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RESEARCH ARTICLE

Re-analysis of the Levänluhta skeletal material: Sex and stature estimation of individuals in an Iron Age water burial in Finland

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Abstract

Levänluhta, an Iron Age water burial site in Finland, and its material consisting of commingled skeletal remains and artifacts, has been studied by several researchers over the past 100 years, resulting in multiple interpretations of the people and the site. Previous skeletal analyses have concluded that the majority of the individuals represented in the remains were females and children and were of relatively short stature, so possibly nutritionally deprived. This study re-analyzed the commingled adult human remains with updated methods. The methods applied in this study to estimate sex and stature were based on more representative European reference samples than the previously applied methods. The methods included morphology, osteometrics, and computed tomography (CT) scans. Our results indicated that depending on the reference data, the majority of the individual adult bones including os coxae (73%, n = 45) and long bones (humerus 83%–89%, n = 52; radius 72%–89%, n = 47; ulna 50%–65%, n = 58; femur 92%–100%, n = 25; tibia 77%–85%, n = 26) were classified as females based on their size and morphology. The cross-sectional bone properties of humerii, femora, and tibiae visualized using CT scanning also supported these findings. However, the cranial morphology did not show as clear female-biased sex ratio as other methods (42% females, 33% males, 24% undetermined, n = 33). In females, the mean stature based on the tibia (155.3 cm, n = 10) was within the range of the coeval European females and did not necessarily indicate nutritional deprivation, which is in line with previously published stable isotope findings from the site. The mean stature based on the tibia suggested that the Levänluhta males were short (164.0 cm, n = 3), but final interpretations were limited due to the small number of male individuals. The current study affirmed that the Levänluhta skeletal assemblage was female biased and gave new insights into interpretation of the stature.

KEYWORDS
cemetery, commingled remains, CT scans, height, morphology, osteometrics

1 | INTRODUCTION

Levänluhta is a unique cemetery within Finnish archeology and is located in southern Ostrobothnia, in SW Finland (Figure 1). The site was first mentioned in the 17th century and has been excavated on several occasions between 1886 and 1984 (Wessman, 2009). During the Iron Age (AD 300–800), approximately 98 individuals were buried with grave goods in a small pond. Today, the curated material consists of 74 kg of unburned bones (69.8 kg human, 3.9 kg animal) and 22 metal artifacts, all commingled due to the water burial (Formisto, 1993; Wessman et al., 2018). Burial in water is so uncommon in Finnish prehistory; there is only one similar site, Käldamäki in Ostrobothnia (for further reading about the sites, see Wessman, 2009). Even though we know very little about the motivations for burial in water, it has been proposed earlier that this was a burial place for a special group of people (Oinonen et al., 2020; Wessman et al., 2018). Therefore, the site is not only very famous, it also has a long and complex research history with many, sometimes colorful, interpretations (Wessman, 2009; Wessman et al., 2018). Based on previous analysis of the human bone, most of the buried individuals in Levänluhta were suggested to be women and children (Formisto, 1993; Niskanen, 2006).

The archaeological material from Levänluhta, currently on display at the Finnish National Museum, reveals that only some individuals were buried with jewelry or grave goods. Some of the metal objects represent prestigious items, but the overall number of metal artifacts is low compared with the estimated number of individuals. Based on what we know about the female dress during the Iron Age, it is possible to define most artifacts as female dress objects (Wessman, 2009). Iron Age burials in Finland typically contain animals or animal parts as grave goods, but in Levänluhta, most of the animal bones dated to later periods (Wessman et al., 2018). Burial in water, the sex bias of

FIGURE 1 Location of Levänluhta in Western Finland. Map: Johanna Roiha. Basemap sources: ESRI, USGS

the deceased, and the lack of weapons and everyday objects, such as pottery, make Levänluhta an unusual burial site (see Wessman, 2009; Wessman et al., 2018).

The skeletal remains of Levänluhta represent occupations spanning over four centuries. Newer studies have investigated the livelihoods and possible origins of the Levänluhta individuals using stable isotopes and ancient DNA (aDNA). One study using stable isotopes identified disparate dietary habits distinguishing three subgroups during the Fimbul winter (Late Antique Little Ice Age [LALIA]), a short climatic cooling in the 6th century AD (Oinonen et al., 2020). According to this study, the versatile livelihoods of the three subgroups provided resilience for survival during the cooling (Oinonen et al., 2020). Another study suggests that the people buried in Levänluhta represent several cultural groups with different livelihoods (Sikora et al., 2019). Wessman et al. (2018) posit that the people in Levänluhta were socially or ideologically deviant members of society, which is supported by the peripheral location of the cemetery compared with the rest of the Iron Age settlements in the area. What part of the population(s) the Levänluhta individuals represent is, however, not known. A possible multicultural origin of the people poses special challenges to the estimation of sex and stature of the individuals, because metric methods are often population specific.

Two previous osteological studies have been conducted on the Levänluhta remains. Formisto (1993) performed a comprehensive osteological analysis using the methods available at the time. Niskanen (2006) applied updated methods on a sample of os coxae and Formisto's (1993) long bone measurements for sex and stature estimation.

The current study re-analyzed the most complete crania, os coxae, and long bones of Levänluhta adults for sex and stature estimation. Because the skeletal remains were commingled, bones could not be directly associated with each other and were analyzed individually. The re-analysis was part of a multidisciplinary project investigating the skeletal material with more precise methods including aDNA, stable isotopes, and geochemical analyses (Holmqvist-Sipilä, Wessman, Mänttäri, & Lahaye, 2019; Oinonen et al., 2020; Sikora et al., 2019; Wessman et al., 2018). Because previous investigations either focused on a restricted sample of os coxae and long bones (Niskanen, 2006) or used inappropriate reference materials in sex and stature estimation (Formisto, 1993), the current skeletal analysis was necessary to clarify the demography of the Levänluhta site. Formisto's (1993) study concluded that most of the Levänluhta adult individuals were females based on the os coxae and long bones, but results from analysis of cranial morphology indicated that mostly males comprised the adult Levänluhta sample. To explore this discrepancy, we matched the previous methods of sex estimation but extended the methods to include a new European reference sample encompassing a wide range of geographical and temporal variation (Ruff, 2018). In addition, computed tomography (CT) scanning of cross-sectional properties of long bone shafts was included to assist in sex estimations. Stature was estimated using regression equations based on the same European sample (Ruff et al., 2012).

