et al. (2020) also showed that higher protein intake among older adults in Southern Suriname was associated with a lower risk of sarcopenia (OR=0.96, $p<0.001$). Similarly, the results of Papadopoulou (2020) showed an important role of protein in the prevention of sarcopenia as protein intake significantly correlated with reduced muscle strength and thus was associated with an increased incidence of sarcopenia.

The Health ABC study (Houston et al. 2017) conducted among 2,101 individuals with a mean age of 74.5 years found that the risk of sarcopenia in individuals with low protein intake (<0.7g/kg BM/day or 0.7 to <1.0g/kg BM/day) was higher by 3.25 times and 1.78 times, respectively, compared with those consuming ≥1.0 g protein/kg BM/day.

Research by Montiel-Rojsa, et al. 2020, conducted among 986 older Europeans (Italy, Poland, the Netherlands, and the United Kingdom) found that similar to what was observed in our study, protein intake was critical to the prevention of sarcopenia. The participants who consumed ≥1.2 g protein/kg BM/day had the lowest incidence of sarcopenia (Montiel-Rojas et al. 2020).

Polish Dietary Reference Intakes recommend that older adults should consume 0.90 g/kg BM/day protein at the Recommended Dietary Allowances level and that in people aged ≥ 65 years, protein should provide at least 15% to 20% of energy, which, at an average of 18% of energy from protein, corresponds to an intake of about 1.2 g/kg BM/day (Jarosz et al. 2020). In contrast, in individuals with already diagnosed sarcopenia, an increased protein intake of 1 to 1.5 g of protein per kilogram of body mass per day combined with appropriately chosen physical exercise is recommended (Bauer et al. 2019). The results obtained in the present study confirm that the most important factors in the prevention and treatment of sarcopenia in older adults are optimal protein intake (Cruz-Jentoft et al. 2019; Hengeveld et al. 2020; Rondanelli et al. 2020; Rong et al. 2020).

Adequate levels of physical activity are also considered one of the key factors in counteracting the risk of developing sarcopenia (English and Paddon-Jones 2010; Dodds et al. 2016; Bauer et al. 2019; Cui et al. 2020; Kitamura et al. 2020; Marcos-Pardo et al. 2021).

The results of the research discussed in this paper show that a high level of physical activity of ≥4,000 steps/day reduced (although insignificantly) the risk of developing sarcopenia (OR=0.58; p=0.08). The lack of significance was probably due to the generally low average number of steps per day among the women tested (4416/day). Nevertheless, it is worth noting the clear but insignificant trend of reducing the risk of developing sarcopenia with the increase in the number of steps per day in women, which encourages continued research on the role of physical activity in the development of this disease.

Aggio et al. (2016) examined 1,286 men aged 70–92 years and demonstrated that each additional 30 min of daily moderate physical activity significantly reduced the risk of severe sarcopenia (OR=0.53; p<0.001) and sarcopenic obesity (OR=0.47; p<0.001). Furthermore, Marcos-Pardo et al. (2021) found that reduced physical activity due to sedentary lifestyles (>300 min/week) significantly reduced physical fitness and increased the risk of sarcopenia and pre-sarcopenia. Participants older than 65 years were more likely to develop sarcopenia as they showed lower levels of vigorous physical activity (VPA) (OR=0.48; p<0.02) compared to those from the younger age group (Marcos-Pardo et al. 2021). Maintaining adequate levels of appropriately selected physical activity promotes the development of age-appropriate muscle strength and mass (Aggio et al. 2016; Tyrovolas et al. 2016; Houston et al. 2017; Bauer et al. 2019; Cruz-Jentoft et al. 2019; Chen et al. 2020). The results of the analyses in this paper showed a trend that taking more than 4,000 steps per day reduced the risk of developing sarcopenia in older women by 42 % (OR=0.58; p=0.08).

In the study by Omelan et al. (2022) of 774 older residents (above 60 years of age) of rural and urban areas in north-eastern Poland, the level of physical activity of the study participants was at a sufficient level, but in the case of women, it depended on socio-economic characteristics. The authors pointed to the need of finding effective ways to support older adults in maintaining or increasing physical activity, with a particular emphasis on women (Omelan et al. 2022). A study of Polish women also showed that BMI was a strong determinant of developing sarcopenia. A one-unit increase in this index significantly increased the risk of developing sarcopenia by 36% (OR=1.36; p<0.001). Other researchers support these findings, e.g., in a study by Cui et al. (2020), the authors found that BMI in the frame of recommended reference (OR=0.365, 95% CI:0.236–0.661) significantly reduced the risk of developing sarcopenia among patients over 65 years of age diagnosed with type 2 diabetes. A study by Marcos-Pardo et al. (2021) also showed that a BMI less than 30kg/m^2 was a preventive factor for pre-sarcopenia but a nutritional status classified as obesity significantly increased the risk of developing sarcopenia by 65% (OR=1.65; p<0.01) or being overweight compared to reference body mass.

Conclusions

In conclusion, we found that sarcopenia of various degrees is frequent and occurrs in almost every third woman examined. Among the analyzed factors, four showed bi-directional associations with sarcopenia in older women, with optimal protein intake and physical activity measured by the number of steps per day decreased (not significantly), while high BMI indicating excessive body mass and a high percentage of body fat in the body tissue composition increased (significantly) the development of sarcopenia. All these risk factors add some knowledge to the assessment of the promoting role that they could play in the development of sarcopenia. All of these risks factors are fully modifiable and their modification should be a priority in prevention and education or therapeutic programs. Our study may have strong implications for dietary and physical activity recommendations for older women.

The strengths of this cross-sectional study include using standardized methods only, face-to-face interviews using validated questionnaires by highly-trained personnel (first author of the paper), and random selection of women from the studied region.

It should be emphasized that there are also some limitations of the study, such as the absence of participants who did not consent to participate due to the lack of mobility or dementia or other reasons, which represents an important limitation in the final assessment of the severity of sarcopenia in the population. It influenced the response rate, which was 40.6%.

Declaration of interest statement

The authors declare that they have no conflict of interest.

Acknowledgments

We would like to thank Bożena Wajszczyk, PhD, from the National Institute of Public Health NIH – National Research Institute, for her help with nutritional analysis and Mikołaj Rybaczuk, MSc, for his help with the analysis. We would also like to thank all participants in the study.

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Authors' contribution

A.B. conceptualization, methodology, investigation, all data collection, analysis, writing the manuscript, public relations; A.K. coordinated the project found administration, supervision, review and editing, public relations; J.C. supervision, visualization, review, and editing, revised the final version.

Funding

This work was supported by the Józef Piłsudski University of Physical Education in Warsaw, Poland under science project DM-62. Scientific work was financed by the Ministry of Science and Higher Education in 2020/2022 as part of the Scientific School of the University of Physical Education in Warsaw-SN No. 5 "Biomedical determinants of physical fitness and sports training in adult population".

Supplemental Material

Supplemental material for this article is available in corresponding author.

Corresponding author

Anna Kopiczko, Józef Piłsudski University of Physical Education in Warsaw, Faculty of Physical Education, Department of Human Biology, Section of Anthropology, 34 Marymoncka Street, 00-968 Warsaw, Poland; e-mail: anna.kopiczko@awf.edu.pl

References

Aggio DA, Sartini C, Papacosta O, Lennon LT, Ash S, Whincup PH, Wannamethee SG, Jefferis BJ. 2016. Cross-selection associations of objectively measured physical activity and sendentary time with sarcopenia and sarcopenic obesity in older men. Prev Med 91:264–272. https://doi.org/10.1016/j.ypmed.2016.08.040

Anker SD, Morley JE, von Haehing S. 2016. Welcome to the ICD-10 code for sarcopenia. J Cachexia Sarcopenia Muscle 7(5):512–514. https://doi.org/10.1002/jcsm.12147

Ballesteros-Pomar MD, Gajete-Martin LM, Pintor de la Maza B, Gonzalez-Arnaiz E, Gonzales-Roza L, Garcia-Perez MP, de Prado-Espinosa R, Cuevas MJ, Fernández-Perez E, Mostaza-Fernández JL, Cano-Rodríguez I. 2021. Disease- related malnutrition and sarcopenia predict worse outcome in medical impatients: A cohort study. Nutrients13(9):2937. https://doi.org/10.3390/nu13092937

Bauer J, Morley JE, Schols AMWJ, Ferrucci L, Cruz-Jentoft AJ, Dent E, Baracos VE, Crawford JA, Doehner W, Heymsfield SB, Jatoi A, Kalantar-Zadeh K, Lainscak M, Landi F, Laviano A, Mancuso M, Muscaritoli M, Prado CM, Strasser F, von Haehling S, Coats AJS, Anker SD. 2019. Sarcopenia; A time for action. An SCWD Position Paper. J Cachexia Sarcopenia Muscle 10(5):956–961. https://doi.org/10.1002/jcsm.12483

Beaudart C, Biver E, Reginster JY, Rizzoli R, Rolland Y, Bautmans I, Petermans J, Gillain S, Buckinx F, Dardenne N, Bruyère O. 2017. Validation of the SarQol, a specific health-related quality of lige questionnaire for Sarcopenia. J Cachexia Sarcopenia Muscle 8(2):238–244. https://doi.org/10.1002/jcsm.12149

Bianchi L, Ferrucci L, Cherubini A, Maggio M, Bandinelli S, Savino E, Brombo G, Zuliani G, Guralnik JM, Landi F, Volpato S. 2016. The predictive value of the EWGSOP definition of sarcopenia: results from the InCHIANTI study. J Gerentol A Biol Sci Med Sci 71(2):259–264. https://doi.org/10.1093/gerona/glv129

Chen TJH, Blum K, Payte JT, Schoolfield J, Hopper D, Stanford M, Braverman ER. 2004. Narcotic antagonists in drug dependence: Pilot study showing enhancement of compliance with SYN-10, amino-acid precursors and enkephalinase inhibition therapy. Med Hypotheses 63(3):538–548. https://doi.org/10.1016/j.mehy.2004.02.051

Chen LK, Woo J, Assantachi P, Auyeung TW, Chou MY, Iijima K, Jang HC, Kang L, Kim M, Kim S, Kojima T, Kuzuya M, Lee JSW, Lee SY, Lee WJ, Lee Y, Liang CK, Lim JY, Lim WS, Peng LN, Sugimoto K, Tanaka T, Won CW, Yamada M, Zhang T, Akishita M, Arai H. 2020. Asian Working Group for Sarcopenia: 2019 Consensus Update on sarcopenia diagnosis and treatment. J Am Med Dir Assoc 21(3):300–3007. https://doi.org/10.1016/j.jamda.2019.12.012

Cho YJ, Lim YH, Yun JM, Yoon H, Park M. 2020. Sex-and age- specific effects of energy intake and physical activity on sarcopenia. Sci Rep 10:9822. https://doi.org/10.1038/s41598-020-66249-6

Cruz-Jentoft AJ, Baeyens JP, Bauer JM, Boirie Y, Cederholm T, Landi F, Martin FC, Michel JP, Rolland Y, Schneider SM, Topinková E, Vandewoude M, Zamboni M. 2010. Sarcopenia: European consensus on definition and diagnosis: Report of the European Working Group on Sarcopenia in Older People. Age Ageing 39(4):412–423. https://doi.org/10.1093/ageing/afq034

Cruz-Jentoft AJ, Bahat G, Bauer J, Boirie Y, Bruyère O, Cederholm T, Cooper C, Landi F, Rolland Y, Sayer AA, Schneider SM, Sieber CC, Topinkova E, Vandewoude M, Visser M, Zamboni M; Writing Group for the European Working Group on Sarcopenia in Older People 2 (EWGSOP2), and the Extended Group for EWGSOP2. 2019. Sarcopenia: revised European consensus on definition and diagnosis. Age Ageing 48(1):16–31. https://doi.org/10.1093/ageing/afy169

Cui M, Gang X, Wang G, Xiao X, Li Z, Jiang Z, Wang G. 2020. A cross-sectional study. Associations between sarcopenia and clinical characteristics of patients with type 2 diabetes. Medicine (Baltimore) 99:2. https://doi.org/10.1097/MD.0000000000018708

Dodds RM, Granic A, Davies A, Kirkwood TBL, Jagger C, Sayer AA. 2017. Prevalence and incidence of sarcopenia in very old: findings from the Newcastle 85+Study. J Cachexia Sarcopenia Muscle 8:229–237. https://doi.org/10.1002/jcsm.12157

Dorhout BG, Overdevest E, Tieland M, Nicolaou M, Weijs PJM, Snijder MS. 2020. Sarcopenia and its relation to protein intake across older ethnic populations in the Netherlands: the HELIUS study. Ethn Health 27(3):705–720. https://doi.org/10.1080/13557858.2020.1814207

English KL, Paddon-Jones D. 2010. Protecting muscle mass and function in older adults during bed rest. Curr Opin Clin Nutr Metab Care 13:34–39. https://doi.org/10.1097/MCO.0b013e328333aa66

Fozouni L, Wang CW, Lai JC. 2019. Sex Differences in the Association Between Frailty and Sarcopenia in Patients With Cirrhosis. Clin Transl Gastroenterol 10(12):e00102. https://doi.org/10.14309/ctg.0000000000000102

Hall JG, Allanson JE, Gripp KW, Slavotinek AM. 2007. Handbook of Physical Measurements. Oxford University Press.

Hengeveld LM, Boer JMA, Gaudreau P, Heymans MW. Jagger C, Mendonca N, Ocké MC, Presse N, Sette S, Simonsick EM, Tapanainen H, Turrini A, Virtanen SM, Wijnhoven HAH, Visser M. 2020. Prevalence of protein intake below recommended in community-dwelling older adults: a meta-analysis across cohorts from the PROMISS consortium. J Cachexia Sarcopenia Muscle 11(5):1212–1222. https://doi.org/10.1002/jcsm.12580

Hosmer DW, Lemeshow S. 1989. Applied Logistic Regression, Second Edition. Wiley, New York. 1–30.

Houston DK, Tooze JA, Visser M, Tylavsky FA, Rubin S, Newman A, Harris TB, Kritchevsky SB. 2017. Protein intake and incydent sarcopenia in older adults: The health ABC study. Innov Aging 1(suppl 1):8–9. https://doi.org/10.1093/geroni/igx004.027

Human Development Report. 2019. United Nations Development Programme. [pdf] USA:United Nations Development Programme. Available at: https://hdr.undp.org/system/files/documents/hdr2019overview-englishpdf.pdf [Accessed 13 March 2023].

Jarosz M, Stoś K, Chwojnowska Z, Cichocka A, Wajszczyk B, Charzewska J. 2018/2019. Picture book of foods and meals. Institute of Food and Nutrition, Warsaw.

Jarosz M, Rychlik E, Stoś K, Charzewska J, editors. 2020. Normy Żywienia dla populacji Polski i ich zastosowanie. [pdf] Warszawa: Narodowy Instytut Zdrowia Publicznego-Państwowy Zakład Higieny. Available at: https://www.pzh.gov.pl/wp-content/uploads/2020/12/Normy_zywienia_2020web-1.pdf [Accessed 13 March 2023].

Jochum SB, Kistner M, Wood EH, Hoscheit M, Nowak L, Poirier J, Eberhardt JM, Saclarides TJ, Hayden DM. 2019. Is sarcopenia a better predictor of complications than body mass index? Sarcopenia and surgical outcomes in patients with rectal cancer. Colorectal Dis 21(12):1372–1378. https://doi.org/10.1111/codi.14751

Juul A, Skakkebeal NE. 2002. Androgens and ageing male. Hum Rep Update 8(5):423–433. https://doi.org/10.1093/humupd/8.5.423

Karakelides H, Nair KS. 2005. Sarcopenia of aging and its metabolic impact. Curr Top Dev Biol 68:123–148. https://doi.org/10.1016/S0070-2153(05)68005-2

Kitamura A, Seino S, Abe T, Nofuji Y, Yokoyama Y, Amano H, Nishi M, Taniguchi Y, Narita M, Fujiwara Y, Shinkai S. 2020. Sarcopenia: prevalence, associated factors, and the risk of mortality and disability in Japanese older adults. J. Cachexia Sarcopenia Muscle 12(1):30–38. https://doi.org/10.1002/jcsm.12651

Kim J, Wang Z, Heymsfield SB, Baumgartner RN, Gallagher D. 2002.Total-body skeletal muscle mass: estimation by a new dual-energy X-ray absorptiometry method. Am J Clin Nutr 76(2):378–383. https://doi.org/10.1093/ajcn/76.2.378

Krzymińska-Siemaszko R. 2014. Wskaźnik niskiej masy mięśniowej w definiowaniu sarkopenii. Rozprawa doktorska. Poznań.

