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Original article

PMCT investigation of mummified forensic evidence from medieval Germany

Elena F. Kranioti, M.D. PhD [a,b,c](#)

^aDepartment of Forensic Sciences, Medical School, University of Crete, Heraklion, Greece

^bEdinburgh Unit for Forensic Anthropology, SHCA, University of Edinburgh

^cEdinburgh Forensic Radiology and Anthropology Centre, University of Edinburgh

Corresponding Author:

* Elena Kranioti, M.D., Ph.D.

Forensic Anthropology

School of History, Classics and Archaeology

University of Edinburgh

Old Medical School, Teviot Place

Edinburgh, EH8 9AG

Tel. +44 (0)131 6502368

Email: elena.kranioti@ed.ac.uk

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Abstract

Objectives: to estimate the sex of a set of mummified right hands from in Medieval Germany with the aid of non-invasive Computed Tomography in an effort to shed light on these people's identities. These hands were initially thought to have belonged to thieves, robbers or impertinent children that were punished by amputation. Recent research identified them in the literature as "*Leibzeichen*", body parts of unknown individuals murdered in the late Middle Ages that represented the dead person in court.

Material and Methods: The dimensions of the metacarpal bones are used as a proxy for size differences between males and females. CT scans were used to obtain the measurements. Four different population-specific equations from the literature were employed and a control sample of modern anatomical specimens and hospital patients' records from Germany were used to validate the equations.

Results: Five hands were classified as probable male (Münster, Erkeln, HWI 2641, Legden, Lunow), one as probable female (Goslar) and one was inconclusive (HWI 4019).

Conclusion: An approximation of sex for the mummified hands under study was possible using PMCT technology. Further DNA analysis must be conducted to verify or reject the preliminary results of morphometric sex assessment for these historical remains.

Keywords: Virtual anthropology; PMCT; mummified hands; sex estimation; metacarpals; hand bones; *Leibzeichen*

INTRODUCTION

Mummified hands were found separated from their bodies in Germany, mostly in cities, which once belonged to the medieval union of the Hanse, like Goslar, Münster, or Wismar. Such mummified hands were discovered in secret niches of churches and castles; some are exhibited in museums as valuable relics while others are carelessly discarded. Naturally, questions concerning the reason for such dismemberment troubles both the public and scientists. Information on these hands mostly derives from local traditions, legends, or ordinary rumors and is thus of limited value.

Local traditions often want these hands to belong to famous aristocrats or heroes who died in battle. Very common widespread tales want the hands to belong to children who raised a hand against their parents and thus were punished by losing their own. This is also mentioned in the Code of Hammurabi, a set of laws in Mesopotamia (today's Iraq): *If a son strikes his father, his hands shall be hewn off* (Code of law 195) [1]. A third explanation suggests that such a hand is a sign of corporal punishment of thieves. Indeed in Sharia, Islamic law, and in Medieval Europe a thief should be penalized either by imprisonment or dismemberment of hands or feet [2], depending on the frequency and severity of the crime. According to other sources, however, the punishment for theft in Medieval Europe was usually hanging or, if the suspect was a female, the penalty could be drowning or burying the person alive [3]. Corporal amputation was also known in the Germanic Law of the "*Sachsenspiegel*" (Saxon mirror) of the early 13th century [4]. One could lose a hand when found guilty of oath breaking, counterfeiting or violence if not able to compensate with a specific amount of money (*wergeld*).

According to recent studies by the archaeologist Peter Pieper [5, 6] these mummified hands represented dead persons in court. In early times, the corpse of a homicide case was brought before the court as a *corpus delicti* to raise a complaint (*klage mit dem toten mann*). Naturally, when legal proceedings were lengthy, or the guilty person could not be identified immediately, decomposition could advance