The main research questions in this re-analysis were as follows: (1) How do the adult sex estimates from different bones and different methods compare with each other and with previous studies on the Levänluhta site? (2) Do the new regression equations and new sex estimates change the adult stature estimates? (3) Do the results of our study affect the interpretations of the Levänluhta site?

2 | MATERIALS AND METHODS

Formisto's (1993) dissertation represents the most detailed study of the Levänluhta skeletal remains. She estimated the minimum number of individuals to be 98 based on crania and cranial fragments, including both children and adults (Formisto, 1993). Excluding children, the minimum number of adult individuals was 62 based on crania and 68 based on os coxae. Long bone fragments gave estimates of minimum number of individuals between 51 (femora) and 71 (humerii) (Formisto, 1993). Formisto (1993) concluded that almost 40% of the remains consisted of bones of children and adolescents.

In our re-analysis, only complete adult bones were examined to gain sufficient measurement and observation data for sex and stature estimation. Our sample consisted of 33 crania, 52 humerii, 47 radii, 58 ulnae, 53 os coxae, 25 femora, and 26 tibiae. Age was not specifically estimated, but only bones exhibiting complete epiphyseal union indicating completion of growth and development were included in the sample. The crania were considered adult based on their suture closure. Dentition was not used for aging due to the prevalence of postmortem tooth loss. A more detailed study on the age structure and pathological conditions observed in Levänluhta skeletal remains will be published later. Long bones were measured using an osteometric board, sliding and spreading calipers (to the nearest 1 and 0.1 mm, respectively) following Ruff (2018).

2.1 | Sex estimation methods

2.1.1 | Os coxae

Analysis of the gross morphology of the pelvis, or os coxae, is the most reliable and thus preferred indicator of sex, and the pubic bone is considered the most sexually dimorphic area of the os coxae (Phenice, 1969). However, the pubic bone is fragile and often not preserved in archaeological samples (Waldron, 1987). In this study, sex estimation preferentially utilized morphological traits found on or around the pubic bone, such as the ventral arc, subpubic concavity, and ischiopubic ramus ridge, if present. Due to limits in preservation of the pubic bone in the Levänluhta sample, sex estimation primarily relied on the morphology of the greater sciatic notch. All the morphological traits on the os coxae were assessed and scored following definitions and illustrations in Buikstra and Ubelaker (1994). However, the interpretation of the greater sciatic notch morphology was slightly modified. Unlike Buikstra and Ubelaker (1994) and Walker (2005), in this study, scores 1–2 were considered representative of females, 3 ambiguous, and 4–5 representative of males (see Ferembach, Schwidetzky, & Stloukal, 1980). Although interpretations of the preauricular sulcus vary (Buikstra & Ubelaker, 1994; Novak, Schultz, & McIntyre, 2012; Rösing et al., 2007; St. Hoyme & Iscan, 1989), in this study, the presence of a preauricular sulcus, scored as present or absent, indicated female morphology in association with the morphology of the greater sciatic notch.

2.1.2 | Long bones

Sex estimation from long bones was solely based on joint dimensions, because they tend to differentiate sexes more accurately than other dimensions (see classification rates in Spradley & Jantz, 2011). Long bone lengths were not used due to the considerable temporal fluctuation in linear dimensions (Ruff, 2018), and bone shaft dimensions were not used because they also reflect age and mechanical loading rather than differentiate females and males (Ruff et al., 2015).

Instead of using discriminant functions to estimate sex, a sectioning point was calculated by averaging male and female joint measurement means (see Spradley & Jantz, 2011) from a European reference skeletal sample including over 2000 skeletons from the Early Upper Paleolithic through the 20th century (Ruff, 2018). When estimating sex of Levänluhta bones, this sectioning point was subtracted from individual joint measurements per bone, and if multiple measurements were present in one bone, their values were then averaged to indicate the sex. Positive sectioning point values indicate males and negative ones females.

The European reference sectioning points were calibrated for the Levänluhta remains based on the acetabular heights of sex-diagnostic Levänluhta os coxae. Regression equations based on the European reference sample were used to extrapolate superior–inferior femoral head diameter (FHSI) from the mean acetabular height (ACH) (Niskanen's unpublished data; females FHSI = 0.763 × ACH + 3.126, r = 0.869, SEE = 1.51; n = 201; males FHSI = 0.797 × ACH + 2.597, r = 0.905, SEE = 1.62; n = 270). The estimate of the FHSI for Levänluhta females was 41.96 mm (ACH mean 50.90 mm based on five right acetabula and 13 left acetabula including three pairs) and the male FHSI 44.87 mm (ACH mean 53.04 mm based on 3 left and 3 right acetabula including two pairs). However, the Levänluhta male sample included an exceptionally small os coxae pair, and without it, the calculated means for ACH and FHSI were 54.62 and 46.13 mm, respectively.

The Levänluhta FHSI female mean was 0.96 mm, and male mean was 2.94 mm smaller (1.68 mm smaller if excluding the small individual) than the means from the European reference sample, whereas the combined mean of these 19 Levänluhta individuals was 0.96 mm smaller. Thus, 1 mm was subtracted from the European reference sample FHSI mean, and the calibrated sectioning point for Levänluhta was 44.1 mm for FHSI. This FHSI sectioning point comprised 97.8% of the European reference sample mean, so all the other European reference sample articular dimension means were multiplied by 0.978 to derive calibrated sectioning points for Levänluhta remains (Table 1).