Lang T, Streeper T, Cawthon P, Baldwin K, Taaffe DR, Harris TB. 2010. Sarcopenia: etiology, clinical consequences, intervention, and assessment. Osteoporos Int 21(4):543–59. https://doi.org/10.1007/s00198-009-1059-y

Lee WJ, Peng LN, Loh CH, Chen LK. 2020. Sex-different associations between serum homocysteine high-sensitivity C-reactive protein and sarcopenia:Results from I-Lan Longitudinal Aging Study. Exp Gerentol 132:110832. https://doi.org/10.1016/j.exger.2020.110832

Liu X, Hao Q, Hou L, Zhao W, Zhang Y, Ge M, Liu Y, Zuo Z, Yue J, Dong B. 2020. Ethnic Groups differences in the prevalence sarcopenia using the AWGS criteria. J Nutr Health Aging 24:665–671. https://doi.org/10.1007/s12603-020-1381-9

Lwanga SK, Lemeshow S. 1991. Sample Size determination in health studies, a practical Manual. [pdf] World Health Ogranization, Geneva. Available at https://tbrieder.org/publications/books_english/lemeshow_samplesize.pdf [Accessed 13.03.2023].

Malafarina V, Uriz-Otano F, Iniesta R, Gil-Guerrero L. 2012. Sarcopenia in the elderly: diagnosis, physiopathology and treatment. Maturitas 71(2):109–14. https://doi.org/10.1016/j.maturitas.2011.11.012

Malmstrom TK, Miller DK, Simonsick EM, Ferrucci L, Morley JE. 2016. SARC-F: punktacja objawów do przewidywania osób z sarkopenią z ryzykiem słabych wyników funkcjonalnych. J Cachexia Sarcopenia Muscle 7:28–36. https://doi.org/10.1002/jcsm.12048

Marcos-Pardo PJ, Gonzalez-Galvez N, Lopez-Vivancos A, Espeso-Gracia A, Martinez-Aranda LM, Gea-Gracia GM, Orquín-Castrillón FJ, Carbonell-Baeza A, Jiménez-García JD, Velázquez-Díaz D, Cadenas-Sanchez C, Isidori E, Fossati C, Pigozzi F, Rum L, Norton C, Tierney A, Äbelkalns I, Klempere-Sipjagina A, Porozovs J, Hannola H, Niemisalo N, Hokka L, Jiménez-Pavón D, Vaquero-Cristóbal R. 2021. Sarcopenia, diet, physical activity and obesity in European middle-age and older adults: The LifeAge Study. Nutrients 13(1):8. https://doi.org/10.3390/nu13010008

Miyakoshi N, Hongo M, Mizutani Y, Shimada Y. 2013. Prevalence of sarcopenia in Japanese women with osteopenia and osteoporosis. J Bone Miner. Metab 31:556–561. https://doi.org/10.1007/s.00774-013-0443-z

Montiel-Rojas D, Nilsson A, Santoro A, Bazzocchi A, de Groot LCPGM, Feskens EJM, Berendsen AAM, Madej D, Kaluza J, Pietruszka B, Jennings A, Fairweather-Tait S, Battista G, Capri M, Franceschi C, Kadi F. 2020. Fighting sarcopenia in ageing European adults: the importance of amount and source of dietary proteins. Nutrients 12(12):3601. https://doi.org/10.3390/nu12123601

Nilsson A, Montiel-Rojas D, Kadi F. 2018. Impact of meeting different guidelines for protein intake on muscle mass and physical function in physical active older women. Nutrients 10:1156. https://doi.org/10.3390/nu10091156

Omelan AA, Borysławski K , Podstawski RS. 2022. Body composition and level of physical activity of elderly people living in north-eastern Poland associated with socioeconomic factors. Anthropol Rev 85(3):31–46. https://doi.org/10.18778/1898-6773.85.3.03

Pacifico J, Geerlings MAJ, Reijnierse EM, Phassouliotis C, Lim WG, Maier AB. 2020. Prevalence of sarcopenia as a comorbid disease: A systematic review and meta-analysis. Exp Geronto 131:110801. https://doi.org/10.1016/j.exger.2019.110801

Pang BWJ, Wee SL, Lau LK, Jabbar KA, Seah WT, Ng DHM, Ling Tan QL, Chen KK, Jagadish MU, Ng TP. 2021. Prevelence and Associated Factors of Sarcopenia in Singapur Adults-The Yishun Study. J Am Med Dir Assoc 22(4):885.e1–885.e10. https://doi.org/10.1016/j.jamda.2020.05.029

Papadopoulou SK. 2020. Sarcopenia: A Contemporary Health Problem among Older Adult Populations. Nutrients 12:1293. https://doi.org/10.3390/nu12051293

Perna S, Alalwan TA, Al-Thawadi S, Negro M, Parimbelli M, Cerullo G. 2020. Evidence-Based Role of Nutrients and antioxidants for chronic pain management in musculoskeletal frailty and sarcopenia in aging. Geriatric 5(1):16. https://doi.org/10.3390/geriatrics5010016

Petermann-Rocha F, Balntzi V, Gray SR, Lara J, Ho FK, Pell JP, Celis-Morales C. 2022. Global prevalence of sarcopenia and severe sarcopenia: a systematic review and meta-analysis. J Cachexia Sarcopenia Muscle 13(1):86–99. https://doi.org/10.1002/jcsm.12783

Rondanelli M, Cereda E, Klersy C, Faliva MA, Peroni G, Nichetti M, Gasparri C, Iannello G, Spadaccini D, Infantino V, Caccialanza R, Perna S. 2020. Improving rehabilitation in sarcopenia: a randomized-controlled trial utilizing a muscle-targeted food for special medical purpose. J Cachexia Sarcopenia Muscle 11:1535–1547. https://doi.org/10.1002/jcsm.12532

Rong S, Wang L, Peng Z, Lio Y, Dan L, Yang X, Nuessler AK, Liu L, Bao W, Yang W. 2020. The mechanism and treatments for sarcopenia: could exosomes be a perspective research strategy in the future? J Cachexia Sarcopenia Muscle 11:248–265. https://doi.org/10.1002/jcsm.12536

Schaap LA, van Schoor NM, Lips P, Visser M. 2018. Associations of Sarcopenia Definitions, and their Components, With the Incidence of Recurrent Fall and Fractures: The Longitudinal Aging Study Amsterdam. J Gerontol A Biol Med Sci 73:1199–1204. https://doi.org/10.1093/gerona/glx245

Shafiee G, Heshmat R, Ostovar A, Khatami F, Fahimfar N, Arzaghi SM, Gharibzadeh S, Hanaei S, Nabipour I, Larijani B. 2020. Comparison of EWGSOP-Aand EWGSOP-2 diagnostic criteria on prevalence of risk factors fo sarcopenia among Iranian older people: The Bushehr Elderly Health (BEH) program. J Diabetes Metab Disord 29;19(2):727–734. https://doi.org/10.1007/s40200-020-00553-w

Shafiee G, Keshtkar A, Soltani A, Ahadi Z, Larijani B, Heshmat R.2017. Prevelence of sarcopenia in the world: a systematic review and meta-analysis of general population studies. J Diabetes Metab Disord 16;16:21. https://doi.org/10.1186/s40200-017-0302-x

Shumway-Cook A, Brauer S, Woollacott M. 2000. Predicting the probability of falls in community-dwelling older adults using the time up and go test. Physical Therapy 80:896–903. https://doi.org/10.1093/ptj/80.9.896

Tanaka T, Kawahara T, Aono H, Yamada S, Ishizuka S, Takahashi K, Iijima K. 2021. A comparison of sarcopenia prevalence between former Tokyo 1964 Olimpic athletes and general community-dwelling older adults. J. Cachexia Sarcopenia Muscle 12(2):339–349. https://doi.org/10.1002/jcsm.12663

Tsutsumimoto K, Doi T, Nakakubo S, Kim M, Ishii H, Shimada H. 2020. Association between anorexia of anging and sarcopenia among Japanese older adults. J Cachexia Sarcopenia Muscle 11:1250–1257. https://doi.org/10.1002/jcsm.1257

Tyrovolas S, Koyanagi A, Olaya B, Ayuso-Mateos JL, Miret M, Chatterji S. 2016. Factors associated with skelet muscle mass, sarcopenia, and sarcopenic obesity in older adults:a multi-continental study. J Cachexia Sarcopenia Muscle 7:312–321. https://doi.org/10.1002/jcsm.12076

Van Ancum JM, Meskers CGM, Reijnierse EM, Yeung SSY, Jonkman NH, Trappenburg M C, Pijnappels M, Maier AB. 2020. Lack of Knowledge Contrasts the Willingness to Counteract Sarcopenia Among Community-Dwelling Adults. J Aging Health 32(7–8):787–794. https://doi.org/10.1177/0898264319852840

Wang YJ, Wang Y, Zhan JK, Tang ZY, He JY, Tan P, Deng HQ, Huang W, Liu YS. 2015. Sarco-osteoporosis: prevalence and association with frailty in Chinese community-dwelling older adults. Int J Endocrinol 2015:482940. https://doi.org/10.1155/2015/482940

World Health Organization. 2008. Waist Circumference and Waist–Hip Ratio: Report of a WHO Expert Consultation. Geneva.

Wytyczne UE dotyczące aktywności fizycznej. 2008. Zalecane działania polityczne wspierające aktywność fizyczną wpływającą pozytywnie na zdrowie. Czwarty projekt skonsolidowany. Zatwierdzony przez Grupę Roboczą UE „Sport i Zdrowie" 25 września 2008 r. [pdf] Available at https://msit.gov.pl/download/1/12484/WytyczneUEdotyczaceaktywnoscifizycznej.pdf [Accessed 13 March 2023].

Yeung SSY, Reijnierse EM, Pham VK, Trappenburg MC, Lim WK, Meskers CGM, Maier AB. 2019. Sarcopenia and its association whith falls and fractures in older adults:a systematic review and meta-analysis. J Cachexia Sarcopenia Muscle 10(3):485–500. https://doi.org/10.1002/jcsm.12411

Zanker J, Scott D, Reijnierse EM, Brennan-Olsen SL, Daly RM, Girgis CM, Grossmann M, Hayes A, Henwood T, Hirani V, Inderjeeth CA, Iuliano S, Keogh JWL, Lewis JR, Maier AB, Pasco JA, Phu S, Sanders KM, Sim M, Visvanathan R, Waters DL, Yu SCY, Duque G. 2019. Establishing an operational definition of sarcopenia in Australia and New Zealand: Delphi method based consensus statement. J Nutr Health Aging 23(1):105–110. https://doi.org/10.1007/s12603-018-1113-6

Anthropological Review • Vol. 86(1), 67–75 (2023)

ANTHROPOLOGICAL REVIEW

Available online at: https://doi.org/10.18778/1898-6773.86.1.06

Sexual variation in the inter-triradial distance of the palm among Bengali Hindu population of Kolkata, India

Ritwik Banerjee[1], *Manashi Das*[2]

[1] Research Scholar (UGC-NET), Discipline of Anthropology, IGNOU, New Delhi, India
[2] Master in Anthropology student, Discipline of Anthropology, IGNOU, New Delhi, India

ABSTRACT: Palm prints are one of the most important forensic tools for human identification in medico-legal investigation. Palm prints are often used for forensic sex estimation to narrow down the pool of suspects through a process of elimination. The aim of this study was to test whether a novel approach of sex estimation from palmar inter-triradial distances previously posited by Badiye and colleagues [Journal of Forensic and Legal Medicine, 2019; 65(March):22–26] can be used as a primary tool for forensic sexing. For this study the bilateral palm prints from 200 Bengali Hindu adults (100 male, 100 female) were collected using traditional ink printing method and were analysed. Descriptive statistics were presented in tables and linear discriminant analysis was conducted to estimate the extent of sexual dimorphism in the inter-triradial distances and to find out variables with the strongest sex discriminating potential. Binary logistic regression analysis (BLR) was performed to derive sex estimation equations. Sexual dimorphism has been found to be statistically significant ($p < 0.001$) using linear discriminant analysis with a sexing accuracy of 79.0 percent for the left and 79.5 percent for the right palm. Distance between a and t triradius has been found to be the most influential on this model followed by the combined abcd-t distance. For the BLR analysis, the correct classification percentage was found to be the highest on the a-t distance of the right palm with a success rate of 80.5 percent which is closely followed by the combined abcd-t distance which has a classification success rate of 80.0 percent for the right palm. The present study has concluded that, inter-triradial distance of the palm is fairly dimorphic sexually but can only be used as a supplementary tool in inference of sex for medico-legal investigation. Due to a higher accuracy, the distance between a and t triradius has been proposed to be used instead of combined abcd-t distance which was suggested in the original study conducted by Badiye and colleagues (2019).

KEY WORDS: Forensic Anthropology, Palm Print, Triradii, Sex Estimation, Discriminant Function Analysis, Dermatoglyphics.

Original article

Received: 30.06.2022; Revised: 6.03.2023; Accepted: 8.03.2023

Introduction

Palm is the ventral surface of hand that is anatomically located in between the base of fingers and the wrist. Latent palm print is the impression left by the palmar epidermal ridges on a surface and is one of the most important means for the determination of individuality in forensic investigation (Christofidis et al. 2018). In almost thirty percent of cases where dermatoglyphic prints are recovered from different surfaces, they are from the palm according to a previous study (Jain and Feng 2009). Such surfaces can include gun grips, knife or sword haft, steering wheels of vehicles, door handles, computer mouse and smartphones (Christofidis et al. 2018).

The palm is divided into thenar, hypothenar and interdigital areas by principal lines on the volar pad (Badiye et al. 2019). Epidermal ridges on palm are formed between 6th and 16th week of gestation period (Gutiérrez-Redomero and Alonso-Rodríguez 2013). Anatomical landmarks of palm are determined by the presence of triradii Palmar triradius is a Y shaped landmark formed by a group of three epidermal papillary ridges of the palm. There are four interdigital triradiilocated at the base of each finger and one axial triradius located proximal to the wrist (Krishan et al. 2014).

Interindividual, population and sexual variation of epidermal ridges on the palmar surface along with its disease associations has long been studied and reported by various scholars in the past (Meier 1980; Schaumann and Meier 1989; Bhat et al. 2014; Dorjee et al. 2014; Singh et al. 2016). Sexual variation in the palmar ridge patterns has also been widely studied in the context of forensic dermatoglyphics. Sexual dimorphism previously observed in the Mean Ridge Breadth (David 1981), epidermal palmar ridge breadth (Cummins et al. 1941; Ohler and Cummins 1942) and palm print ridge density (Krishan et al. 2014) can be used as a potential tool for forensic sexing. Recently Badiye et al. (2019) has presented a novel approach of sex determination using the distance between interdigital and axial triradii of palm among a heterogenous population of central India (Badiye et al. 2019). The present study has attempted to validate the measurements described by Badiye et al. (2019) on a sample of Bengali Hindu adults with the intention to test if the novel approach taken by Badiye et al. (2019) can reliably be used for sex estimation in medico legal context and also have provided a discussion in light of the previous literature.

Materials and methods

Study area and people

A group of 200 adult individuals (100 males and 100 females) of Bengali Hindu origin were randomly chosen from the city of Kolkata, India for this study with informed consent. Sample size was kept in line with the previous study conducted by Badiye et al. (2019). Subjects chosen were all healthy, without any congenital deformity, burn and injury, amputations, surgical marks in the palm. Subjects with a missing c triradius at the base of the fourth digit were excluded from the study since the c-t distance is required for analysis. The purpose of the study along with their rights according to the ethical standards of human experiments as laid down in the Helsinki Declaration were clearly explained to all participants.

Method

Palm prints of all the study participants were collected using traditional ink printing method as described by Cumins and Midlo (Cummins and Midlo 1926). First the participants were asked to clean their hands with soap and water and dried their hands with a clean towel. Then a clean plain glass plate of 15 x 15 cm size was smeared with Kores black ink with the help of a roller to get a uniformly coated thin film of ink on the surface of the sheet. The ink was then applied to the palm of each participant by placing the palmar surface on the inked glass plate and gently pressing the dorsal surface of the hand against the plate. Care was taken so that the hollow of the palm and the flexor creases of the wrist get uniformly coated with ink without any appearance of a smudge. Following this procedure, the inked hands were pressed against a plain piece of white paper sheet (placed on a flat table) from proximal to distal direction. Finally, the hand was lifted from the paper from distal to proximal end leaving a clear impression of the whole palm. Same procedure was repeated for both right and left hands. Participant's age and sex were also recorded while taking the palm prints.

After the palm prints were taken, they were used for dermatoglyphic analysis using a handheld magnifying glass. All four triradii located at the base of second, third, fourth and fifth digits were identified and were labeled as 'a', 'b', 'c', and 'd' triradius respectively. The axial triradius proximal to the wrist was labeled as 't' triradius. Distances between a-t, b-t, c-t, and d-t were measured using a scale. Combined abcd-t distance was calculated by summing up a-t, b-t, c-t, and d-t distances. All readings were recorded for further statistical analysis.