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4 significantly and the deceased had to be eventually buried. Therefore, a so-called
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6 “Leibzeichen” [6] was retained as a piece of evidence, representing the victim
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8 during the trial. Such a mummified hand is likely to be a substitute of the dead
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10 person who did not find justice in the past and remained as evidence in the
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12 archives. Several records describe the use of a hand, later a finger, or even a piece
13
14 of bloody clothing, representing a dead person in court [5, 6].
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16 Some of these hands were investigated in the Department of Archaeology,
17
18 at the Heinrich Heine University in Düsseldorf, Germany during the last decade.
19
20 They are body parts of unknown individuals who lived some centuries ago. Due to
21
22 their their special nature they are without a doubt of historical significance. The
23
24 purpose of this study is to identify the sex of seven mummified hands that are
25
26 thought to have lived between the 15th and 18th century in Germany in order to
27
28 give more information about their social significance. With respect to the
29
30 preservation of these historical relics a non-invasive technique was applied so that
31
32 preservation of the remains could be secured. In this regard, CT scanning was
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34 determined to be most appropriate method, allowing a more detailed inspection of
35
36 the hands’ morphology and potential pathology.
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38 To date no study reports sex estimation standards for the German
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40 population based on hand bone measurements, thus, four published studies of sex
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42 estimation using metacarpal measurements of different European samples [7-10]
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44 were used to assess sex. The suitability of these osteometric methods for the virtual
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46 metacarpal bones from the mummified hands and the validity of methods
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48 developed from different populations was assessed using a control sample of
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50 German descent.
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52 53 **MATERIALS AND METHODS**

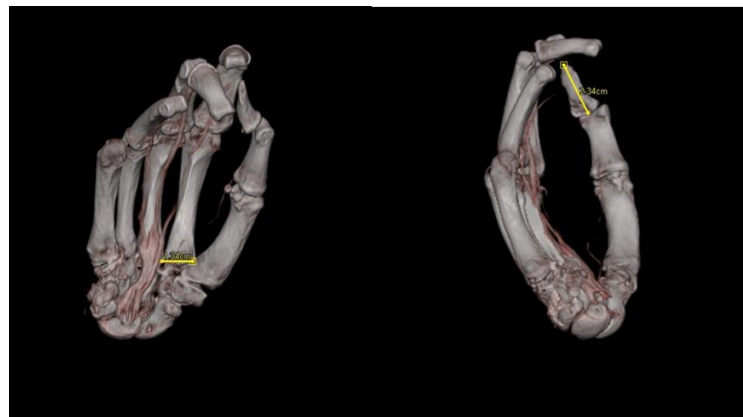
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55 The study sample consists of 19 individuals divided in 3 groups.
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57 **Group 1 (G1):** Seven right mummified hands of unknown sex, stature and age that
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59 were found in different regions of Germany. Each of these hands was classified as
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4 Leibzeichen by the archaeologist Peter Pieper who conducted the morphological
5 analysis [6] and they are described in brief below.
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8 *Münster Hand* (*Abgeschlagene Hand*): This hand is exhibited in the old City Hall
9 Museum of Münster, Germany, placed in a small oak box. The box dates from the
10 second half of the 16th century, but the hand itself is believed to be earlier. The
11 museum catalogue has a reference to a hand of a forger [11]. Nevertheless, the
12 hand is seemingly carefully dissected from the wrist while the carpal bones
13 remained intact. All distal phalanges, 4th and 5th medial phalanges and the 5th
14 proximal phalanx were missing, most likely decayed with time.
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18 *Erkeln Hand*: It was found inside a secret niche of a wall in an old church in Erkeln
19 [12]. A wall was built up after the dissection very likely to keep the relic hand out
20 of sight. The hand is complete, displays no obvious pathology and is small and
21 finely shaped suggesting that it had not been used in manual labor. It was cut with
22 a sharp object recognized by smooth surface of the distal ends of the radius and
23 ulna.
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50 **Figure 1. 3D reconstructions of the Erkeln Hand using CT images. Image credit:**
51 **Dr. Pieter Pieper.**
52