TABLE 1 Sectioning points (mm) for differentiating males and females from joint dimensions

Dimension	European	Levänluhta
Humerus: head SI breadth	44.0	43.0
Humerus: epicondylar breadth	58.6	57.3
Radius: maximum head breadth	21.6	21.1
Radius: distal articular ML breadth	27.5	26.9
Ulna: olecranon fossa articular ML breadth	22.1	21.6
Ulna: olecranon fossa articular SI breadth	23.1	22.6
Femur: head SI breadth	45.1	44.1
Femur: epicondylar ML breadth	77.5	75.8
Femur: distal articular ML breadth	71.2	69.6
Tibia: proximal articular ML breadth	71.4	69.8
Tibia: proximal epiphyseal ML breadth	72.9	71.3
Tibia: distal epiphyseal ML breadth	44.2	43.2

Note: European sectioning points are midsex means based on a European reference sample (Ruff, 2018). Levänluhta sectioning points are calibrated sectioning point values for the Levänluhta sample (see text for more details).
Abbreviations: ML, medio-lateral; SI, supero-inferior.

Both the European reference and the calibrated Levänluhta sectioning points were applied to Levänluhta sample, and the sex estimates were based on one to three measurements depending on the bone and its completeness.

2.1.3 | CT scans and structural bone properties

Bone structural data were obtained using peripheral quantitative computed tomography (pQCT) scanner Stratec XCT Research SA or SA+ (Stratec Medizintechnik GmbH, Pforzheim, Germany), which is an automated system for the measurement of bone density and biomechanical parameters in bone samples. Scans were analyzed using the manufacturer's software (Version 6.20) with built-in algorithms for converting the CT scan into quantitative bone density measures. A hydroxyapatite calibration phantom was used with daily quality assurance (measurement error < 1%).

The diaphysis of the femur and tibia was scanned at 50% of total length and 35% for the humerus. Scan resolution was 0.30 mm, and slice thickness 1.0 mm. We used a 500 mg/cm^3 bone–air threshold for all diaphyseal sections. For each scan, the appropriate region of interest (ROI) was automatically detected by the software. The following cross-sectional geometric properties were included in this study: Ix (antero-posterior bending strength), Iy (medio-lateral bending strength), and Zp (torsional and average bending strength).

To test whether the structural properties of a long bone diaphysis could provide additional information on sex estimation of Levänluhta samples, we utilized a reference sample (from Ruff, 2018) consisting of well-preserved, adult skeletons (n = 30 female, n = 34 male) from several Iron Age sites from Denmark dating from 0 to 400 AD.

2.1.4 | Cranium

The sex of the crania was estimated using morphological traits and measurements. Both methodological approaches have limitations: scoring of morphological traits is subjective (see Petaros, Sholts, Slaus, Bosnar, & Wärmländer, 2015; Shearer, Sholts, Garvin, & Wärmländer, 2012; Walrath, Turner, & Bruzek, 2004), and interpretation of metrics analyses requires appropriate reference samples (see Spradley, 2016). Thus, both methods were used when possible to amplify the strengths of the methods and to minimize the effects of the deficiencies. Cranial morphology was scored following Buikstra and Ubelaker (1994) using nuchal crest, mastoid process, supraorbital margin, and supraorbital ridge/glabella traits. In addition, the general morphology of the cranium was incorporated to inform the final estimate. However, the nuchal area of the occipital in Levänluhta crania presented challenges for scoring, because some crania exhibited a form of an occipital bun, also called hemibun (see Gunz & Harvati, 2007; Lieberman, Pearson, & Mowbray, 2000), which has been encountered in many past and present Northwest Europeans (Niskanen, 1994). No mandibles were included in the study, because the shape and size of the female and male mandibles tend to exhibit considerable overlap (Bejdová et al., 2013), thus reducing distinction between the sexes.

Fordisc 3 software (Version 3.1.312) is used for sex, and ancestry estimation in forensic anthropology (see Jantz & Ousley, 2013) and in this study was used to estimate sex from the Levänluhta cranial measurements. Fordisc's reference dataset of Howells' cranial measurements of various past populations (Howells, 1973) was used to compare Levänluhta crania with female and male crania from three European populations: Norse (mostly early medieval, Norway), Berg (late 19th century, Austria), and Zalavar (mostly 9th–11th centuries, Hungary). However, some of the original sex estimations in the dataset were based on cranial morphology rather than the pelvis, and thus, the classifications may not be accurate.

2.2 | Stature estimation

Stature from the Levänluhta humerii, radii, femora, and tibiae was estimated using regression equations generated from the reference European sample (Ruff et al., 2012). The regression equations do not include the ulna, so ulnar lengths were converted to maximum radial lengths using a subsample of the reference European material (Ruff, 2018).

A sex-specific regression equation was used depending on the sex assessment of a particular long bone. The stature was calculated using sex estimates based on both the reference European and the calibrated Levänluhta sectioning points. Both estimates are reported here, because the reference European sectioning points were derived from a larger sample, but Levänluhta sectioning points may be more appropriate for this sample. Without complete individuals with known sex, neither the European nor Levänluhta sectioning points can be preferred.

3 | RESULTS

3.1 | Sex estimation

All the adult os coxae with at least the greater sciatic notch available for scoring were included in the study. The final sample included 53 os coxae (*n* = 25 left, *n* = 28 right). Only eight os coxae pairs could be identified based on similar size and morphology. Out of these pairs, three classified as males, four as females, and one was ambiguous. Only eight os coxae had a pubic bone preserved for scoring, and all were scored as females. The rest of the os coxae were classified based on the greater sciatic notch or a combination of greater sciatic notch and preauricular sulcus. Including only one side of the paired os coxae (*n* = 45), the sample was female biased, with 73.3% of the os coxae as female, whereas 22.2% were male and 4.4% indeterminate (Table 2).

Table 3 shows the sex ratios based on the long bone dimensions, using both the European and calibrated Levänluhta sectioning points. The distributions are slightly different because the higher European sectioning points resulted in a smaller number of males in the sample. Using the European sectioning points, all the bone types (humerus, radius, ulna, femur, and tibia) indicated that the majority of the individual bones classify as females (percentages ranging from 65.5% using ulna to 100% using femur). The number of classified males increased when calibrated Levänluhta sectioning points were used, especially for the ulna (50%). Other bones were still mostly classified as females ranging from 72.3% for the radius to 92.0% for the femur.