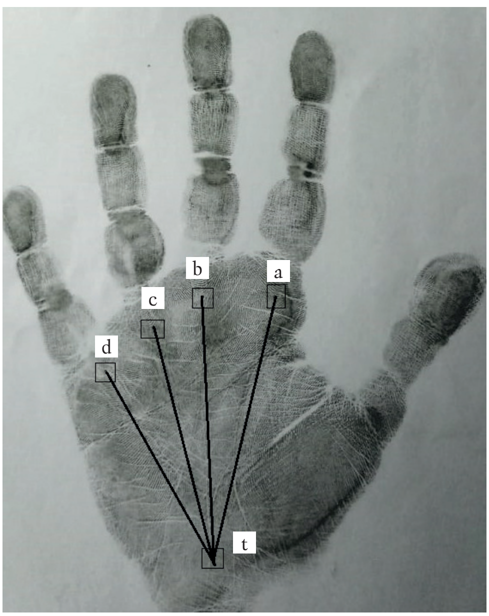
Statistical analysis

The data obtained were analysed using IBM SPSS statistics software version 27.0, Chicago, Illinois, USA. The descriptive statistics of a-t, b-t, c-t, d-t, and combined abcd-t distance of both hands for male and female has been presented in tabular form. Discriminant function analysis was used to visualize the degree of overlap between males and females and to identify the variables with strongest sex discriminating potential. The extent of sexual dimorphism has also been described using Wilks' lambda values with a scale ranging between 0 and 1, where 0 indicates total discrimination and 1 indicates no discrimination. Finally, Binary Logistic Regression analysis with a classification cutoff set as 0.5 was performed to derive sex estimation equations from inter triradial distances mentioned above for both hands.

Inter and Intra observer error

Inter and intra observer error in the measurement of a-t distance on the left palm was quantified by RB and MD before commencement of the study by taking both impression of the palm as well as the measurement in 30 randomly selected participants (pooled sex). Systematic error of measurement was measured using the paired t-test while the random error was measured using Technical Error in Measurement (TEM). Absolute TEM was calculated using the standard formula $TEM= \sqrt{(\sum D^2/2N)}$, where D is the deviations between measurements, and N is the number of individuals measured (Perini et al. 2005). Relative TEM was then calculated using the formula $\%TEM= (TEM/VAV) x100$, where % TEM is the TEM expressed as percentage, and VAV is the Variable

Average Value (Perini et al. 2005). RB and MD have tested for inter observer error in measurements while MD has tested for intra observer error in measurements within a gap of a few days. No significant inter (t= -0.812, df= 29, p= 0.423) as well as intra (t= -0.571, df= 29, p= 0.573) observer error was found for the a-t distance on left palm using the paired t-test. The relative TEMs for inter and intra examiners for the same repeated a-t distance measurement on the left palm were 0.04 percent and 0.06 percent respectively, and are well below the accepted 5 percent mark (Rajaah et al. 2010). The results indicate that the measurements are reproducible without any significant error.



Legends: a - Triradius 'a'; b - Triradius 'b'; c - Triradius 'c'; d - Triradius 'd'; t - Triradius 't'

Fig. 1. Left palmprint showing five palmar triradii namely a, b, c, d, t and inter-triradial distances in between (fig: Field source)

Results

Descriptive statistics for all variables have been presented in the Table 1 and the result of linear discriminant analysis along with its correct classification accuracy has been presented in the Table 2, for both left and right palm. Overall 79.0 percent accuracy has been achieved for the left palm and 79.5 percent accuracy has been achieved for the right palm. 78 percent males and 80 percent females were correctly classified from left palm prints, while 77 percent males and 82 percent females were correctly classified from right palm prints. Table 3 has presented Wilks' lambda values which are 0.598 and 0.568 for the left and right palms respectively. Wilks' lambda values indicate that the difference between males and females in terms of the inter triradial distance is statistically significant ($p<0.001$) for all the variables analyzed in the present study. Table 4 has presented the structure matrix for left and right palm and it has been observed that a-t distance has the greatest sex discriminating potential followed by the combined abcd-t distance. Finally, the result of Binary Logistic Regression analysis along with its correct classification percentage for each variable has been presented in the Table 5 for both left and right palm. For the right palm, the highest classification success rate of 80.5 percent was found for the a-t distance, which is closely followed by the combined abcd-t distance for which the correct classification percentage was 80.0 percent. The classification success rate for logistic equations was found to be slightly lower for the left palm, where the correct classification percentages achieved were 78 percent and 77 percent for the a-t and combined abcd-t distance respectively.

Table 1. Descriptive Statistics for left and right palms

Descriptive statistics for left palms					
	Sex	*n*	Mean (cm)	Std. Deviation	Std. Error
a-t	Male	100	8.29	0.60	0.06
	Female	100	7.30	0.64	0.06
b-t	Male	100	8.47	0.63	0.06
	Female	100	7.49	0.73	0.07
c-t	Male	100	8.04	0.62	0.06
	Female	100	7.08	0.70	0.07
d-t	Male	100	7.24	0.61	0.06
	Female	100	6.35	0.68	0.06
abcd-t	Male	100	32.05	2.37	0.23
	Female	100	28.23	2.69	0.26
Descriptive statistics for right palms					
	Sex	*n*	Mean (cm)	Std. Deviation	Std. Error
a-t	Male	100	8.28	0.56	0.05
	Female	100	7.35	0.54	0.05
b-t	Male	100	8.43	0.57	0.05
	Female	100	7.53	0.63	0.06
c-t	Male	100	8.03	0.53	0.05
	Female	100	7.16	0.65	0.06
d-t	Male	100	7.22	0.57	0.05
	Female	100	6.44	0.63	0.06
abcd-t	Male	100	31.98	2.12	0.21
	Female	100	28.49	2.39	0.23

Table 2. Classification results for left and right palm. 79.0% of original grouped cases correctly classified for left palm and 79.5% of original grouped cases correctly classified for right palm

Result of linear discriminant analysis for left palms					
		Sex	Predicted group membership		Total
			Female	Male	
Original	Count	Female	80	20	100
		Male	22	78	100
Result of linear discriminant analysis for right palms					
		Sex	Predicted group membership		Total
			Female	Male	
Original	Count	Female	82	18	100
		Male	23	77	100

Table 3. Wilks' lambda value for left and right palms, indicating a significant difference between males and females

Wilks' lambda for left palms				
Test of function(s)	Wilks' lambda	Chi-squared	df	Sig.
1	0.59	100.80	4	$p<0.001$
Wilks' lambda for right palms				
Test of function(s)	Wilks' lambda	Chi-squared	df	Sig.
1	0.56	110.85	4	$p<0.001$

Table 4. Structure matrix listing variable influence on the model for left and right palms

Structure matrix for left palms	
Function 1	
a-t	0.97
abcd-t	0.92
c-t	0.88
b-t	0.87
d-t	0.83
Structure matrix for right palms	
Function 1	
a-t	0.97
abcd-t	0.89
b-t	0.86
c-t	0.84
d-t	0.74

Table 5. Result of binary logistic regression analysis for left and right palms

Result of binary logistic regression analysis for left palms			
Variables	Regression model	Correct classification percentage	Wald
a-t	-21.187+2.707(a-t)	78.0	47.76
b-t	-18.741+2.337(b-t)	74.5	44.58
c-t	-18.218+2.399(c-t)	73.0	45.56
d-t	-15.738+2.306(d-t)	72.5	44.21
abcd-t	-20.263+0.669(abcd-t)	77.0	45.57
Result of binary logistic regression analysis for right palms			
Variables	Regression model	Correct classification percentage	Wald
a-t	-28.230+3.610(a-t)	80.5	47.86
b-t	-21.797+2.721(b-t)	74.5	46.61
c-t	-21.059+2.756(c-t)	78.0	46.35
d-t	-15.834+2.307(d-t)	75.5	43.40
abcd-t	-23.516+0.775(abct-t)	80.0	47.67

Discussion

The observed difference between males and females with respect to the inter triradial distance is largely attributable to the fact that male hands are larger than female hands on an average (Kanchan and Krishan 2011) leaving a larger palmar area for males. The novel approach taken by Badiye et al. (2019) was applied to 65 males and 63 females and sexual dimorphism was reported to be statistically significant at $p < 0.01$ level (Badiye et al. 2019). They have suggested that a combined abcd-t distance of less than or equal to 30 cm will more likely to be of a female, and greater than or equal to 32.5 cm will more likely be of a male. It has been observed in the present study that the a-t distance has a higher sexing accuracy than combined abcd-t distance. Therefore, it is proposed that instead of taking the combined abcd-t distance (as has been suggested by Badiye et al. 2019), the a-t distance may be of better use since it has the most influence on this model.

In a similar study conducted by Jerković et al. (2023) on 119 left palmprints (66 males and 53 females) and 134 right palmprints (73 males and 61 females) reported sexing accuracy lied between 64 and 85 percent for univariate model and between 81 and 87 percent for multivariate model with the sexual dimorphism being statistically significant at $p < 0.001$ level (Jerković et al. 2023). Although Badiye et al. (2019) did not report the sexing accuracy of their novel technique, we report a sexing accuracy of 79.0 percent on the left palm and 79.5 percent on the right palm for LDA, and 80.5 percent for the logistic equation of the a-t distance on the right palm by using their technique. It has also been observed that the percentage success for correct classification using this technique is marginally greater for the logistic regression analysis of a-t and combined abcd-t measurements of the right palm than the linear discriminant analysis. Traditionally, the reference guide for classifying the accuracy of a test is considered in the following way: fail test (0.50–0.60), poor test (0.60–0.75), fair test (0.75–0.90), good test (0.90–0.97), and excellent test (0.97–1.00) (Krishan et al. 2014). Based on this traditional reference guide we conclude that the novel approach taken by Badiye et al. (2019) is only a fair test and it can only be used as a supplementary tool in inference of sex from palm prints recovered from a crime scene.

Conclusion

In conclusion, forensic sex estimation from palm prints remains a challenge, but this study has validated the inter-triradial distances between ‘a’, ‘b’, ‘c’, ‘d’, and ‘t’ triradii as a potential supplementary tool for forensic sexing of palm prints. The a-t distance has been identified as producing the most accurate results in sex estimation. Binary Logistic Regression models have been presented for a-t, b-t, c-t, d-t, and combined abcd-t distances, which can be used to predict sex. However, future studies are needed to further investigate the influence of the combined abcd-t distance on this model for different populations. Moreover, future research should focus on investigating sexual variation in subadult individuals and the exact age of full expression of these inter-triradial distances. Further exploration should also be carried out to estimate stature and other body dimensions from palmar inter-triradial distances, opening new avenues for human identification in medico-legal contexts. Overall, the findings of this study provide valuable insights for forensic experts and legal authorities in identifying individuals through palm prints.

List of abbreviations

SPSS – Statistical Package for Social Sciences
IBM – International Business Machine

Acknowledgements

We thank all the participants who cooperated in the fieldwork and data collection.

Ethics approval and consent to participate

Verbally informed consent was obtained from participants prior to conducting the study, Ethics committee approval was not required. Written informed consent was not taken.

Conflict of interest

The authors declare that there is no conflict of interests.

Funding

No funding was obtained for this study.

Authors' contribution

RB – project design, statistical analysis and report writing
MD – Fieldwork and data collection, data extraction, tabulation

Corresponding author

Ritwik Banerjee, Research Scholar (UGC-NET), Discipline of Anthropology, School of Social Sciences, Indira Gandhi National Open University (IGNOU), New Delhi, India; e-mail: ritwik.banerjee@yahoo.co.in

References

Badiye A, Kapoor N, Mishra SD. 2019. A Novel Approach for Sex Determination Using Palmar Tri-Radii: A Pilot Study. J Forencic Leg Med 65(3):22–26. https://doi.org/10.1016/j.jflm.2019.04.005

Bhat G, Mukhdoomi M, Shah B, Ittoo M. 2014. Dermatoglyphics: In Health and Disease - a Review. IJRMS 2(1):31.

Christofidis G, Morrissey J, Birkett JW. 2018. Detection of Fingermarks–Applicability to Metallic Surfaces: A Literature Review. JFS 63(6):1616–1627.

Cummins H, Midlo C. 1926. Palmar and Plantar Epidermal Ridge Configurations (Dermatoglyphics) in European-Americans. Am J Phys Anthropol 9(4):471–502. https://doi.org/10.1002/ajpa.1330090422

Cummins H, Waits WJ, McQuitty JT. 1941. The Breadths of Epidermal Ridges on the Finger Tips and Palms: A Study of Variation. Am J Anat 68(1):127–150. https://doi.org/10.1002/aja.1000680106

David TJ. 1981. Distribution, Age and Sex Variation of the Mean Epidermal Ridge Breadth. Hum Hered 31(5):279–282.

Dorjee B, Mondal N, Sen J. 2014. Applications of Dermatoglyphics in Anthropological Research. South Asian Anthropologist 14(2):171–180.

Gutiérrez-Redomero E, Alonso-Rodríguez C. 2013. Sexual and Topological Differences in Palmprint and Ridge Density in the Caucasian Spanish Population. Forensic Sci Int 229(1-3):159.e1-159.e10.

Jain AK, Feng J. 2009. Latent Palmprint Matching. IEEE TPAMI 31(6):1032–1047.

Jerković I, Ljubić T, Bardić L, Kolić A, Anđelinović Š. 2023. Application of Palmar Digital Intertriradial Distances for Sex Classification from Palmprints: A Preliminary Study. Aust J Forensic Sci 55(1):34–45. https://doi.org/10.1080/00450618.2021.1882573

Kanchan T, Krishan K. 2011. Anthropometry of Hand in Sex Determination of Dismembered Remains - A Review of Literature. JFLM 18 (1):14–17.

Krishan K, Kanchan T, Sharma R, Pathania A. 2014. Variability of Palmprint Ridge Density in a North Indian Population and Its Use in Inference of Sex in Forensic Examinations. HOMO-Journal of Comparative Human Biology 65(6):476–488. http://doi.org/10.1016/j.jchb.2014.08.003

Meier RJ. 1980. Anthropological Dermatoglyphics: A Review. Am J Phys Anthropol 23(1S):147–178.

Ohler EA, Cummins H. 1942. Sexual Differences in Breadths of Epidermal Ridges on Finger Tips and Palms. Am J Phys Anthropol 29(3):341–362.

Perini TA, de Oliveira GL, dos Santos Ornellas J, Palha de Oliveira F. 2005. Technical Error of Measurement in Anthropometry. Rev Bras de Medicina Do Esporte 11(1):81–90.

Rajaah M, Jamaiyah H, Geeta A, Safiza MN, Khor GL, Wong NF, Kee CC, et al. 2010. Reliability, Technical Error of Measurements and Validity of Length and Weight Measurements for Children under Two Years Old in Malaysia. Med J Malays 65:131–137.

Schaumann BA, Meier RJ. 1989. Trends in Dermatoglyphic Research. Int J Anthropol 4(4):247–254.

Singh A, Gupta R, Zaidi S, Singh A. 2016. Dermatoglyphics: A Brief Review. Int J Adv Integr Med Sci 1(3):111–115.

Anthropological Review • Vol. 86(1), 77–90 (2023)

ANTHROPOLOGICAL REVIEW

Available online at: https://doi.org/10.18778/1898-6773.86.1.07

POLSKIE TOWARZYSTWO ANTROPOLOGICZNE

Do the short die young? Evidence from a large sample of deceased Polish adults

Piotr Paweł Chmielewski[1], *Sławomir Kozieł*[2], *Krzysztof Borysławski*[3]

[1] Division of Anatomy, Department of Human Morphology and Embryology, Faculty of Medicine, Wroclaw Medical University, Wroclaw, Poland
[2] Department of Anthropology, Ludwik Hirszfeld Institute of Immunology and Experimental Therapy, Polish Academy of Sciences, Wroclaw, Poland
[3] The Institute of Health, Angelus Silesius State University, Walbrzych, Poland

Abstract: Body height is associated with various socioeconomic and health-related outcomes. Despite numerous studies, the relationship between stature and longevity remains uncertain. This study explores the association between self-reported height and lifespan. Data from 848,860 adults who died between 2004 and 2008 in Poland were collected. After excluding a small proportion of records due to missing data or errors, we examined records for 848,387 individuals (483,281 men, age range: 20–110 years; 365,106 women, age range: 20–112 years). Height was expressed as standardized residual variance derived from linear regression in order to eliminate the variance of year of birth on height. After the elimination of the cohort effect, five height classes were designated using centiles: very short, short, medium, tall and very tall. The differences between sexes and among classes were evaluated with two-way ANOVA and post hoc Tukey's test. The effect size was assessed using partial eta squared (η^2). Pearson's *r* coefficients of correlation were calculated. The effect of sex on lifespan was nearly 17 times stronger than the effect of height. No correlation between height and lifespan was found. In conclusion, these findings do not support the hypothesis that taller people have a longevity advantage. We offer tentative explanations for the obtained results.

Key words: age, aging, body height, height, lifespan, longevity, stature, survival.

Original article

Received: 23.01.2023; Revised: 28.02.2023; Accepted: 6.03.2023

Introduction

Stature is an important anthropometric measurement for several reasons. Body height is a relatively easy anthropological measure to collect. It has been suggested that adult height is a useful marker of variation in cumulative net nutrition, biological deprivation and standard of living between and within human populations (Perkins et al. 2016). Stature is one of the most conspicuous morphological characteristics that has important social, ecological and biological consequences (Little 2020; Raghavan et al. 2022). Height is also a polygenic trait with high heritability (Silventoinen et al. 2003; Jelenkovic et al. 2016; You et al. 2021).

Therefore, anthropologists, actuaries, historians and economists often use height as an indicator of the health status and disease exposure of human populations and it has been shown that greater height is associated with longer lifespan (Finch and Crimmins 2004; Austad 2010). Numerous studies have also demonstrated that stature correlates positively with educational attainment, income, socioeconomic status (SES) and physical health (Peck and Vågerö 1989; Cernerud 1995; Meyer and Selmer 1999; Silventoinen et al. 1999; 2000; Gunnell et al. 2001; Turrell 2002; Heineck 2005; Magnusson et al. 2006; Case and Paxon 2008; Özaltin 2012; Rietveld et al. 2015), although the socioeconomic gradient in adult height has declined in affluent countries (Ayuda and Puche-Gil 2014; Öberg 2014; Perkins et al. 2016).

It has been established that adult height and cardiovascular disease (CVD) mortality are inversely correlated (Paajanen et al. 2010). Shorter individuals are also more vulnerable to type 2 diabetes (Lawlor et al. 2002; 2004). Nonetheless, it should be noted that not all authors agree that shorter people are more prone to CVD as individuals of similar body proportions and body mass index (BMI) should be compared with each other (Samaras 2013). Interestingly, the extent to which tallness is associated with health indices and survival remains unclear since recent studies have challenged this assumption (Miller et al. 2002; Rollo 2002; Samaras et al. 2003; Bartke 2012; 2017; Salaris et al. 2012). However, many studies have reported that taller people are healthier and live longer compared to their shorter counterparts (Davey Smith et al. 2000; Gunnell et al. 2001; Finch and Crimmins 2004; Kemkes-Grottenthaler 2005; Özaltin 2012; Perkins et al. 2016; Marco-Gracia and Puche 2021). This view is popular among anthropologists and physicians. Nevertheless, studies on the relationship between adult stature and longevity have yielded conflicting findings.

The present study aims to determine the association between self-reported height and lifespan in the Polish population. Our research has the potential to contribute to the anthropological literature by using a large and representative dataset and by employing better statistical methods.

Materials and methods

Data on 848,860 individuals, including 483,512 men (57%) and 365,348 women (43%) were collected. The data were obtained from two electronic databases at the Ministry of Internal Affairs and Administration in Warsaw: (1) the Universal Electronic System for Registration of the Population (sex, date of birth and death) and (2) signalments in the census obtained from identity card offices throughout Poland (adult height in cm declared on the identity card of a deceased person).

Extreme values of height (<140 cm for men; <130 cm for women) were excluded from the analysis. After excluding a small proportion (<0.06%) of records due to missing data or obvious errors, we examined records for 848,387 individuals (483,281 men, age range: 20-110 years, born between 1897 and 1984; 365,106 women; age range: 20–112 years, born between 1896 and 1984). All of these records include data on adult deaths in the years 2004–2008 in Poland.

Lifespan (in years) was calculated as the difference between the date of death and the date of birth. After the elimination of the cohort effect, the sample was divided into five height classes using centiles: very short (0–20), short (21–40), medium (41–60), tall (61–80) and very tall (81–100). Height was standardized on year of birth to sex-specific Z-scores in order to eliminate the effects of secular trends in stature. Subsequently, standardized residual variance was used. Pearson's r coefficients of correlation were calculated. The differences between sexes and among five height classes in lifespan were evaluated with two-way ANOVA and post hoc Tukey's test. The effect size was estimated using partial eta squared (η^2).

The collected data have several important advantages. First, the study sample is very large and representative for the entire population. Second, the research material includes typical causes of death as all records were analyzed, regardless of the cause of death. It should be emphasized that the use of declared stature instead of measured height is acceptable. Although it is true that males often overestimate their height (Cizmecioglu et al. 2005), these effects are especially pronounced in dating services or in studies on physical attractiveness. In general, women only marginally over- or underestimate their height (Brunner Huber 2007). Moreover, it has been shown that data on self-reported height tend to be more reliable when stated for legal and official purposes, and especially in such large samples (Krzyżanowska and Umławska 2002; Bowring et al. 2012; Olfert et al. 2018). Third, in this study data on the exact dates of birth and death were certified by relevant documents. Therefore, the collected data are reliable and the information concerning lifespan is credible.

Results

Body height and lifespan were normally distributed. Men were taller than women (171.6 ± 6.6 cm versus 159.6 ± 6.2 cm; $F = 1.14$; $p < 0.001$) and had shorter lives (67.9 ± 13.8 years versus 75.0 ± 12.7 years; $F = 1.19$; $p < 0.001$).

Before the elimination of the effects of secular trends in body height, an inverse correlation was found between the declared height and lifespan (Pearson's $r = -0.304$, $p < 0.001$ for men; $r = -0.258$, $p < 0.001$ for women). The values of lifespan and declared height before the elimination of the cohort effect are shown in Table 1.

Sex was the most important factor affecting lifespan, whereas body height and the interaction between height and sex had relatively small effects on lifespan. The effects of height on lifespan were 16.5 times weaker than the effects of sex (Table 2). After allowing for the cohort effect, medium men exhibited the longest lives among men, whereas very short women had the longest lives among women (Fig. 1).

Table 1. Twelve lifespan classes (in years) and stature (in cm) in men and women who died between 2004 and 2008 in Poland. These values were calculated before the elimination of the cohort effect

Lifespan	Men			Women		
	N	Mean	SD	N	Mean	SD
<50	55603	175.7	(6.8)	16405	163.3	(6.1)
50-54	37551	173.7	(6.3)	14485	161.8	(5.7)
55-59	47715	172.9	(6.2)	21737	161.6	(5.6)
60-64	44072	172.1	(6.1)	21799	161.3	(5.6)
65-69	55889	171.2	(6.0)	30165	160.6	(5.6)
70-74	71313	170.8	(6.0)	46338	160.1	(5.7)
75-79	75537	170.3	(6.1)	66739	159.5	(5.9)
80-84	56442	169.7	(6.4)	72112	158.8	(6.0)
85-89	26644	169.3	(6.7)	45436	158.1	(6.2)
90-94	9649	168.2	(6.9)	21448	156.8	(6.3)
95-99	2510	167.3	(7.0)	7269	156.2	(6.3)
>100	373	166.7	(6.8)	1177	155.3	(6.5)

Table 2. Lifespan (in years) in five categories of body height in both sexes after the elimination of the cohort effect. Differences between sexes and among height classes were assessed with two-way ANOVA and post hoc Tukey's test ($p < 0.001$ for all compared pairs of means). The effect size was estimated using partial eta squared (η^2)

Height class	Men		Women	
	N	Mean (SD)	*N*	Mean (SD)
Very short	96655	68.05 (13.96)	73021	75.91 (13.42)
Short	96657	66.58 (13.98)	73021	73.89 (13.09)
Medium	96656	68.87 (14.29)	73021	75.00 (12.10)
Tall	96654	66.39 (13.45)	73022	74.05 (13.22)
Very tall	96659	68.24 (15.15)	73021	75.83 (12.31)
		Two-way ANOVA		
		F	*p*	partial η^2
	Sex	59620.0	<0.0001	0.066
	Height	812.0	<0.0001	0.004
	Interaction	106.0	<0.0001	0.001

All of the vertical (e.g. very short men versus short men and so on) and horizontal (e.g. very short men versus very short women and so on) differences between pairs of means were statistically significant (the post hoc Tukey's test, $p < 0.001$ for all compared pairs of means).

After the elimination of the cohort effect, no correlation between height and lifespan (Pearson's $r = -0.0012$, $p > 0.05$ for men; $r = -0.0004$, $p > 0.05$ for women; Fig. 2A and 2B, respectively) was found.

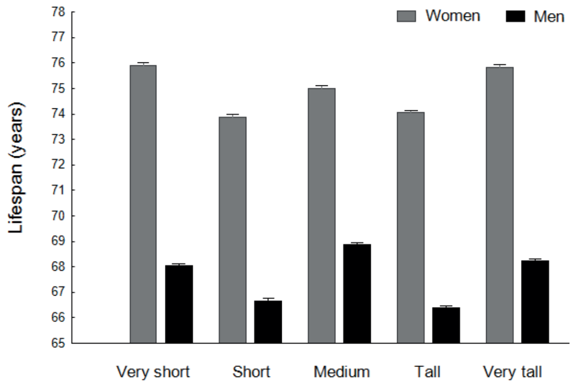


Fig. 1. Differences between sexes and among five height groups in lifespan after the elimination of the cohort effect. Means ± 95% CI are shown. Differences between all pairs of means were significant (post-hoc Tukey's test, $p < 0.001$)

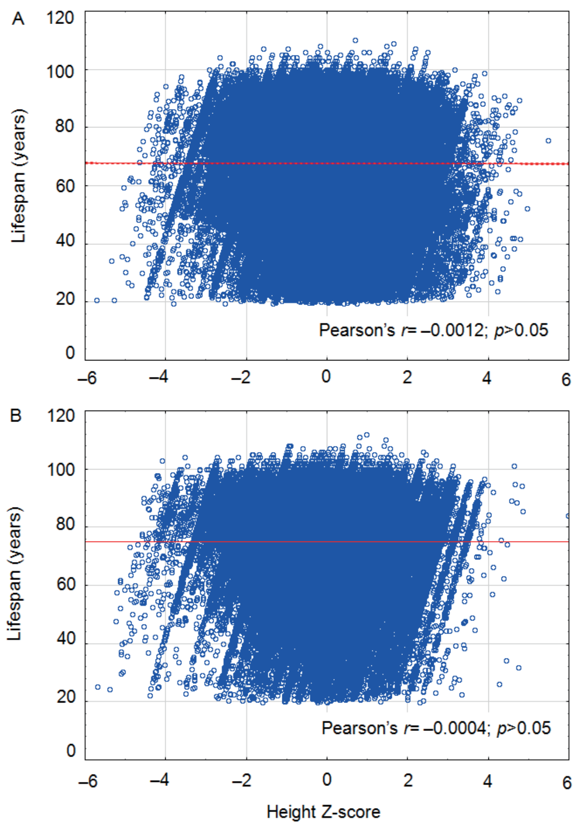


Fig. 2. No correlation between standardized height (Z-scores) and lifespan in men (A) and women (B)

Discussion

A multitude of studies have investigated the relationship between stature and later outcomes in life, including survival. Interestingly, this research has revealed that taller individuals do not have a longevity advantage over their shorter counterparts, which is in line with several studies (Wilhelmsen et al. 2011; Salaris et al. 2012; He et al. 2014).

In our previous articles (Chmielewski 2016; Chmielewski and Borysławski 2016; Chmielewski 2022; 2023), we did not address the problem of the variance of year of birth on stature and we did not express the values of height as standardized residual variance derived from linear regression. Therefore, the current study contributes to previous research by eliminating the cohort effect and, thus, evaluates the association between adult height and lifespan more appropriately.

No correlation between self-reported height and lifespan was found in this study. One possible explanation is that the costs of taller stature cancelled out the well-known benefits, while the benefits of shorter height were too modest to matter (Table 3). Considering that the level of cancer diagnosis and treatment is highly unsatisfactory in Poland, taller individuals are at a disadvantage. Thus, greater height is not associated with longer lifespan in the studied population.

It has been established that many factors and processes contribute to human height, including genetic, epigenetic, nutritional, ecological and social factors such as pathogens, parasites, stress level, amount of sleep, diseases or disorders. It should be noted that not only environmental and lifestyle-related factors, such as an unhealthy diet and malnutrition, but also genetic disorders (e.g. Down syndrome, Russel-Silver syndrome, Noonan syndrome, Turner syndrome, Prader-Willi syndrome and dwarfism) and physiological dysfunctions, such as growth hormone (GH) deficiencies, usually result in short stature.

Beard and Blaser (2002) contended that infectious diseases in childhood can negatively affect adult stature. For instance, a number of studies have shown that adults who suffered from diarrhea and dehydration during childhood were significantly shorter than those who did not have these problems. Also a study by Martorell and associates (1975) demonstrated that in Guatemala children relatively free from diarrhea during the first seven years of life were roughly 4 cm taller compared to those children who often suffered from diarrhea. Interestingly, it has been estimated that each episode of diarrhea in childhood is associated with a decrease in adult height by approximately 0.6 cm (Black et al. 1984). Moreover, several other studies have reported that infectious diseases in the first years of life are important factors affecting stature. Clinical observations suggest that certain medical problems and conditions, such as chronic granulomatous disease (CGD), can also result in diminished final height.

Epidemiological and clinical studies have provided evidence that taller stature is linked to an increased risk of cancer as well as decreased survival (Kabat et al. 2013; Wirén et al. 2014; Sohn 2016) even though it is unclear why taller people are more likely to develop cancer and die. However, a number of tentative explanations can be offered. For example, taller and larger individuals have consistently more somatic cells compared to their shorter and slimmer counterparts. Indeed, it has been established that the total number of cells in the body can predict the relation between body size and cancer (Nunney 2018). This is because a higher number of cells in the body increases the risk factor for DNA damage and somatic mutations.

Furthermore, an organism that accumulates extra senescent cells, e.g. a tall and overweight person who is getting older, is more likely to reach higher levels of chronic systemic inflammation (CSI), which can be detrimental to health. CSI and senescence-associated secretory phenotype (SASP) play an important role in aging, promote cancer and increase the risk of other age-related pathologies such as CVD and neurodegenerative disorders (Chmielewski 2018; Chmielewski and Strzelec 2018). Normal growth and development depend on GH/insulin/IGF-1 signaling and mammalian/mechanistic target of rapamycin (mTOR). However, these signaling pathways, when up-regulated, can stimulate cancer development and progression (van Heemst et al. 2005; Bartke 2012; 2017; Tian et al. 2019; Zou et al. 2020).

Growth is physiologically costly and among mammals smaller individuals (within the same species) tend to have lower mortality rates (Rollo 2002). For example, dogs and mice have been studied for years and smaller ones live longer (Miller et al. 2002; Bartke 2012). Interestingly, several studies have reported that primates on CR exhibit reduced body fat and increased insulin sensitivity. CR also reduces bone mass, muscle mass, muscle size and strength (Villareal et al. 2006; Weiss et al. 2007; Kemnitz 2011; Austad 2012). Simultaneously, CR extends lifespan (Anderson et al. 2009; Colman et al. 2009; Mattison et al. 2017), even though not all authors agree.

A number of studies have also suggested that taller people are less likely to reach advanced ages (Samaras et al. 2003; Wilhelmsen et al. 2011; Salaris et al. 2012; He et al. 2014). It is possible that the correlation between taller height and lower mortality is incidental to increased life expectancy. Nowadays people tend to live longer due to better sanitation, education, hygiene, nutrition and advances

Table 3. Selected biological advantages associated with taller and shorter height

Benefits of taller height	Benefits of shorter height
Taller stature reflects biological quality and is associated with better childhood nutrition and higher SES, including income, remuneration and educational attainment	Fewer cells in the body; the total number of somatic cells predicts the relationship between adult height and cancer risk (Nunney 2018)
Lower maximum oxygen uptake, lower heart rate and lower basal metabolic rate	Reduced GH/insulin/IGF-1 signaling and less active mTOR (van Heemst et al. 2005; Bartke 2012)
Taller individuals are less vulnerable to atherosclerosis and cardiovascular disease (Paajanen et al. 2010)	Shorter nonagenarians have longer telomeres (Maier et al. 2005), and shorter telomeres are a risk factor of cancer
Taller individuals are stronger, run faster, have better jumping ability, are better swimmers and fighters. In our evolutionary past, they provided better security and more resources (e.g. food, water, goods) for their sexual partners and offspring	Shorter people have faster reaction times, greater stability, lower risk of falls, greater endurance and reduced back problems. They are better endurance runners. Furthermore, hip fractures are more common in taller individuals

in preventive and therapeutic medicine (Kirkwood 2017). Taller individuals may benefit more from these advances as they score better in terms of SES.