In our analyses of Levänluhta, we utilized pQCT scans of humeral (*n* = 23), femoral (*n* = 8), and tibial (*n* = 21) bone shafts. Comparisons of Ix (antero-posterior bending strength), Iy (medio-lateral bending strength), and Zp (torsional and average bending strength) values showed that Levänluhta individuals exhibited less variation in and lower average values of bone rigidity than the partly contemporary Iron Age Danes. Comparisons with sex-specific Danish samples revealed that almost all Levänluhta individuals fell within the female range. However, approximately a quarter (23%) of the Levänluhta bones also fell within the male range as the sex-specific samples overlap to some extent in bone shaft rigidity. In humerus, the number of Levänluhta bones exceeding the minimum values of Danish male sample was seven (30.4%), in tibia four (19.0%), and in femur just one (12.5%).

All Levänluhta crania and cranial fragments including at least two scorable morphological traits were included in the analysis. Out of a total sample of 33 individuals, almost half of the crania (15 of 33) had all major traits (nuchal crest, mastoid process, supraorbital margin, and glabella) available for scoring. Fourteen (42.4%) crania were estimated as females, 11 (33.3%) males, and 8 (24.2%) were ambiguous. Six of the ambiguous crania were more likely females than males, and two were more likely males than females when compared with the relevant examples of female and male crania in Levänluhta. However, the actual sex of those examples cannot be verified by other skeletal indicators.

Eight Levänluhta crania had nine or more measurements for input to Fordisc 3, and analyses were run against three reference European

TABLE 2 Sex estimates based on the morphology of the os coxae

	Side	Male	Female	Ambiguous
Pubic area	R	0	5[a]	0
	L	0	5[a]	0
Greater sciatic notch + preauricular sulcus	R	6[a]	13[b]	1[b]
	L	7[a]	14[b]	2[b]
Number of bones analyzed	R (*n* = 28)	7 (25%)	19 (68%)	2 (7%)
	L (*n* = 25)	6 (24%)	18 (72%)	1 (4%)
Estimates for individuals[c]	(*n* = 45)	10 (22.2%)	33 (73.3%)	2 (4.4%)

[a]Includes three pairs.
[b]Includes one pair.
[c]Includes only one side of the pair.

TABLE 3 Sex ratios based on long bone dimensions

		European		Levänluhta		
Bone	Side	Male	Female	Male	Female	Number of bones analyzed
Humerus	R	3 (12.0%)	22 (88.0%)	3 (12.0%)	22 (88.0%)	25
	L	3 (11.1%)	24 (88.9%)	6 (22.2%)	21 (77.8%)	27
	R + L	6 (11.5%)	46 (88.5%)	9 (17.3%)	43 (82.7%)	52
Radius	R	2 (9.5%)	19 (90.5%)	7 (33.3%)	14 (66.7%)	21
	L	3 (11.5%)	23 (88.5%)	6 (23.1%)	20 (76.9%)	26
	R + L	5 (10.6%)	42 (89.4%)	13 (27.7%)	34 (72.3%)	47
Ulna	R	8 (27.6%)	21 (72.4%)	12 (41.4%)	17 (58.6%)	29
	L	12 (41.4%)	17 (58.6%)	17 (58.6%)	12 (41.4%)	29
	R + L	20 (34.5%)	38 (65.5%)	29 (50.0%)	29 (50.0%)	58
Femur	R	0 (0%)	9 (100%)	1 (11.1%)	8 (88.9%)	9
	L	0 (0%)	16 (100%)	1 (6.3%)	15 (93.7%)	16
	R + L	0 (0%)	25 (100%)	2 (8.0%)	23 (92.0%)	25
Tibia	R	1 (7.7%)	12 (92.3%)	2 (15.4%)	11 (84.6%)	13
	L	3 (23.1%)	10 (76.9%)	4 (30.8%)	9 (69.2%)	13
	R + L	4 (15.4%)	22 (84.6%)	6 (23.1%)	20 (76.9%)	26

groups to see whether the unknown Levänluhta classified as females or males. Fordisc classified all of these crania, except one, closest to females in the Zalavar or the Norse samples with posterior probabilities ranging from 0.618 to 0.933 (typicality probabilities 0.304–0.786). The single exception classified closest to Norse males (posterior probability 0.879, typicality probability 0.161). Based on cranial morphology, we estimated three of these Levänluhta crania as females, three as males, and two as indeterminate. This indicated that the general size of the crania was more similar to females than the morphological traits suggested.

Additionally, Levänluhta cranial measurement means were compared with the means of Iron Age (Late Roman period ca. 160/170 AD–400 AD) Danes (Sellevold, Hansen, & Jørgensen, 1984). Out of 11 measurements, seven of the Levänluhta means were smaller than the Danish sample female means (Table 4), three Levänluhta means were between males and females, and nasal breadth was bigger than the Danish sample male mean. Because the Levänluhta sample sizes for the measurements widely varied from 4 to 17, no definitive conclusions could be drawn. However, the comparison suggested that the Levänluhta craniometrics were on average closer to females than males in the Late Roman period Danish sample.

3.2 | Stature estimation

Sex-specific estimates of stature from the long bones were calculated using both the European and calibrated Levänluhta sectioning points (Tables 5 and 6). The bone-specific mean estimates for females were within 1.3 cm regardless of the sectioning point, but in males, the differences were up to 2.5 cm.

The stature estimates for females ranged from 149.5 to 156.1 cm depending on the long bone, bone side, and sectioning points used. The tibial lengths of Levänluhta females gave stature estimates of 155.3 cm (*n* = 10) and 155.9 cm (*n* = 9) using the European and calibrated Levänluhta sectioning points, respectively. However, the femora (with similar sample sizes) gave estimates about 3 cm shorter than

TABLE 4 Cranial measurement means (mm) of the Late Roman Danes (from Sellevold et al., 1984) and the Levänluhta sample

	Late Roman Danes		Levänluhta
	Mean (*N*)		Mean (*N*)
Cranial measurement	Males	Females	All
Maximum length	192.8 (27)	183.1 (28)	176.8 (16)
Nasion–basion height	104.3 (12)	99.0 (14)	95.7 (9)
Maximum breadth	137.9 (26)	130.5 (21)	133.0 (15)
Minimum frontal breadth	95.8 (29)	93.1 (27)	93.9 (17)
Biauricular breadth	122.3 (16)	116.3 (20)	115.1 (14)
Basion–bregma height	135.9 (16)	131.5 (14)	125.6 (10)
Bizygomatic breadth	128.8 (16)	120.8 (14)	125.3 (4)
Nasal breadth	24.5 (15)	23.7 (17)	25.2 (5)
Nasal height	50.3 (17)	49.2 (17)	47.1 (5)
Orbital breadth	41.1 (18)	38.9 (18)	38.6 (6)
Orbital height	33.1 (18)	33.7 (18)	30.9 (6)

Note: *N* = sample size.

the tibial estimates. For males, the sample size was smaller, and the stature estimates ranged between 156.0 and 164.0 cm. The tibial lengths using the European sectioning point estimated the average height for Levänluhta males to be 164.0 cm (n = 3), whereas the Levänluhta sectioning point gave a mean estimate of 161.7 cm (n = 4). Stature estimates from the tibia were preferred in the comparisons, because the tibia generally provides nearly as accurate estimates as the femur but provided a larger sample size for males in the Levänluhta assemblage. In males, the stature estimates from tibia were the highest, whereas in females, the tibia stature estimates were similar or lower than estimates from upper limb bones.

4 | DISCUSSION

This re-analysis supported previous results (Formisto, 1993; Niskanen, 2006) that the majority of the Levänluhta os coxae (73%) show female morphology. Even though most of the Levänluhta os coxae were missing the pubic bone, which is the most sexually dimorphic area of the os coxae, secondary morphological traits such as greater sciatic notch and presence of preauricular sulcus mostly indicated that the Levänluhta individuals were female. This distribution was similar to Formisto's results, which classified 37 os coxae as females (77.1%) and 11 os coxae as males (22.9%). Niskanen (2006) studied 23 Levänluhta os coxae, and all but one exhibited female morphology (95.6%).

Comparing the results of the long bone measurements between our study (using European reference sample) and the results of Formisto (1993), our study estimated a higher percentage of females based on humeral (88.5% vs. 65%) and radial (89.4% vs. 67%) measurements. Femora and tibiae results were quite similar in both studies, but the ulna showed higher percentages of males in our study (34.5% vs. 19%), especially when using the Levänluhta sectioning points (50% of males). Niskanen (2006) used Formisto's measurements, but he did not report sex ratios by bone. However, Niskanen (2006) mentions that using different methods changed his sex classifications from male to female in 12 bones (seven humerii, four radii, and one femur) and from female to male in two cases (one

TABLE 5 Stature estimates by bone and sex assessment

		Males				Females			
Bone	Side	*N*	Mean	SD	Range	*N*	Mean	SD	Range
Humerus	R	2	163.4	-	160.2–166.7	17	152.0	4.3	142.5–158.0
	L	2	162.8	-	160.2–166.7	19	153.3	4.7	146.5–164.1
	R + L	4	163.1	3.5	160.2–166.7	36	152.7	4.5	142.5–164.1
Radius	R	-	-	-	-	12	155.4	6.7	143.7–164.3
	L	2	161.7	-	158.5–164.8	16	155.6	5.2	142.9–163.9
	R + L	2	161.7	-	158.5–164.8	28	155.5	5.7	142.9–164.3
Ulna[a]	R	3	162.3	3.4	160.1–166.6	8	155.9	4.5	149.6–163.2
	L	6	160.2	5.2	151.5–165.9	11	155.1	6.0	143.5–162.3
	R + L	9	161.1	4.7	151.5–166.6	19	155.4	5.3	143.5–163.2
Femur	R	-	-	-	-	7	150.4	6.0	139.3–156.3
	L	-	-	-	-	10	152.7	7.7	141.5–164.1
	R + L	-	-	-	-	17	151.8	7.0	139.3–164.1
Tibia	R	1	160.5	-	-	9	152.0	5.1	142.5–157.7
	L	3	164.0	5.0	159.3–169.2	10	155.3	5.9	148.3–165.6
	R + L	4	163.1	4.4	159.3–169.2	19	153.7	5.6	142.5–165.6

Note: Sex assessments are based on the reference European sectioning points.
[a]Radius maximum length = 0.958 × ulna maximum length − 10.574, r = 0.979, SEE = 3.71, N = 70; radius maximum length = 1.041 × ulna physiological length + 1.079 (r = 0.983, SEE = 3.23, N = 81). Physiological length was preferred over maximum length. Sexes are pooled.

TABLE 6 Stature estimates (cm) by bone and sex assessment

		Males				Females			
Bone	Side	N	Mean	SD	Range	N	Mean	SD	Range
Humerus	R	2	163.4	-	160.2–166.7	17	152.0	4.3	142.5–158.0
	L	5	159.5	6.2	151.7–165.6	16	152.6	4.2	146.5–158.7
	R + L	7	160.6	5.7	151.7–166.7	33	152.3	4.2	142.5–158.7
Radius	R	4	160.2	4.9	152.4–163.9	8	153.0	6.3	143.7–164.3
	L	5	160.0	2.8	158.0–164.8	13	154.9	5.5	142.9–163.9
	R + L	9	160.1	3.6	152.4–164.8	21	154.2	5.7	142.9–164.3
Ulna[a]	R	4	160.4	5.7	153.0–166.6	7	156.1	4.8	149.6–163.2
	L	9	158.0	6.1	148.0–165.9	8	155.1	6.6	143.5–162.3
	R + L	13	158.8	5.8	148.0–166.6	15	155.6	5.7	143.5–163.2
Femur	R	1	156.0	-	-	6	149.5	6.0	139.3–156.3
	L	1	157.9	-	-	9	152.1	8.0	141.5–164.1
	R + L	2	157.0	-	156.0–157.9	15	151.1	7.2	139.3–164.1
Tibia	R	2	159.6	-	158.6–160.5	8	151.3	4.9	142.5–157.4
	L	4	161.7	6.2	154.6–169.2	9	155.9	6.2	148.3–165.6
	R + L	6	161.0	5.0	154.6–169.2	17	153.5	5.9	142.5–165.6

Note: Sex assessments are based on the estimated Levänluhta sectioning points.
[a]See Table 5.

ulna and one tibia) in comparison with Formisto's (1993) classifications.