According to Samaras, who studied various human populations and ethnic groups, short individuals tend to live longer (Samaras et al. 2003; Samaras 2013), especially if they are slim and maintain a healthy lifestyle. Similarly, Salaris and colleagues (2012) reported that shorter men lived about 2 years longer than their taller counterparts. Similarly, Holzenberger and associates (1991) found that shorter Spanish men lived longer than taller ones. These authors tracked the mortality of 1.3 million men over a 70-year period. However, Austad (2010) argues that Samaras reached his conclusion by comparing heights of different groups of people (e.g. different sexes or ethnic groups) within a given country. Due to variation in hormonal milieu, diet, lifestyle and multiple other factors, it is difficult to evaluate the claim that smaller people live longer in the face of a mountain of opposing epidemiological evidence. However, one can argue that this mountain of opposing data is based on mortality studies that did not track the entire cohorts to advanced ages or until death.

He and associates (2014) investigated a population of over 8,000 Japanese Hawaiian elderly males. Based on a 40 year follow up study, they found that shorter men had lower mortality rates and lived longer. Likewise, Wilhelmsen and collaborators (2011) tracked a group of 67-year old Swedish men to 90 years of age. They concluded that individuals who were shorter at baseline were more likely to reach age 90 compared to taller men. Gavrilova and Gavrilov (2008) probably summarized the situation accurately when they pointed out that: "Historical demographers are confident that small body size is associated with increased mortality, while biologists are firmly convinced that a small body size is preferable for longevity". These researchers found that the highest percentage of centenarians were average in height, which is in agreement with the current study in the case of men. These results also suggest that tall people are less likely to reach advanced ages.

The present study has several limitations that should be noted. First, only self-reported height was used, even though adults often overestimate their stature. Second, older people can also overestimate their stature. Adults lose about 1 cm every 10 years after age 40, and height loss is even more rapid in later stages of ontogeny (Chmielewski et al. 2015a; 2015b; 2016). Since a lot of people do not measure themselves regularly, it is possible that many of them provided outdated information. If so, the actual height was shorter than the self-reported height and the hypothesis that taller people live longer was favored. Third, the collected data vary with respect to the age at which height was declared as this information was unavailable in the current study. We assume that adult height declared on the identity card corresponds with the actual values. Finally, this analysis did not consider potentially significant confounding factors, such as BMI, lifestyle, the cause of death and SES, because these data were not available. Given that shorter individuals score worse in terms of SES, it is rather intriguing that in our study we did not find that taller individuals live longer than their shorter counterparts. Future studies may expand on this research by addressing the limitations of this study.

Conclusions

No correlation between body height and lifespan was found. The effects of sex on lifespan were nearly 17 times stronger than the effects of height, indicating that greater height was not associated with longer lifespan in the studied population. Thus, these results do not support the hypothesis that taller individuals have a longevity advantage.

Conflict of interests

The authors declare that they have no conflict of interests.

Authors' contribution

PPC conceptualized and designed the study, collected the data, interpreted the results, wrote the manuscript and revised it for important intellectual content. KB conceived the study, supervised the research and reviewed the manuscript. SK performed the statistical analyses, interpreted the results and critically reviewed the manuscript.

Corresponding author

Piotr Paweł Chmielewski, PhD, Division of Anatomy, Department of Human Morphology and Embryology, Faculty of Medicine, Wroclaw Medical University, Wroclaw, Poland, 6a Chałubińskiego Street, 50-368 Wrocław, Poland; Tel.: +48 71-784-13-45; Fax: +48 71-784-00-79; e-mail: piotr.chmielewski@umw.edu.pl

References

Anderson RM, Shanmuganayagam D, Weindruch R. 2009. Caloric restriction and aging: studies in mice and monkeys. Toxicol Pathol 37:47–51. https://doi.org/10.1177/0192623308329476

Austad SN. 2010. Animal size, metabolic rate, and survival, among and within species. In: NS Wolf, editor. The comparative biology of aging. Heidelberg: Springer-Verlag.

Austad SN. 2012. Ageing: mixed results for dieting monkeys. Nature 489:210–11. https://doi.org/10.1038/nature11484

Ayuda MI, Puche-Gil J. 2014. Determinants of height and biological inequality in Mediterranean Spain, 1859–1967. Econ Hum Biol 15:101–19. https://doi.org/10.1016/j.ehb.2014.07.003

Bartke A. 2012. Healthy aging: is smaller better? – a mini-review. Gerontology 58:337–43. https://doi.org/10.1159/000335166

Bartke A. 2017. Somatic growth, aging, and longevity. NPJ Aging Mech Dis 3:14. https://doi.org/10.1038/s41514-017-0014-y

Beard AS, Blaser MJ. 2002. The ecology of height: the effect of microbial transmission on human height. Perspect Biol Med 45:475–98. https://doi.org/10.1353/pbm.2002.0064

Black RE, Brown KH, Becker S. 1984. Effects of diarrhea associated with specific enteropathogens on the growth of children in rural Bangladesh. Pediatrics 73:799–805.

Bowring AL, Peeters A, Freak-Poli R, Lim MS, Gouillou M, Hellard M. 2012. Measuring the accuracy of self-reported height and weight in a community-based sample of young people. BMC Med Res Methodol 12:175. https://doi.org/10.1186/1471-2288-12-175

Brunner Huber LR. 2007. Validity of self-reported height and weight in women of reproductive age. Matern Child Health J 11:137–44. https://doi.org/10.1007/s10995-006-0157-0

Case A, Paxon C. 2008. Stature and status: height, ability, and labor market outcomes. Journal of Political Economy 116:499–532. https://doi.org/10.1086/589524

Cernerud L. 1995. Height and social mobility. A study of the height of 10 year olds in relation to socio-economic background and type of formal schooling Scand J Soc Med 23:28–31. https://doi.org/10.1177/140349489502300106

Chmielewski P. 2016. The relationship between adult stature and longevity: tall men are unlikely to outlive their short peers – evidence from a study of all adult deaths in Poland in the years 2004–2008. Anthropol Rev 79:439–60. https://doi.org/10.1515/anre-2016-0032

Chmielewski P. 2018. Leukocyte count, systemic inflammation, and health status in older adults: a narrative review. Anthropol Rev 81:81–101. https://doi.org/10.2478/anre-2018-0007

Chmielewski PP. 2022. Do taller people live longer? Evaluating the relationship between adult stature and longevity. Med J Cell Biol, In press.

Chmielewski PP. 2023. The association between body height and longevity: evidence from a national population sample. Folia Morphol, In press.

Chmielewski P, Borysławski K, Chmielowiec K, Chmielowiec J. 2015a. Height loss with advancing age in a hospitalized population of Polish men and women: magnitude, pattern and associations with mortality. Anthropol Rev 78:157–68. https://doi.org/10.1515/anre-2015-0011

Chmielewski P, Borysławski K, Chmielowiec K, Chmielowiec J. 2015b. Longitudinal and cross-sectional changes with age in selected anthropometric and physiological traits in hospitalized adults: and insight from the Polish Longitudinal Study of Aging (PLSA). Anthropol Rev 78:317–36. https://doi.org/10.1515/anre-2015-0025

Chmielewski P, Borysławski K. 2016. Understanding the links between month of birth, body height, and longevity: why some studies reveal that shorter people live longer – further evidence of seasonal programming from the Polish population. Anthropol Rev 79:375–95. https://doi.org/10.1515/anre-2016-0028

Chmielewski P, Borysławski K, Chmielowiec J, Chmielowiec K. 2016. Ubytki wysokości ciała a ryzyko zgonu u osób starszych. Gerontologia Współczesna 4:73–80.

Chmielewski PP, Strzelec B. 2018. Elevated leukocyte count as a harbinger of systemic inflammation, disease progression, and poor prognosis: a review. Folia Morphol 77:171–8. https://doi.org/10.5603/FM.a2017.0101

Cizmecioglu F, Doherty A, Paterson WF, Young D, Donaldson MD. 2005. Measured versus reported parental height. Arch Dis Child 90:941–2. https://doi.org/10.1136/adc.2005.073007

Colman RJ, Anderson RM, Johnson SC, Kastman EK, Kosmatka KJ, Beasley TM, Allison DB, Cruzen C, Simmons HA, Kemnitz JW, Weindruch R. 2009. Calorie restriction delays disease onset and mortality in rhesus monkeys. Science 325:201–4. https://doi.org/10.1126/science.1173635

Davey Smith G, Hart C, Upton M, Hole D, Gillis C, Watt G, Hawthorne V. 2000. Height and risk of death among men and women: aetiological implications of associations with cardiorespiratory disease and cancer mortality. J Epidemiol Community Health 54:97–103. https://doi.org/10.1136/jech.54.2.97

Finch CE, Crimmins EM. 2004. Inflammatory exposure and historical changes in human life-spans. Science 305:1736–9. https://doi.org/10.1126/science.1092556

Gavrilova N, Gavrilov L. 2008. Can exceptional longevity be predicted? Contingencies. Journal of the American Academy of Actuaries 1:82–8.

Gunnell D, Rogers J, Dieppe P. 2001. Height and health: predicting longevity from bone length in archaeological remains. J Epidemiol Community Health 55:505–7. https://doi.org/10.1136/jech.55.7.505

He Q, Morris BJ, Grove JS, Petrovitch H, Ross W, Masaki KH, Rodriguez B, Chen R, Donlon TA, Willcox DC, Willcox BJ. 2014. Shorter men live longer: association of height with longevity and FOXO3 genotype in American men of Japanese ancestry. PLoS One 9:e94385. https://doi.org/10.1371/journal.pone.0094385

Heineck G. 2005. Up in the skies? The relationship between body height and earnings in Germany. Labour 19:469–89. https://doi.org/10.1111/j.1467-9914.2005.00302.x

Holzenberger M, Martín-Crespo RM, Vicent D, Ruiz-Torres A. 1991. Decelerated growth and longevity in men. Arch Gerontol Geriatr13:89–101. https://doi.org/10.1016/0167-4943(91)90019-m

Jelenkovic A, Sund R, Hur YM, Yokoyama Y, Hjelmborg JV, Möller S, Honda C, Magnusson PK, Pedersen NL, Ooki S, Aaltonen S, Stazi MA, Fagnani C, D'Ippolito C, Freitas DL, Maia JA, Ji F, Ning F, Pang Z, Rebato E, Busjahn A, Kandler C, Saudino KJ, Jang KL, Cozen W, Hwang AE, Mack TM, Gao W, Yu C, Li L, Corley RP, Huibregtse BM, Derom CA, Vlietinck RF, Loos RJ, Heikkilä K, Wardle J, Llewellyn CH, Fisher A, McAdams TA, Eley TC, Gregory AM, He M, Ding X, Bjerregaard-Andersen M, Beck-Nielsen H, Sodemann M, Tarnoki AD, Tarnoki DL, Knafo-Noam A, Mankuta D, Abramson L, Burt SA, Klump KL, Silberg JL, Eaves LJ, Maes HH, Krueger RF, McGue M, Pahlen S, Gatz M, Butler DA, Bartels M, van Beijsterveldt TC, Craig JM, Saffery R, Dubois L, Boivin M, Brendgen M, Dionne G, Vitaro F, Martin NG, Medland SE, Montgomery GW, Swan GE, Krasnow R, Tynelius P, Lichtenstein P, Haworth CM, Plomin R, Bayasgalan G, Narandalai D, Harden KP, Tucker-Drob EM, Spector T, Mangino M, Lachance G, Baker LA, Tuvblad C, Duncan GE, Buchwald D, Willemsen G, Skytthe A, Kyvik KO, Christensen K, Öncel SY, Aliev F, Rasmussen F, Goldberg JH, Sørensen TI, Boomsma DI, Kaprio J, Silventoinen K. 2016. Genetic and environmental influences on height from infancy to early adulthood: An individual-based pooled analysis of 45 twin cohorts. Sci Rep 6:28496. https://doi.org/10.1038/srep28496

Kabat GC, Anderson ML, Heo M, Hosgood HD 3rd, Kamensky V, Bea JW, Hou L, Lane DS, Wactawski-Wende J, Manson JE, Rohan TE. 2013. Adult stature and risk of cancer at different anatomic sites in a cohort of postmenopausal women. Cancer Epidemiol Biomarkers Prev 22:1353–63. https://doi.org/10.1158/1055-9965.EPI-13-0305

Kemkes-Grottenthaler A. 2005. The short die young: the interrelationship between stature and longevity-evidence from skeletal remains. Am J Phys Anthropol 128:340–7. https://doi.org/10.1002/ajpa.20146

Kemnitz JW. 2011. Calorie restriction and aging in nonhuman primates. ILAR J 52:66–77.

Kirkwood TBL. 2017. Why and how are we living longer? Exp Physiol 102:1067–74. https://doi.org/10.1113/EP086205

Krzyżanowska M, Umławska W. 2002. Measured versus self-reported body height. Int J Anthropol 17:113–20. https://doi.org/10.1007/BF02447402

Lawlor DA, Ebrahim S, Davey Smith G. 2002. The association between components of adult height and Type II diabetes and insulin resistance: British Women's Heart and Health Study. Diabetologia 45:1097–106. https://doi.org/10.1007/s00125-002-0887-5

Lawlor DA, Taylor M, Davey Smith G, Gunnell D, Ebrahim S. 2004. Associations of components of adult height with coronary heart disease in postmenopausal women: the British women's heart and health study. Heart 90:745–9. https://doi.org/10.1136/hrt.2003.019950

Little MA. 2020. Evolutionary strategies for body size. Front Endocrinol 11:107.

Magnusson PK, Rasmussen F, Gyllensten UB. 2006. Height at age 18 years is a strong predictor of attained education later in life: cohort study of over 950,000 Swedish men. Int J Epidemiol 35:658–63. https://doi.org/10.1093/ije/dyl011

Maier AB, van Heemst D, Westendorp RG. 2008. Relation between body height and replicative capacity of human fibroblasts in nonagenarians. J Gerontol A Biol Sci Med Sci 63:43–5. https://doi.org/10.1093/gerona/63.1.43

Marco-Gracia FJ, Puche J. 2021. The association between male height and lifespan in rural Spain, birth cohorts 1835-1939. Econ Hum Biol 43:101022. https://doi.org/10.1016/j.ehb.2021.101022

Martorell R, Habicht JP, Yarbrough C, Lechtig A, Klein RE, Western KA. 1975. Acute morbidity and physical growth in rural Guatemalan children. Am J Dis Child 129:1296–301. https://doi.org/10.1001/archpedi.1975.02120480022007

Mattison JA, Colman RJ, Beasley TM, Allison DB, Kemnitz JW, Roth GS, Ingram DK, Weindruch R, de Cabo R, Anderson RM. 2017. Caloric restriction improves health and survival of rhesus monkeys. Nat Commun 8:14063. https://doi.org/10.1038/ncomms14063

Meyer HE, Selmer R. 1999. Income, educational level and body height. Ann Hum Biol 26:219–27. https://doi.org/10.1080/030144699282723

Miller RA, Harper JM, Galecki A, Burke DT. 2002. Big mice die young: early life body weight predicts longevity in genetically heterogeneous mice. Aging Cell 1:22–9. https://doi.org/10.1046/j.1474-9728.2002.00006.x

Nunney L. 2018. Size matters: height, cell number and a person's risk of cancer. Proc Biol Sci 285:20181743. https://doi.org/10.1098/rspb.2018.1743

Olfert MD, Barr ML, Charlier CM, Famodu OA, Zhou W, Mathews AE, Byrd-Bredbenner C, Colby SE. 2018. Self-Reported vs. Measured Height, Weight, and BMI in Young Adults. Int J Environ Res Public Health. 15:2216. https://doi.org/10.3390/ijerph15102216

Öberg S. 2014. Long-term changes of socioeconomic differences in height among young adult men in Southern Sweden, 1818–1968. Econ Hum Biol 15:140–52. https://doi.org/10.1016/j.ehb.2014.08.003

Özaltin E. 2012. Commentary: the long and short of why taller people are healthier and live longer. Int J Epidemiol 41:1434–5. https://doi.org/10.1093/ije/dys144

Paajanen TA, Oksala NK, Kuukasjärvi P, Karhunen PJ. 2010. Short stature is associated with coronary heart disease: a systematic review of the literature and a meta-analysis. Eur Heart J 31:1802–9. https://doi.org/10.1093/eurheartj/ehq155

Peck AM, Vågerö DH. 1989. Adult body height, self perceived health and mortality in the Swedish population. J Epidemiol Community Health 43:380–4. https://doi.org/10.1136/jech.43.4.380

Perkins JM, Subramanian SV, Davey Smith G, Özaltin E. 2016. Adult height, nutrition, and population health. Nutr Rev 74:149–65. https://doi.org/10.1093/nutrit/nuv105

Raghavan S, Huang J, Tcheandjieu C, Huffman JE, Litkowski E, Liu C, Ho YA, Hunter-Zinck H, Zhao H, Marouli E, North KE; VA Million Veteran Program; Lange E, Lange LA, Voight BF, Gaziano JM, Pyarajan S, Hauser ER, Tsao PS, Wilson PWF, Chang KM, Cho K, O'Donnell CJ, Sun YV, Assimes TL. 2022. A multi-population phenome-wide association study of genetically-predicted height in the Million Veteran Program. PLoS Genet 18:e1010193. https://doi.org/10.1371/journal.pgen.1010193

Rietveld CA, Hessels J, van der Zwan P. 2015. The stature of the self-employed and its relation with earnings and satisfaction. Econ Hum Biol 17:59–74. https://doi.org/10.1016/j.ehb.2015.02.001

Rollo CD. 2002. Growth negatively impacts the life span of mammals. Evol Dev 4:55–61.