It is recommended that the reference samples utilized for sex estimation should be appropriate for the population under study (Spradley, 2016). Thus, the discrepancies between our study and previous studies can mostly be explained by the inclusion of different methods: Formisto (1993) used discriminant functions with multiple measurements based on a Japanese population, and Niskanen (2006) used functions based on an American White population. The sample sizes in our current study are larger, because we used one to three sectioning points per bone instead of discriminant functions. These sectioning points were derived from a reference European sample (Ruff, 2018) that should provide more reliable results than previously utilized reference samples. However, the ulna seems to be problematic. In our study, the proximal ulna joint size appears larger relative to other forearm skeletal dimensions. At this point, we do not offer a possible explanation for this sample-specific characteristic.

In our analyses of structural properties, all studied Levänluhta long bones fell within the range of properties of the Danish Iron Age females. One quarter of the Levänluhta sample also fell within Danish Iron Age male individuals. This was mainly due to the wide range in bending strength values of our male reference sample. Levänluhta individuals differed from the more robust bone shafts seen in the Danish Iron Age males. In fact, the most robust Levänluhta individuals resemble the most gracile Danish Iron Age males. According to biomechanical values of the humeral, femoral, and tibial shafts, almost all Levänluhta individuals were similar to Iron Age females or gracile males. This supported the results from the articular joint dimensions of these bones.

Formisto (1993) reported 75% of the Levänluhta crania classified as males based on morphology, whereas our results suggested that about 60% of the crania resembled females more than males. However, using craniometrics, Formisto (1993) classified seven out of eight crania as females using discriminant functions for Japanese and Finnish populations. Our results from craniometrics analyses using the same six crania (out of eight) matched Formisto's results. Formisto's cranial morphology results differed from the results of other bone groups, so to investigate this discrepancy, Formisto's scores and descriptions of cranial morphology were reviewed. Formisto (1993) describes the Levänluhta crania as exhibiting traits more consistent with females like small glabella, small nuchal crest, and mostly sharp supraorbital margin, but large mastoid process is most consistent with males. However, the scoring of the glabella and supraorbital margins indicated that glabella seemed to be scored as more male and supraorbital margins as neutral or male (Formisto, 1993, p. 93, tab. 46). Descriptions of nuchal crest and mastoid processes seemed to match the scoring. These discrepancies challenge her actual sex estimation results for cranial morphology.

Our scoring indicated that the Levänluhta crania tend to exhibit robust mastoid processes in combination with more gracile glabella and nuchal area. The supraorbital margins were more neutral. As mentioned previously, some of the Levänluhta crania exhibited a hemibun, which affects the shape of the nuchal area and thus may complicate the scoring. The nuchal cresting is generally weaker and harder to score in a bun-shaped occiput than in a more typical occiput. The occipital bone contour influences the development of nuchal cresting by affecting the angle of muscle pull relative to that of the occipital bone. The most extensive nuchal cresting is seen in skulls where the nuchal muscle insertions form the most posterior part of the skull; that is, the inion is also the opisthocranion. Combined with craniometrics, we suggest that most of the Levänluhta crania were female, which would agree more with other bones. However, because

TABLE 7 Coeval comparative samples for Levänluhta mean statures (cm) selected from an Excel file included in an electronic version of Ruff (2018)

Sample	Date		Male stature	Female stature
Levänluhta	300–800 AD	*N*	3	10
		Mean	164.0	155.3
		SD	5.0	5.9
		Min	159.3	148.3
		Max	169.2	165.6
Late Roman Period Denmark	200–400 AD	*N*	22	22
		Mean	174.3	162.1
		SD	7.7	5.7
		Min	158.9	146.5
		Max	187.0	171.5
Viking Period Denmark	700–1050 AD	*N*	24	20
		Mean	168.3	157.50
		SD	7.4	5.6
		Min	155.2	147.4
		Max	181.1	166.8
Iron Age England	300–400 AD	*N*	22	22
		Mean	165.0	157.4
		SD	5.6	4.5
		Min	154.5	150.5
		Max	175.2	168.9
Medieval France	600–700 AD	*N*	10	7
		Mean	163.5	153.7
		SD	5.1	4.6
		Min	156.3	148.1
		Max	173.8	159.3
Medieval Austria	600–800 AD	*N*	65	54
		Mean	165.4	157.6
		SD	5.9	4.9
		Min	149.5	146.0
		Max	174.5	173.2
Medieval Italy	400–1000 AD	*N*	22	16
		Mean	166.7	155.7
		SD	6.9	4.8
		Min	158.2	147.9
		Max	183.1	168.6

the actual sexual dimorphism in cranial morphology in Levänluhta remains unknown, these results should be interpreted with caution.

Cranial morphology and its use in sex estimation are not straightforward, because the degree of sexual dimorphism in cranial morphology can vary between geographical and temporal populations (Godde, 2015; Walker, 2008). Many of these cranial traits are in fact muscle attachment sites, and thus, their expression can vary between populations depending on many factors such as diet and activity (Krüger, L'Abbé, Stull, & Kenyhercz, 2015; Walker, 2008). For example, Walker's (2008) study showed that modern English crania were less robust than modern European–American crania, and prehistoric Native Americans were the most robust group with the smallest degree of sexual dimorphism. It has been suggested that population-specific discriminant function analysis for sex estimation from the cranial traits should be used (Krüger et al., 2015; Walker, 2008). However, no appropriate equations exist that could have been applied to the Levänluhta sample.