Salaris L, Poulain M, Samaras TT. 2012. Height and survival at older ages among men born in an inland village in Sardinia (Italy), 1866-2006. Biodemography Soc Biol 58:1–13. https://doi.org/10.1046/j.1525-142x.2002.01053.x

Samaras TT. 2013. Shorter height is related to lower cardiovascular disease risk - a narrative review. Indian Heart J 65:66–71. https://doi.org/10.1016/j.ihj.2012.12.016

Samaras TT, Elrick H, Storms LH. 2003. Is height related to longevity? Life Sci 72:1781–802. https://doi.org/10.1016/s0024-3205(02)02503-1

Silventoinen K, Lahelma E, Rahkonen O. 1999. Social background, adult body-height and health. Int J Epidemiol 28:911–8. https://doi.org/10.1093/ije/28.5.911

Silventoinen K, Kaprio J, Lahelma E. 2000. Genetic and environmental contributions to the association between body height and educational attainment: a study of adult Finnish twins. Behav Genet 30:477–85. https://doi.org/10.1023/a:1010202902159

Silventoinen K, Sammalisto S, Perola M, Boomsma DI, Cornes BK, Davis C, Dunkel L, De Lange M, Harris JR, Hjelmborg JV, Luciano M, Martin NG, Mortensen J, Nisticò L, Pedersen NL, Skytthe A, Spector TD, Stazi MA, Willemsen G, Kaprio J. 2003. Heritability of adult body height: a comparative study of twin cohorts in eight countries. Twin Res 6:399–408. https://doi.org/10.1375/136905203770326402

Sohn K. 2016. Now, the Taller Die Earlier: The Curse of Cancer. J Gerontol A Biol Sci Med Sci 71:713–9. https://doi.org/10.1093/gerona/glv065

Tian T, Li X, Zhang J. 2019. mTOR signaling in cancer and mtor inhibitors in solid tumor targeting therapy. Int J Mol Sci 20:755. https://doi.org/10.3390/ijms20030755

Turrell G. 2002. Socio-economic position and height in early adulthood. Aust N Z J Public Health. 26:468–72. https://doi.org/10.1111/j.1467-842x.2002.tb00349.x

van Heemst D, Beekman M, Mooijaart SP, Heijmans BT, Brandt BW, Zwaan BJ, Slagboom PE, Westendorp RGJ. 2005. Reduced insulin/IGF-1 signalling and human longevity. Aging Cell 4:79–85. https://doi.org/10.1111/j.1474-9728.2005.00148.x

Villareal DT, Fontana L, Weiss EP, Racette SB, Steger-May K, Schechtman KB, Klein S, Holloszy JO. 2006. Bone mineral density response to caloric restriction-induced weight loss or exercise-induced weight loss: a randomized controlled trial. Arch Intern Med 166:2502–10. https://doi.org/10.1001/archinte.166.22.2502

Weiss EP, Racette SB, Villareal DT, Fontana L, Steger-May K, Schechtman KB, Klein S, Ehsani AA, Holloszy JO, Washington University School of Medicine CALERIE Group. 2007. Lower extremity muscle size and strength and aerobic capacity decrease with caloric restriction but not with exercise-induced weight loss. J Appl Physiol 102:634–40. https://doi.org/10.1152/japplphysiol.00853.2006

Wilhelmsen L, Svärdsudd K, Eriksson H, Rosengren A, Hansson PO, Welin C, Odén A, Welin L. 2011. Factors associated with reaching 90 years of age: a study of men born in 1913 in Gothenburg, Sweden. J Intern Med 269:441–51. https://doi.org/10.1111/j.1365-2796.2010.02331.x

Wirén S, Häggström C, Ulmer H, Manjer J, Bjørge T, Nagel G, Johansen D, Hallmans G, Engeland A, Concin H, Jonsson H, Selmer R, Tretli S, Stocks T, Stattin P. 2014. Pooled cohort study on height and risk of cancer and cancer death. Cancer Causes Control 25:151–9.

You C, Zhou Z, Wen J, Li Y, Pang CH, Du H, Wang Z, Zhou XH, King DA, Liu CT, Huang J. 2021. Polygenic Scores and Parental Predictors: An Adult Height Study Based on the United Kingdom Biobank and the Framingham Heart Study. Front Genet 12:669441. https://doi.org/10.3389/fgene.2021.669441

Zou Z, Tao T, Li H, Zhu X. 2020. mTOR signaling pathway and mTOR inhibitors in cancer: progress and challenges. Cell Biosci 10:31. https://doi.org/10.1186/s13578-020-00396-1

Anthropological Review • Vol. 86(1), 91–106 (2023)

ANTHROPOLOGICAL REVIEW

Available online at: https://doi.org/10.18778/1898-6773.86.1.08

Trends in body size and prevalence of underweight and overweight in 7–9 year old children from eastern Poland between 2006 and 2021

Agnieszka Wasiluk[1], *Anna Bodasińska*[2], *Jerzy Saczuk*[1]

[1] Department of Health Promotion, Faculty of Physical Education and Health in Biała Podlaska, Józef Piłsudski University of Physical Education in Warsaw, Poland
[2] Department of Team Games, Faculty of Physical Education and Health in Biała Podlaska, Józef Piłsudski University of Physical Education in Warsaw, Poland

Abstract: Malnutrition and the overnutrition of children and adolescents is a severe problem in most countries. Aim of the study: Determination of fifteen-year changes in body height, and BMI in girls and boys living in towns and villages in eastern Polish voivodeships.

In 2006, 2016, and 2021 a study was conducted on children and adolescents living in the Podlaskie, Lubelskie, and Podkarpackie voivodeships (7048 girls and 7686 boys aged 7–9 years). Body mass index (BMI) was calculated based on height and weight measurements. In the calendar age groups, arithmetic means and dissemination measures for body height and BMI were calculated on particular time periods of the study. The statistical significance of the differences between the groups was conducted using the ANOVA analysis of variance and the Newmann-Keuls test. From the research material, study participants exhibiting underweight, overweight and those falling within a normal range of weight-to-height proportions were selected taking into account places of residence (town, village). The statistical significance of the differences between the number of people classified into the above-described groups was determined using the χ^2 test.

In the analysed period in groups of girls, a systematic increase in body height was observed. However, in boys, such tendency was found only in rural residents. In the period of 2006–2016, greater changes in BMI were found in girls from rural areas and boys from cities. The opposite observation was recorded in the 2016–2021 period. In the years between 2006 and 2021, the incidence of both underweight and normal BMI decreased, while the incidence of overweight and obesity increased.

Our results indicate the need for conducting systematic research assessing the nutritional status of young people living in the Lubelskie and Podlaskie voivodships, as well as an in-depth analysis of the causes of malnutrition and undertaking educational activities.

Key words: secular trend, town, village, girls, boys, BMI.

Original article

Received: 22.02.2023; Revised: 15.03.2023; Accepted: 16.03.2023

Introduction

The issue of the nutritional status of children and adolescents in various regions of the world is widely discussed. Data shows that the average BMI value and the prevalence of obesity have increased worldwide (NCD Risk Factor Collaboration 2017). Although the trend of increasing excessive body weight in children and adolescents has stopped in highly developed countries (Wabitsch et al. 2017), it continues in developing countries (Rivera et al. 2014). As a result, a double threat to the health of children and adolescents can be observed. On the one hand, the number of people with excessive body weight is increasing, and, on the other hand, the problem of malnutrition in adolescents is becoming more visible. Analyses conducted by Garrido-Miguel et al. (2021) show that in Europe the prevalence of underweight is significant and amounts to approximately 8–9% of population, with an upward trend. The coexistence of malnutrition and overnutrition is a serious problem in most countries and is also noticeable in the eastern regions of Poland. The research by Saczuk (2018) conducted in the years 1986–2016 shows that the highest incidence of both deficiency and excess body weight is observed in youngest children.

The last fifteen years in Poland have been a period of rapid changes and social transformations due to the accession to the European Union. At that time, a deepening disproportion in the economic status of Polish society has been observed, and differences in the nutritional status of children and adolescents has become more apparent. This problem is observed both in areas of the country with higher economic indicators (Nowak-Szczepanska et.al 2021), as well as in regions exhibiting a slower pace of development (Wasiluk and Saczuk 2015). During the last five years the Family 500+ program in the field of social policy has been implemented, which was designed to help families raise children by providing monthly childcare benefits in the amount of PLN 500 for each child in the family. Moreover, changes in lifestyle related to the covid-19 pandemic has also been observed. It is, therefore, of great importance to determine the rate at which changes in the nutritional status occur in children living in different environments, including those living in economically underdeveloped areas of the country. The aim of this study is to determine changes observed during the last fifteen years in body height, BMI, and the incidence of underweight, normal weight-to-height proportions, and overweight among girls and boys living in towns and villages in eastern Polish voivodships.

Material and methods

In the years 2005–2006, as part of the statutory research of the Academy of Physical Education in Warsaw (D.S 45), research was carried out on children and adolescents aged 7–19. This included a continuation of the observations conducted in 1985–1986 and 1995–1996 (Saczuk 2011). During the first part of the study (1985–1986), 70 schools were randomly selected from the list of educational institutions obtained from the Education Superintendents, in accordance with the settlement structure of these areas, aimed to maintain an equal number in all voivodships. All students in each school were measured. In 2006, other educational institutions were randomized to the schools evaluated twenty years earlier, aiming to maintain comparable numbers of rural and urban residents. The study covered 3691 students, including 1703 girls and 1988 boys aged 7–9, living in eastern voivodeships of the country (Podlaskie, Lubelskie, and Podkarpackie).

Observations covering the same schools were repeated in 2015–2016 as a part of the statutory research of the Academy of Physical Education in Warsaw (D.S 203). Data of 2,149 students was collected, including 1,024 girls and 1,125 boys aged 7–9. Research staff of the AWF Branch in Biała Podlaska, as well as school teachers and students of the Department of Health Promotion, were assisting in conducting the study.

This study, with the consent of the Rector of the University of Physical Education in Warsaw, also includes data obtained from a research conducted in 2021 as a part of the nationwide program "Active return to school – PE with AWF", of which the authors of this study were co-executors. The results of 4321 schoolgirls and 4573 schoolchildren were used in the study, which constituted 8894 respondents from the following voivodships: Podlaskie, Lubelskie, and Podkarpackie. In the "Active return to school – physical education from the University of Physical Education" program, the data were collected by properly trained physical education teachers.

Detailed information regarding the number of examined girls and boys in subsequent observation dates, including age and the population size of the place of residence, is presented in Table 1.

Table 1. The number of girls and boys surveyed, taking into account the date of observation and place of residence

year of study	town			village		
	2006	2016	2021	2006	2016	2021
age (years)	boys					
7	214	132	637	213	222	651
8	358	153	801	483	304	728
9	286	129	879	434	185	877
total	858	414	2317	1130	711	2256
age (years)	girls					
7	251	116	586	265	203	682
8	313	143	752	274	205	690
9	272	136	816	328	221	795
total	836	395	2154	867	629	2167

Source: own study.

The research was conducted in accordance with the principles contained in the Declaration of Helsinki and was approved by the Senate Ethics Committee operating at the University of Physical Education in Warsaw. Questionnaire-derived information regarding the date of birth and the environmental conditions in which the respondents were brought up was collected. Anthropometric measurements were carried out in accordance with approved anthropometric techniques (IBP 1969). Body mass index (BMI), i.e., weight in kilograms divided by height squared of the study participants was also measured. Gender, arithmetic means, and dissemination measures for body height and BMI were also calculated within the calendar age groups. Such statistics were made using studies from 2006, 2016, and 2021. Subsequently, differences in the size of the mentioned development indicators were calculated between the dates of the research. Significant differences between the groups were verified by the ANOVA analysis of variance and the Newmann-Keuls test.

From the research material, study participants exhibiting underweight, overweight, and normal BMI values were selected, basing on the selection method developed by Cola et al. (2007, 2010). The obtained results allowed to calculate the percentages of girls and boys with I°, II°, and III° underweight, normal BMI, overweight and obese. Such calculations were made at subsequent observation dates, taking into account places of residence (town, village). Subsequently, differences in BMI percentage between 2016 and 2006 and 2021 and 2016 were calculated. This allowed to determine the size and direction of changes in BMI. Statistical differences between the number of people classified into each of the above-described groups was determined using the χ^2 test.

Results

From 2006 to 2016, body height of girls from towns in eastern Poland increased by an average of 1.76 cm (Figure 1, Table 2). The greatest changes were observed in nine-year-olds (2.88 cm), and the smallest in eight-year-olds (2.88 cm). In the analysed decade, greater differences in body height were observed in rural girls. The average difference, when all age groups were considered, was 2.33 cm. The greatest changes in body height were observed in eight-year-olds (3.96 cm), and the smallest in nine-year-olds (0.64 cm) although not all changes were statistically significant.

In the years 2016–2021, the body height of young women living in towns of eastern Poland increased by 0.88 cm. The greatest differences were found in eight-year-olds (1.78 cm), followed by nine-year-olds (1.20 cm). However, among the youngest girls, the difference was -0.33 cm. Among girls from the village in the analysed period, greater differences in height were found. The average difference in body height between 2021 and 2016 was 1.71 cm. The largest changes were noted in nine-year-olds (3.39 cm) and seven-year-olds (1.78 cm). In 2016 and 2021, the results of eight-year-olds were at a similar level, the difference was -0.05 cm.

In boys, a large, statistically significant increase in body height was also observed between 2006 and 2016. In urban dwellers, height increased by 3.73 cm, and in rural areas by 2.01 cm. In urban residents, the greatest differences were noted in seven-year-olds (5.27 cm), followed by nine-year-olds (3.54 cm) and eight-year-olds (2.37 cm). Among the villagers, the greatest changes were observed at the age of 7 years (3.21 cm), followed by 8 years (2.10 cm) and nine years (0.73 cm).

Lower values of the secular trends of the body height of boys were recorded in the years 2016–2021. In 2021, urban residents had a slightly lower height (-0.42 cm) compared to the results from 2016. A significant deceleration was observed in seven-year-olds (-2.15 cm) while a slight deceleration in nine-year-olds (-0.13 cm). In eight-year-olds, the difference was 1.03 cm. In the same period of time, body height among boys from rural areas increased on average by 1.65 cm, and statistically significant differences were found in nine-year-olds (3.04 cm) and eight-year-olds (1.34 cm).