Recent aDNA analyses of Levänluhta identified the four examined Levänluhta individuals as females (Sikora et al., 2019). The sampled mandibles were randomly chosen for the DNA analysis, and despite the results being based on a small sample, it can be considered to support the female-dominated sex distribution. The aDNA indicated that the genomes of three Levänluhta individuals were similar to genomes common among modern-day Sámi people and that during the Iron Age ancestors of modern Sámi inhabited much more southern regions of Finland (Sikora et al., 2019). However, further work is required to broaden the aDNA data.

Previous studies (Formisto, 1993; Niskanen, 2006) have suggested that the Levänluhta individuals were slightly shorter than other groups at the time. Due to the lack of complete individuals, we could not establish body proportions in this sample and thus we could not prefer any long bone and its stature estimates over other long bones. Using the European sectioning points for sex estimation, Levänluhta female statures ranged from 151.8 to 155.5 cm depending on the bone with both left and right sides included. These estimates were well within the range (148.0–163.9 cm) of Formisto's (1993) estimates based on Telkkä's (1950) equations. Formisto's summary on stature states that Levänluhta people were short. However, the female mean statures were not very short, whereas the male statures were similar to females and thus would be considered short. Our estimates were similar to Niskanen's (2006) estimates, which ranged between 150.9 and 154.9 cm. Niskanen concluded that Levänluhta individuals were rather short but not exceptionally short. To bring our estimates into a larger context, the stature based on tibia was compared with other Iron Age and Early Medieval European samples. The comparisons indicated that Levänluhta females were in the lower range of the contemporary mean statures (Table 7), but not strikingly short. The Levänluhta male means were clearly shorter than the comparative samples, but Levänluhta means may be biased due to the small samples (usually five or less).

5 | CONCLUSIONS

Results of our study supported earlier analyses and interpretations that Levänluhta was a burial place mainly for females and children. All the bone groups, os coxae (~70%), long bones (50%–100%), and crania (~60%), indicated the majority of the adult bones classified as females. Some discrepancies in sex ratios could be seen in individual bone groups compared with previous studies, likely due to the applied methods and reference samples. New sex estimates from long bones and new stature estimation equations provided stature estimates that do not fully support the previous arguments that Levänluhta females were shorter than the average European Iron Age females. Because so few men were represented in the material, we do not think that the recognized shorter stature of males in Levänluhta is significant. Thus, there is perhaps no reason to think that the Levänluhta individuals suffered from insufficient nutrition, leading to restricted growth as previously suggested by Niskanen (2006). Moreover, stable isotope data from Levänluhta also suggested that the LALIA did not affect the people in this area (Oinonen et al., 2020).

As we have demonstrated, it is challenging to get definitive results about the female–male ratio from a commingled bone assemblage using traditional osteometric and morphological methods. Hence, our results did not change the previous interpretations of the Levänluhta site as a burial place for mostly females and children. Regardless, further aDNA analyses should more accurately clarify the sex distribution of the Levänluhta remains. This study did show the stature of the Levänluhta individuals in a new light where they are not considered as short and as nutritionally deprived as in previous osteological studies. This is more in line with the stable isotope results revealing diverse food sources in Levänluhta to suggest that the Levänluhta people were not dependent on only one livelihood, which would have made them prone to food shortages and adverse effects such as growth stunting.

CONFLICT OF INTEREST

The authors have no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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REFERENCES

Bejdová, S., Krajíček, V., Velemínská, J., Horák, M., & Velemínský, P. (2013). Changes in the sexual dimorphism of the human mandible during the last 1200 years in Central Europe. *Homo*, *64*, 437–453. https://doi.org/10.1016/j.jchb.2013.05.003

Buikstra, J., & Ubelaker, D. (1994). *Standards for data collection from human skeletal remains*. Arkansas Archaeological Survey Research Series No. 44. Fayetteville, AR: Arkansas Archaeological Survey.

Ferembach, D., Schwidetzky, I., & Stloukal, M. (1980). Recommendations for age and sex diagnoses of skeleton. *Journal of Human Evolution*, *9*, 517–549.

Formisto, T. (1993). *An osteological analysis of human and animal bones from Levänluhta*. Vammala: Vammalan Kirjapaino Oy.

Godde, K. (2015). Secular trends in cranial morphological traits: A socioeconomic perspective of change and sexual dimorphism in North Americans 1849–1960. *Annals of Human Biology*, *42*, 253–259. https://doi.org/10.3109/03014460.2014.941399

Gunz, P., & Harvati, K. (2007). The Neanderthal "chignon": Variation, integration and homology. *Journal of Human Evolution*, *52*, 262–274. https://doi.org/10.1016/j.jhevol.2006.08.010

Holmqvist-Sipilä, E., Wessman, A., Mänttäri, I., & Lahaye, Y. (2019). Lead isotope and geochemical analyses of copper-based metal artefacts from the Iron Age water burial in Levänluhta, Western Finland. *Journal of Archaeological Science*, *26*, 1–15. https://doi.org/10.1016/j.jasrep.2019.05.019

Howells W. W. (1973). Cranial variation in man: A study by multivariate analysis of patterns of difference among recent human populations. Harvard University.

Jantz, R., & Ousley, S. (2013). Introduction to Fordisc 3. In M. Tersigni-Tarrant, & N. Shirley (Eds.), *Forensic anthropology. An introduction* (pp. 253–269). Boca Raton: CRC Press.

Krüger, G. C., L'Abbé, E. N., Stull, K. E., & Kenyhercz, M. W. (2015). Sexual dimorphism in cranial morphology among modern South Africans. *International Journal of Legal Medicine*, *129*, 869–875. https://doi.org/10.1007/s00414-014-1111-0

Lieberman, D., Pearson, O., & Mowbray, K. (2000). Basicranial influence on overall cranial shape. *Journal of Human Evolution*, *38*, 291–315. https://doi.org/10.1006/jhev.1999.0335

Niskanen, M. (1994). *An exploratory craniometric study of northern and central European populations. Doctoral dissertation*. Pullman, WA, USA: Department of Anthropology, Washington State University.