Table 2. Body height of girls and boys, taking into account the dates of observation and place of residence

age (years)	year of study						Anova	Newmann-Keuls test		
	2006		2016		2021			2006–2016	2006–2021	2016–2021
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD				
	girls town									
7	124.81	6.10	127.14	7.10	126.81	6.95	8.67	4.34*	5.55*	0.68
8	130.26	6.84	130.34	6.16	132.12	6.45	11.23	0.17	6.00*	4.23*
9	134.36	7.27	137.24	2.25	138.44	6.80	39.44	5.90*	12.55*	2.79*
	girls village									
7	122.81	5.35	125.21	6.55	126.99	6.70	40.73	5.65*	12.63*	4.92*
8	127.87	6.77	131.83	6.73	131.78	6.40	29.94	8.67*	10.62*	0.14
9	134.04	7.35	134.68	8.03	138.07	6.56	40.9	1.37	10.82*	9.02*
	boys town									
7	125.31	6.01	130.58	6.87	128.43	6.23	34.47	10.74*	9.76*	4.36*
8	130.25	5.97	132.62	6.6	133.65	6.35	36.31	5.53*	12.05*	2.63
9	135.66	7.74	139.2	7.96	139.07	6.54	24.81	6.67*	9.77*	0.28
	boys village									
7	124.23	6.39	127.44	6.32	128.00	6.29	30.76	7.65*	11.02*	1.61
8	130.28	5.96	132.38	5.76	133.72	6.54	44.59	6.53*	13.35*	4.47*
9	135.27	7.7	136.00	8.58	139.04	6.63	44.62	1.63	12.59*	7.36*

*statistically significant differences at p≤0.05

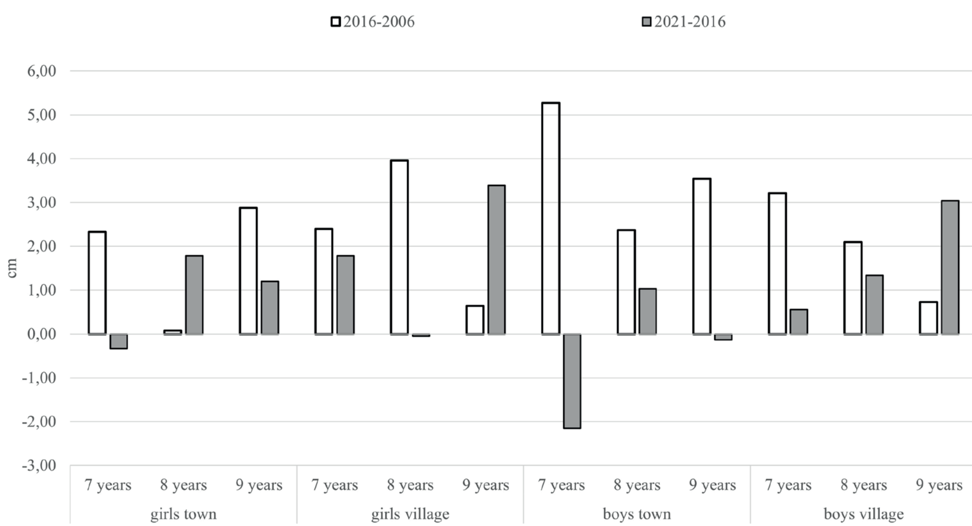


Fig. 1. Differences in the body height of girls and boys in particular stages of the study, taking into account the size of the place of residence

During the period of 2006–2016, the BMI of urban girls aged 7–9 increased, on average, by 0.17 kg/m^2. During the same period, BMI of seven-year-olds decreased by -0.19 kg/m^2, while an increase of 0.49 kg/m^2 and 0.22 kg/m^2 was observed among nine-year-olds and eight-year-olds respectively (Table 3, Figure 2). Between the years 2006 and 2016, rural girls showed greater differences in BMI, on average by 0.23 kg/m^2. The highest values of the secular trend were found at the age of 8 (0.75 kg/m^2), followed by a seven-year-old (0.17 kg/m^2). Nine-year-olds recorded a decrease in the value of this height-weight index by 0.24 kg/m^2.

It should be emphasized that in 2016–2021, much more significant changes in BMI were observed than in the previous decade. In girls living in towns, BMI increased by an average of 1.14 kg/m^2, and 0.68 kg/m^2 in their peers from the countryside. In the first group, the most significant differences were observed among seven-year-olds (1.65 kg/m^2), followed by eight-year-olds (0.99 kg/m^2), and the smallest in nine-year-olds (0.79 kg/m^2). In the respondents from the countryside, the greatest changes were noted in nine-year-olds (0.74 kg/m^2) and eight-year-olds (0.72 kg/m^2). The lowest changes in BMI values were observed among seven-year-olds (0.58 kg/m^2).

From 2006 to 2016, a greater increase in BMI was observed among boys from towns compared to their peers living in countryside, with the average differences of 0.76 kg/m^2 and 0.47 kg/m^2 respectively. In boys from towns, the greatest differences in BMI values were found in nine-year-olds (0.84 kg/m^2), while the greatest BMI differences in boys living in rural areas were found among eight-year-olds (0.62 kg/m^2). On the other hand, the smallest differences in rural residents were recorded at the age of 9 (0.36 kg/m^2) and at the age of 8 in urban respondents (0.65 kg/m^2).

Between the years 2016 and 2021, greater changes in BMI values were recorded in students of rural schools compared to their peers from towns. The average differences, when considering all age groups, were as follows: 1.02 kg/m^2 and 0.56 kg/m^2. Among urban residents, the greatest changes were found in seven-year-olds (0.99 kg/m^2), and the smallest in nine-year-olds (0.19 kg/m^2). On the other hand, in the respondents from the countryside, the difference in nine-year-olds was 1.14 kg/m^2, and in eight-year-olds it was 0.89 kg/m^2. All described above changes were statistically significant at the level of $p< 0.05$.

The picture of secular trends in body mass index described above is somewhat flattened and represents the results of all study participants. It is interesting, however, what changes occurred in girls regarding weight-height proportions and individual degrees of underweight, overweight, and obesity. Figure 3 and Table 4 show that the percentage of girls with I° underweight decreased between 2006 and 2016 and this decrease was statistically significantly ($p<0.05$) (5.07%). In the remaining groups, the differences were small and statistically insignificant. In contrast, between the years 2016 and 2021, a significant ($p< 0.05$) reduction in the incidence of III° underweight (by 3.67%) and overweight (by 4.41%) was observed among young women living in towns. On the other hand, there was a significant increase (by 11.00%) in the incidence of obesity.

Table 3. BMI of girls, taking into account the dates of observation and place of residence

age (years)	year of study						Anova	Newmann-Keuls test		
	2006		2016		2021			2006	2016	2021
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD				
	girls town									
7	15.33	2.20	15.14	2.59	16.79	3.01	18.46	4.38*	4.46*	8.15*
8	15.96	2.21	16.18	2.53	17.17	3.16	16.81	0.10	7.28*	5.26*
9	16.75	2.50	17.24	2.25	18.03	3.44	7.72	0.21	4.70*	3.80*
	girls village									
7	16.12	2.42	16.29	2.50	16.87	2.96	30.05	5.30*	10.91*	3.76*
8	16.16	2.43	16.91	2.51	17.63	3.54	23.01	4.31*	9.31*	4.06*
9	17.29	2.72	17.05	2.80	17.79	3.41	11.90	1.42	6.18*	4.36*
	boys town									
7	15.01	2.10	15.80	2.36	16.79	2.74	41.15	3.94*	12.42*	5.71*
8	16.25	1.90	16.90	2.96	17.40	3.19	20.07	3.32*	8.92*	2.80*
9	16.92	2.40	17.76	3.15	17.95	3.11	12.99	3.77*	7.20*	0.96
	boys village									
7	15.74	2.15	16.16	2.35	17.18	3.23	24.65	2.14	8.95*	6.39*
8	16.37	1.78	16.99	3.42	17.88	3.35	38.98	4.05*	12.30*	6.23*
9	17.19	2.32	17.55	3.29	18.69	3.69	33.07	1.75	10.96*	6,01*

*statistically significant differences at p≤0.05

Fig. 2. Differences in the BMI of girls and boys at particular stages of the study, taking into account the size of the place of residence

Between the years 2006 and 2016, a significant ($p<0.05$) decrease in the prevalence of overweight (-3.98%) as well as an increase in obesity (by 6.12%) and II degree underweight (1.64%) were found among rural girls. Between the years 2016 and 2021, a significant ($p<0.05$) increase in the incidence of overweight (by 4.63%) and obesity (by 7.50%) was observed, as well as a decrease of II° underweight (2.14%) and normal BMI (7.97%).

Using the χ^2 test, environmental differences between all groups in particular study dates showed significant ($p< 0.05$) differences in the occurrence of III degree underweight (1.69% and 2.18%) in 2006 and 2016, in overweight (3, 81%) in 2006 and in obesity (3.50%) in 2016. Other differences were statistically insignificant (Table 4).

Table 4. Percentage of examined girls in 2006, 2016, and 2021 from towns and villages in groups with III°, II°, I° degree of underweight, normal BMI, overweight and obesity, and χ^2 test values for environmental differences

	year of study			χ^2 test values		
	2006	2016	2021	2006 – 2016	2006 – 2021	2016 – 2021
percentage of urban girls surveyed						
III° underweight	3.34	4.60	0.93	1.317	26.963*	21.948*
II° underweight	3.15	2.91	2.18	0.065	3.233	0.722
I° underweight	10.88	5.81	7.94	8.952*	7.882*	2.068
normal weight	61.16	63.20	58.87	0.136	0.507	0.668
overweight	18.06	18.89	14.48	0.104	6.286*	3.584*
obesity	3.40	4.60	15.60	1.178	139.327*	35.321*
percentage of village girls surveyed						
III° underweight	1.65	1.42	0.78	2.062	3.184	2.062
II° underweight	2.48	4.12	1.98	8.411*	0.520	8.411*
I° underweight	10.91	9.66	8.26	1.082	3.264	1.082
normal weight	68.76	66.48	58.51	3.372	4.879*	3.372
overweight	14.21	10.23	14.86	7.857*	0.117	7.857*
obesity	1.98	8.10	15.60	21.721*	90.472*	21.721*
χ^2 test values for environmental differences						
III° underweight	4.748*	7.900*	0.260			
II° underweight	0.681	0.063	0.199			
I° underweight	0.000	0.864	0.128			
normal weight	2.404	0.219	0.014			
overweight	3.410*	0.289	0.090			
obesity	3.114	10.958*	0.009			

*statistically significant differences at $p\leq0.05$

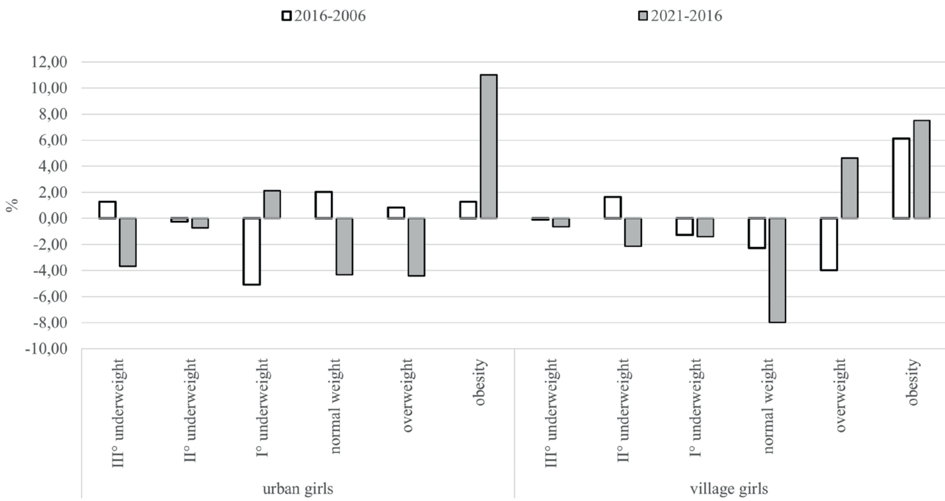


Fig. 3. Differences in the percentage of BMI in girls at particular stages of the study, taking into account the size of the place of residence

From 2006 to 2016, significant changes in weight-to-height proportions were also observed in boys (Figure 4, Table 5). Among urban residents, a significant ($p<0.05$) increase in the frequency of III○ underweight by 2.60% and overweight by 6.33% was observed. In the remaining BMI groups, the differences were small and statistically insignificant. A similar direction of changes in young residents of towns in eastern Poland was observed between the years 2016 and 2021. A decrease of 3.95% and 1.52% was found among the respondents exhibiting III° and II° underweight respectively, and an increase in the prevalence of obesity by 6.41%. Such differences were also observed among boys from rural areas. Between the years 2006 and 2016, a significant ($p< 0.05$) decrease in the percentage of underweight III° (by 1.81%) and an increase in the percentage of underweight I° (by 2.74%) among boys was found with obesity by 5.45%. Between the years 2016 and 2021, significant differences ($p<0.05$) were observed among boys from rural areas in all age groups. There was a decrease in the incidence of underweight III° (by 0.84%), II° (by 2.88%), I° (by 3.76%), and normal BMI (by 9.17%). The opposite changes were observed in overweight (9.67% and obesity (6.97%).

When evaluating environmental differences between urban and rural boys in 2006, a significant ($p<0.05$) higher frequency of underweight III○ (by 1.23%) and lower underweight II° (by 1.34%) was observed in rural boys. In 2016, compared to their peers from towns, boys from rural areas had a higher percentage of underweight I° subjects (by 3.85%) and obesity (by 3.50%). Inverse relationships were observed in the incidence of underweight III° (by 3.18%) and overweight (by 8.66%). In 2021, a higher percentage of overweight (by 3.00%) and obesity (by 4.06%) was found, while the frequency of normal BMI was lower (by 6.16%).

Table 5. Percentage of examined boys in 2006, 2016, and 2021 from towns and villages in groups with III°, II°, I° degree of underweight, normal BMI, overweight and obesity, and χ^2 test values for environmental differences

	year of study			χ^2 test values		
	2006	2016	2021	2006–2016	2006–2021	2016–2021
percentage of urban boys surveyed						
III° underweight	2.00	4.60	0.65	7.527*	14.749*	29.383*
II° underweight	2.72	2.91	1.39	0.039	8.907*	4.140*
I° underweight	8.00	5.81	6.59	2.124	2.615	0.315
normal weight	70.93	63.20	63.47	1.764	5.019*	0.003
overweight	12.56	18.89	16.90	7.821*	11.213*	0.667
obesity	3.78	4.60	11.01	0.530	68.128*	16.026*
percentage of village boys surveyed						
III° underweight	3.23	1.42	0.58	5.416*	28.565*	4.255*
II° underweight	1.38	4.12	1.24	10.967*	0.097	19.072*
I° underweight	9.46	9.66	5.90	0.015	10.092*	9.613*
normal weight	71.97	66.48	57.31	1.000	12.992*	4.585*
overweight	11.30	10.23	19.90	0.377	24.914*	27.821*
obesity	2.65	8.10	15.07	21.773*	99.863*	19.427*
χ^2 test values for environmental differences						
III° underweight	3.42*	9.422*	0.100			
II° underweight	4.91*	1.044	0.181			
I° underweight	1.32	4.572*	0.820			
normal weight	0.05	0.261	4.472*			
overweight	0.69	12.273*	4.736*			
obesity	2.20	4.660*	12.863*			

*statistically significant differences at p≤0.05

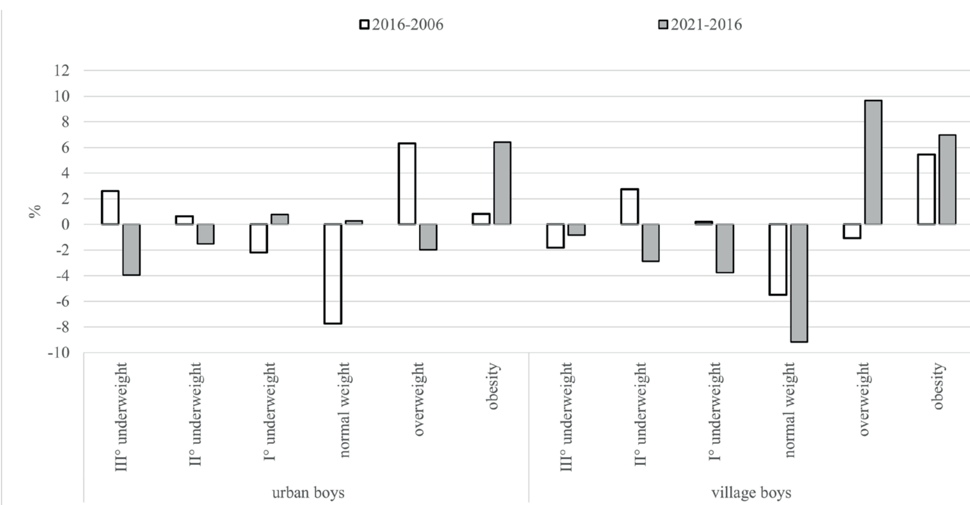


Fig. 4. Differences in the percentage of BMI in boys at particular stages of the study, taking into account the size of the place of residence

Discussion

The observed phenomenon of high growth of societies, resulting in an increase in body weight relative to its height, as well as the pace of intergenerational changes in BMI depends, to a large extent, on the socio-economic status and living conditions. Lower values of secular trends were observed among rural girls and boys who exhibited a lower standard of living. With the improvement of the latter, these differences tend to increase, which has been reported in studies conducted in countries with a rapid economic growth. In addition, in countries with a high degree of industrialization, a weakening trend in body height is observed coupled with an accelerated increase in body weight (Fudvoye and Parent 2017). Nevertheless, there are still significant differences in body height among young people living in economically developed countries in Europe and the USA (Gomula et.al 2021). Body weight, on the other hand, is less genetically determined and more influenced by the environment.

The socio-economic changes that have taken place after Poland's accession to the European Union has had an impact on the magnitude of the secular trend in somatic development. Among girls and boys studied in selected regions of the country observed from 1966 to 2012, a positive secular trend was observed in both body height and BMI, with the exception of the relative body weight of girls aged 14–18 (Kozieł et al. 2014, Gomula et al. 2015). The authors observed greater changes in body height in the years 1966–1988 compared to the years 1988–2012. However, regarding BMI, the differences were greater in the years 1988–2012, i.e., in the period of political transformation and post-accession to the European Union. Dobosz (2012), in a study on a large nationwide sample, found a slowdown in the growth rate of the body height of children and adolescents in the years between 1999 and 2009 compared to the period of 1989–1999, as evidenced by the results of the oldest adolescents. On the other hand, in younger age groups, he noted the further acceleration of developmental processes exhibited by an acceleration of growth and maturation. In addition, a high rate of change in body weight observed in previous decades was maintained, especially among the youngest, among whom the greatest increase in the BMI values was observed (Dobosz 2012).

The secular trend in somatic features varied depending on region. For instance, in children and adolescents from Krakow in the years between 2000 and 2010, the average body height increased slightly (by approx. 1.00 cm), with a greater increase in body weight and BMI (Kowal 2011). Greater differences in growth were observed in primary and lower secondary school students from Lower Silesia during the 2001–2002 and 2010–2011 periods. The girls' average body height increased from 1.75 cm to 2.45 cm. A significant increase in average body weight and BMI was also found (Ignasiak et al. 2016). In addition, in the years between 1986 and 2006, schoolgirls from eastern Poland exhibited an increase in body height and weight, resulting in higher BMI values. The greatest changes were observed in the period of 1996–2006 especially among girls in the prepubertal and pubertal periods, which indicates the acceleration of puberty (Saczuk 2018). Significant secular changes in the height and weight of rural schoolgirls from central-western Poland in the 1986–2016 period were reported by the Bartkowiak et al. (2021)

study, which showed an average increase in the girls' body height by 4.65 cm and body weight by 5.20 kg. In the line with the above study, we show that the trend of growing taller was still observed, with greater differences observed urban boys and girls from the countryside. However, in the next five years, higher values of secular trends of this somatic feature were found in girls from towns and boys from rural areas. Interestingly, in the years between 2016 and 2021, height changes among boys from towns were at a similar level. The magnitude of these changes might have been influenced by the environment of the place of residence. The lifestyle of young inhabitants of towns and villages differs significantly (Kaczmarek and Wolański 2018). Such changes may also be caused by the acceleration of puberty, as well as "catching up with developmental delays" in rural residents, which has been reported in previous years (Saczuk 2018). It has been previously shown that when the living conditions improve (when the stress stops), the slowdown in the growth rate occurring in childhood is quickly compensated (the catch-up growth phenomenon).

In the first of the analysed decades, greater changes in body mass index were observed in girls from rural areas and boys from towns. However, in the years between 2016 and 2021, higher BMI values were recorded in boys from rural areas as well as girls from towns. Moreover, in the years between 2016 and 2021, the differences in BMI were greater compared to the previous decade.

The described changes in the level of BMI are worrying and may suggest that future generations of young people will exhibit excess body mass in the further stages of ontogenesis. This assumption is supported by the incidence of deficiency and excess body mass. In the entire analysed decade as well as during the last five years, a decrease in the frequency of underweight and normal height-to-weight ratios was observed. However, a significant increase in the prevalence of obesity was found. Importantly, greater changes were observed in the rural environment. Nowadays there is a tendency towards reducing the number of children and adolescents with body weight deficiency and increase with its excess. This is supported by research by Ng et al. (2014) conducted in the years 1980–2013 in many countries around the world. This trend can be observed in developing countries and in economically highly developed countries. This trend, however, occurs with a greater intensity among urban than rural residents. The above finding is based on a study conducted on girls and boys in Brazil, China, Russia, USA (Wang et al. 2002), and Australia (Hardy et al. 2017). Eating and exercise habits may affect changes in increasing excess body weight (Wang et al. 2002; Hardy et al. 2017). Hardy et al. (2017) point out that the trend of increasing excess body weight in developed countries is slowing down. Therefore, the decrease in the incidence of underweight in all groups can be considered positive. It is an important clinical and public health problem among children and adolescents associated with adverse health outcomes at all stages of human life and may reflect food poverty (Ieiri et al. 2021), unhealthy eating habits (Rawal et al. 2021), or an increased risk of many diseases. Underweight children and adolescents are more likely to suffer from infectious diseases (Goutines et al. 2021), have reduced cognitive functions (Suryawan et al. 2021), mental disorders (Donkor et al. 2021; Zeiler et al. 2021) and have low scores your health (Linardon et al. 2021).

According to the Eurostat report (2018), the voivodeships of eastern Poland are among the poorest macro-regions of the European Union, where the income per capita does not exceed 50% of the average income in the EU. Despite the introduction of the 500+ government program in 2016, under which PLN 500 per child is donated monthly and suppose to help economically disadvantaged families, significant environmental differences in the level of nutrition are still observed among adolescents. Moreover, the changes observed in the last five years are particularly disturbing. The reduction in physical activity observed among children and adolescents since 2020 has been affected by restrictions related to the COVID-19 pandemic, during which distance learning was introduced and sports facilities were closed, all of which reduced their physical activity. The latter, in turn, might be responsible for the recent increase in the incidence of excess body weight among children who participated in this study.

Conclusions

1. In the analyzed period, significant changes in body height and body mass index were found among schoolchildren.
2. Among girls, a systematic increase in body height was observed between 2006 and 2021. However, in boys, such a tendency was found only in rural residents.
3. In the 2006–2016 period, greater changes in BMI were found in girls from rural areas and boys from towns, while the opposite pattern was recorded in the 2016–2021 period.
4. In the years between 2006 and 2021, the incidence of underweight and normal BMI decreased, while the incidence of overweight and obesity increased.
5. The results of this study indicate the need for conducting systematic research in order to assess the nutritional status of young people living in the Lubelskie, Podlaskie, and Podkarpackie voivodeships, and to conduct an in-depth analysis regarding the causes of malnutrition and undertake educational activities.

Acknowledgments

The research was carried out with the financial support research of the Academy of Physical Education in Warsaw and as part of the "Active return to school – PE with AWF" program.

Conflict of interest

The authors declare that there is no conflict of interests regarding the publication of this study.

Authors' contributions

AW and JS design the study, collected the data, oversaw the statistical analysis/interpretation, and were the authors of the written content. AB collected the data, and was the author of the written content

Corresponding author

Agnieszka Wasiluk, Faculty of Physical Education and Health, 2 Akademicka Street, 21-500 Biala Podlaska, Poland; e-mail: agnieszka.wasiluk@awf-bp.edu.pl

References

Bartkowiak S, Konarski JM, Strzelczyk R, Janowski J, Malina RM. 2021. Secular change in height and weight of rural school children and youth in west-central Poland: 1986 to 2016. Am J Hum Biol 33(2):e23461. https://doi.org/10.1002/ajhb.23461

Cole TJ, Bellizzi MC, Flegal KM, Dietz WH. 2000. Establishing a standard definition for child overweight and obesity worldwide: international survey. BMJ 320(7244): 1240–1243. https://doi.org/10.1136/bmj.320.7244.1240

Cole TJ, Flegal KM, Nicholls D, Jackson AA. 2007. Body mass index cut offs to define thinness in children and adolescents: international survey. BMJ 335(7612):194. https://doi.org/10.1136/bmj.39238.399444.55

Dobosz J. 2012. Stan kondycji fizycznej dzieci i młodzieży w Polsce. W: S Nowacka-Dobosz, A Zarychta, J Dobosz, redaktorzy. Raport z ogólnopolskiej debaty o uwarunkowaniach edukacji fizycznej w Polsce. AWF Warszawa.

Domínguez I, Hernández-Castillejo LE, Cavero-Redondo I. 2021. Prevalence and trends of underweight in European children and adolescents: a systematic review and meta-analysis. Eur J Nutr 60(7):3611–3624. https://doi.org/10.1007/s00394-021-02540-0

Donkor HM, Toxe H, Hurum J, Bjerknes R, Eide GE, Juliusson P, et al. 2021. Psychological health in preschool children with underweight, overweight or obesity: a regional cohort study. BMJ Paediatr Open 15,5(1):e000881. https://doi.org/10.1136/bmjpo-2020-000881

Eurostat. 2018. Quality of life indicators. Statistics Explained. http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Quality_of_life indicators (Accessed January 2022).

Fudvoye J, Parent AS. 2017. Secular trends in growth. Ann Endocrinol 78(2):88–91. https://doi.org/10.1016/j.ando.2017.04.003

Garrido-Miguel M, Martínez-Vizcaíno V, Oliveira A, Martínez-Andrés M, Sequí-Domínguez I, Hernández-Castillejo LE, et al. 2021. Prevalence and trends of underweight in European children and adolescents: a systematic review and meta-analysis. Eur J Nutr 60(7):3611–3624. https://doi.org/10.1007/s00394-021-02540-0

Gomula A, Nowak-Szczepanska N, Danel DP, Koziel S. 2015. Overweight trends among Polish schoolchildren before and after the transition from communism to capitalism. Econ Hum Biol 19:246–57. https://doi.org/10.1016/j.ehb.2015.09.002

Gomula A, Nowak-Szczepanska N, Koziel S. 2021. Secular trend and social variation in height of Polish schoolchildren between 1966 and 2012. Acta Paediatr 110(4):1225–1230. https://doi.org/10.1111/apa.15572

Goutines J, Miller LC, Sorge F. 2021. Infections and nutritional status of internationally adopted children in France. Acta Paediatr 110(4):1359–1365. https://doi.org/10.1111/apa.15612

Hardy LL, Mihrshahi S, Gale J, Drayton BA, Bauman A, Mitchell J. 2017. 30-year trends in overweight, obesity and waist-to-height ratio by socioeconomic status in Australian children, 1985 to 2015. Int J Obes 41(1):76–82. https://doi.org/10.1038/ijo.2016.204

IBP. 1969. A guide to field methods. Handbook 9, Human Biology, Oxford.

Ieiri MCA, Kosaka S, Tomitsuka E, Umezaki M. 2021. Factors affecting undernutrition among school children in Cebu, Philippines. Ecol Food Nutr 60(2):182–197. https://doi.org/10.1080/03670244.2020.1813733

Ignasiak Z, Sławińska T, Malina RM. 2016. Short term secular change in body size and physical fitness of youth 7–15 years in Southwestern Poland: 2001–2002 and 2010–2011. Anthropological Review 3:311–29. https://doi.org/10.1515/anre-2016-0023

Kaczmarek M, Wolański N. 2018. Rozwój człowieka od poczęcia do śmierci. Warszawa: Wydawnictwo PWN.

Kowal M, Cichocka B, Woronkiewicz A, Pilecki M, Sobecki J, Kryst Ł. 2011. Międzypokoleniowe zmiany w budowie ciała i akceleracja pokwitania u dzieci i młodzieży w wieku 7–15 lat z populacji wielkomiejskiej w świetle uwarunkowań psychosocjalnych. Monografie AWF Kraków. 4.

Kozieł S, Nowak-Szczepańska N, Gomuła A. 2014. Antropologiczne badania dzieci i młodzieży w Polsce w latach 1966–2012. Zmiany sekularne i różnicowanie społeczne. Wrocław: Oficyna Wydawnicza: Arboretum.

Linardon J, Greenwood CJ, Fuller-Tyszkiewicz M, Macdonald JA, Spry E, Hutchinson DM, et al. 2021. Young adult mental health sequelae of eating and body image disturbances in adolescence. Int J Eat Disord 54(9):1680–1688. https://doi.org/10.1002/eat.23575

NCD Risk Factor Collaboration (NCD-RisC). 2017. Worldwide trends in body-mass index, underweight, overweight, and obesity from 1975 to 2016: a pooled analysis of 2416 population-based measurement studies in 128·9 million children, adolescents, and adults. Lancet 390(10113):2627–42. https://doi.org/10.1016/s0140-6736(17)32129-3

Ng M, Fleming T, Robinson M, Thomson B, Graetz N, Margono C. 2014. Global, regional, and national prevalence of overweight and obesity in children and adults during 1980–2013: a systematic analysis for the Global Burden of Disease Study. Lancet 384(9945):766–81. https://doi.org/10.1016/s0140-6736(14)60460-8

Nowak-Szczepanska N, Gomula A, Sebastjan A, Ignasiak Z, Koziel S. 2021. Blood lead level and nutritional status indicators in preadolescent Polish schoolchildren. J Trace Elem Med Biol 68:126847. https://doi.org/10.1016/j.jtemb.2021.126847

Rawal T, Willeboords M, Arora M, Sharma N, Nazar GP, Tandon N. et al. 2021. Prevalence of excessive weight and underweight and its associated knowledge and lifestyle behaviors among urban private school-going adolescents in New Delhi. Nutrients, 13(9):3296. https://doi.org/10.3390/nu13093296

Rivera JÁ, de Cossío TG, Pedraza LS, Aburto TC, Sánchez TG, Martorell R. 2014. Childhood and adolescent overweight and obesity in Latin America: a systematic review. Lancet Diabetes Endocrinol 2(4):321–332. https://doi.org/10.1016/s2213-8587(13)70173-6

Saczuk J. (2018). Morphofunctional development of children and youth from eastern Poland in the period of systemic transformatio. Monographs and Studies Józef Piłsudski University of Physical Education in Warsaw, Branch in Biała Podlaska.

Suryawan A, Jalaludin MY, Poh BK, Sanusi R, Tan VMH, Geurts JM, et al. 2022. Malnutrition in early life and its neurodevelopmental and cognitive consequences: a scoping review. Nutr Res Rev 35(1):136–149. https://doi.org/10.1017/s0954422421000159

Wabitsch M, Moss A, Kromeyer-Hauschild K. 2014. Unexpected plateauing of childhood obesity rates in developed countries. BMC Med 12:17. https://doi.org/10.1186/1741-7015-12-17

Wang Y, Monteiro C, Popkin BM. 2002. Trends of obesity and underweight in older children and adolescents in the United States, Brazil, China, and Russia. Am J Clin Nutr 75(6): 971–77. https://doi.org/10.1093/ajcn/75.6.971

Wasiluk A, Saczuk J. 2015. Underweight, overweight, and obesity in boys and girls at the age of 7–18 years from eastern Poland in the years 1986-2006. Medical Studies 2:99–105. https://doi.org/10.5114/ms.2015.52907

Zeiler M, Philipp J, Truttmann S, Waldherr K, Wagner G, Karwautz A. 2021. Psychopathological symptoms and well-being in overweight and underweight adolescents: a network analysis. Nutrients 13(11):4096. https://doi.org/10.3390/nu13114096

Notes for Authors

The Anthropological Review is the official journal of the Polish Anthropological Society, founded by Adam Wrzosek in 1926. It succeeds the Przegląd Antropologiczny (1926–2000; vols. 1–63) and Przegląd Antropologiczny – Anthropological Review (2001–2006; vols. 64–69), and it is abstracted in: Index Copernicus (Medical Science Int.), IBSS: International Bibliography of the Social Sciences (LSE), SCOPUS (Elsevier), Zoological Record (Thomson Reuters).

Open access to the journal is via https://czasopisma.uni.lodz.pl/ar/index. Anthropological Review comes out four times a year in print and online. It publishes peer-reviewed papers from physical anthropology and related disciplines, including: biology, ecology, human auxology, population genetics, bio-demography and bio-archeology. The journal accepts original research reports, overview articles, literature reviews and meta-analyses, short notes and communications and book reviews.

Submission of a paper to Anthropological Review implies that the paper is not being considered for publication elsewhere. The paper (in English) should be prepared in accordance with the instruction for authors and submitted electronically by https://czasopisma.uni.lodz.pl/ar/index.

Each submission should be accompanied by a cover letter, and the istructions can be downloaded from https://czasopisma.uni.lodz.pl/ar/index.

Preliminary accepted articles are subject to evaluation by two anonymous reviewers and, where appropriate, by the Statistical Advisor. The principle of double-blinded reviewing applies with names of both the authors and reviewers concealed. The reviews received, including Editors' comments, are forwarded to the Author as PDF documents. Author's revisions must be in PDF format within the deadline set by the journal Editors. The corrected version will be re-evaluated where nessesary, and the Editors will notify the Author whether the article has been accepted for publication.

The Editors' correspondence is conducted by e-mail. Editorial corrections are permitted to authors only in substantial matters and the Editors reserve the right to make necessary corrections and shortenings without the authors' prior consent. The Editors may refuse article publication following consultation with Editorial Board members.

Material accepted for publication becomes the property of the Editors and may not be published in whole or in part in other journals without prior written consent.

Initiating Editor: Katarzyna Smyczek
Language Editor: Piotr Fedurek, Ludwik Hirszfeld Institute of Immunology and Experimental Therapy, Polish Academy of Sciences
Technical Editor: Anna Jakubczyk
Typesetting: Munda – Maciej Torz
Cover design: Tomasz Kasperczyk
Adjusting the cover design: Monika Rawska
Cover photos: stock.adobe.com/klevo; stock.adobe.com/adimas

Łódź University Press
90-237 Łódź, ul. Jana Matejki 34A
www.wydawnictwo.uni.lodz.pl
e-mail: ksiegarnia@uni.lodz.pl
tel. 42 635 55 77