Niskanen, M. (2006). Stature of the Merovingian-period inhabitants from Levänluhta, Finland. *Fennoscandia Archaeologica*, *XXIII*, 24–36.

Novak, L., Schultz, J. J., & McIntyre, M. (2012). Determining sex of the posterior ilium from the Robert J. Terry and William M. Bass collections. *Journal of Forensic Sciences*, *57*, 1155–1160. https://doi.org/10.1111/j.1556-4029.2012.02122.x

Oinonen, M., Alenius, T., Arppe, L., Bocherens, H., Etu-Sihvola, H., Helama, S., … Wessman, A. (2020). Buried in water, burdened by nature—Resilience carried the Iron Age people through Fimbulvinter. *PLoS ONE*, *5*(4), e0231787. https://doi.org/10.1371/journal.pone.0231787

Petaros, A., Sholts, S. B., Slaus, M., Bosnar, A., & Wärmländer, S. K. T. S. (2015). Evaluating sexual dimorphism in the human mastoid process: A viewpoint on the methodology. *Clinical Anatomy*, *28*, 593–601. https://doi.org/10.1002/ca.22545

Phenice, T. (1969). A newly developed visual method of sexing in the os pubis. *American Journal of Physical Anthropology*, *30*, 297–301. https://doi.org/10.1002/ajpa.1330300214

Rösing, F. W., Graw, M., Marre, B., Ritz-Timme, S., Rothschild, M. A., Rötzscher, K., … Geserick, G. (2007). Recommendations for the forensic diagnosis of sex and age from skeletons. *HOMO – Journal of Comparative Human Biology*, *58*, 75–89. https://doi.org/10.1016/j.jchb.2005.07.002

Ruff, C. B. (Ed.) (2018). *Skeletal variation and adaptation in Europeans: Upper Paleolithic to the twentieth century*. Hoboken: Wiley Blackwell. https://doi.org/10.1002/9781118628430

Ruff, C. B., Holt, B. M., Niskanen, M., Sladek, V., Berner, M., Garofalo, E., … Whittey, E. (2015). Gradual decline in mobility with the adoption of food production in Europe. *Proceedings of the National Academy of Sciences of the United States of America*, *112*, 7147–7152. https://doi.org/10.1073/pnas.1502932112

Ruff, C. B., Holt, B. M., Sladék, V., Berner, M., Garofalo, E., Garvin, H. M., … Tompkins, D. (2012). Stature and body mass estimation from skeletal remains in the European Holocene. *American Journal of Physical Anthropology*, *148*, 601–617. https://doi.org/10.1002/ajpa.22087

Sellevold, B., Hansen, U., & Jørgensen (1984). *Iron Age man in Denmark. Prehistoric man in Denmark, Vol. III*. København: Det Kongelige Nordiske Oldskriftselskab.

Shearer, B. M., Sholts, S. B., Garvin, H. M., & Wärmländer, S. K. T. S. (2012). Sexual dimorphism in human browridge volume measured from 3D models of dry crania: A new digital morphometrics approach. *Forensic Science International*, *222*, 400.e1–400.e5. https://doi.org/10.1016/j.forsciint.2012.06.013

Sikora, M., Pitulko, V., Sousa, V., Allentoft, M., Vinner, L., Rasmussen, S., … Willerslev, E. (2019). The population history of northeastern Siberia since the Pleistocene. *Nature*, *570*, 182–188. https://doi.org/10.1038/s41586-019-1279-z

Spradley, M. K. (2016). Metric methods for the biological profile in forensic anthropology: Sex, ancestry, and stature. *Academic Forensic Pathology*, *6*, 391–399. https://doi.org/10.23907/2016.040

Spradley, M. K., & Jantz, R. L. (2011). Sex estimation in forensic anthropology: Skull versus postcranial elements. *Journal of Forensic Sciences*, *56*, 289–296. https://doi.org/10.1111/j.1556-4029.2010.01635.x

St. Hoyme, L. E., & Iscan, M. Y. (1989). Determination of sex and race: Accuracy and assumptions. In M. Y. Iscan, & K. A. R. Kennedy (Eds.), *Reconstruction of life from the skeleton* (pp. 53–93). New York: Wiley-Liss.

Telkkä, A. (1950). On the prediction of human stature from the long bones. *Acta Anatomica*, *9*, 103–117. https://doi.org/10.1159/000140434

Waldron T. 1987. The relative survival of the human skeleton: implication for palaeopathology. In *Death, decay and reconstruction*, Boddington A, Garland AN, Janaway RC (eds). Manchester University Press, Manchester; 55–64.

Walker, P. L. (2005). Greater sciatic notch morphology: Sex, age, and population differences. *American Journal of Physical Anthropology*, *127*, 385–391. https://doi.org/10.1002/ajpa.10422

Walker, P. L. (2008). Sexing skulls using discriminant function analysis of visually assessed traits. *American Journal of Physical Anthropology*, *136*, 39–50. https://doi.org/10.1002/ajpa.20776

Walrath, D. E., Turner, P., & Bruzek, J. (2004). Reliability test of the visual assessment of cranial traits for sex determination. *American Journal of Physical Anthropology*, *125*, 132–137. https://doi.org/10.1002/ajpa.10373

Wessman, A. (2009). Levänluhta—A place punishment, sacrifice or just a common cemetery. *Fennoscandia Archaeologica*, *XXVI*, 81–105.

Wessman, A., Alenius, T., Holmqvist, E., Mannermaa, K., Perttola, W., Sundell, T., & Vanhanen, S. (2018). Hidden and remote: New perspectives on the people in the Levänluhta water burial, Western Finland (c. AD 300–800). *European Journal of Archaeology*, *21*(3), 431–454. https://doi.org/10.1017/eaa.2017.84

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