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55 *Wismar hands*: Two hands along with two wooden plates were given to the Wismar
56 ‘Schabbelhaus’ Museum in 1898. They were carefully separated from the rest of the
57 body and identified as Leibzeichen [6]. CT scanning did not reveal any obvious
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4 signs of trauma or pathology. The first hand (HWI 2640 KO) seems more robust,
5 but incomplete with the thumb missing. The maximum length, measured from the
6 wrist to the distal end of the third distal phalanx, is 14.9 cm and the weight 76.1 g.
7
8 The second (HWI 4019 KO) is complete, unarticulated as well and weighed 93.8 g.
9
10 The maximum length is estimated to be 13.5 cm.
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14 *Goslar Hand*: mummified right hand, delivered to the Goslar Museum in 1905.
15
16 Rumours suggest that it belonged to a female but this could not be confirmed
17 through the archival records. First digit is absent, very likely decayed through
18 time, but not removed surgically. It was cut professionally with a special
19 instrument revealing the surface of both os triquetrum and scaphoideum of the
20 wrist [6].
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26 *Legden Hand (perjury-hand)*: this mummified hand was stored in a wooden box
27 inside the old St. Brigida Church (Figure 2). It was discovered preserved in lime
28 during the demolition of an old fortified town in 1905. It is thought to have
29 belonged to a young aristocrat who was murdered. Other legends suggest that it
30 belonged to someone that broke an oath, and it was cut to serve as a bloody lesson
31 to anybody else contemplating straying from the truth. Yet, nobody knows the real
32 history behind the hand and no archival information was available. In 2012 the
33 hand was stolen from the church [13] but luckily morphological and virtual
34 examination through CT scans were performed previously. The hand is complete
35 and carefully dissected. All carpal bones are intact and undamaged [6]. This
36 suggests that it was not cut while the person was alive, which is inconsistent with
37 the theory of punishment for oath breaking.
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Figure 2. The Legden Hand: Image credit:thelocal.de

Lunow Hand: It is placed in a niche of an old Church built in 1250 in the village of Barnim. The hand was discovered in the 16th century and dated between 13th and 16th century. According to a local legend it represents the hand of a child who was found dead after beating his father. It is said that after the burial the hand appeared on the surface and no matter how hard they tried they could not rebury it [6].

Group 2 (G2): Five adult modern individuals (3 males and 2 females) obtained from the Anatomy department of Heinrich-Heine University of Düsseldorf) were analysed.

Group 3 (G3): Six (3 males and 3 females) randomly selected anonymized scans of individuals taken for diagnostic purposes Department of Radiology of University-Clinic, Düsseldorf were analysed.

Methods

In order to determine the sex of the 7 hands in group 1 the following measurements from metacarpal (MTC) and phalangeal (P) bones were selected using previous studies as seen in **Table 1**:

The unknown sample of the G1 group were CT-scanned and then measured. Hand dimensions of G2 were obtained with a caliper and CT scan so that the calibration

could be verified while G3 was measured only on the 3D reconstructions of the CT scans. The CT series for sampling were recorded with a Somatom Plus 4 scanner (Siemens, Erlangen, Germany) using a tube current of 20 mA, tube voltage of 110 kV, slice thickness of 0.75 mm, and slice increment of 0.5 mm. Scans with a field of view of 250 X 250 mm² (matrix 512 X 512) were made in the coronal plane. Voxel size was 0.5 X 0.5 X 0.5 mm³.

Table 1: List of measurements, definitions and abbreviations.

Measurement	Abbreviation	Reference
Maximum interarticular length	ML	[7]
Anterior-posterior diameter of distal epiphysis	APDDE	[7]
Medio-lateral diameter of distal epiphysis	MLDDE	[7]
Anterior-posterior diameter of proximal epiphysis	APDPE	[7]
Mediolateral diameter of proximal epiphysis	MLDPE	[7]
Anterior-posterior midshaft diameter	apmid	[8]
Mediolateral midshaft diameter	mlmid	[8]
Maximum length M1	MaxL	[10]

RESULTS

The lack of published osteometric data on sex determination from metacarpals for the German population creates the need for using earlier formulae. All published studies [7-10] are based on modern samples and thus are population-specific, therefore they must be carefully tested before applied to the mummified hands assumed to be of German descent. Additionally they are created using osteometric data so it must be determined whether they are applicable for measurements that are taken through CT scanning. In this regard G2 and G3 of known sex were used to test the selected formulae and make sure that they satisfied the above mentioned

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4 criteria, so they could be applied in the CT scan measurements of the unknown
5 hands of G1.
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10 *Comparison of osteometric and virtual measurements*

11 Paired T-test between measurements of G2 obtained by osteometry and CT scans
12 showed no statistically significant differences between the mean values.
13 Differences in the measurements were smaller than 0.5mm in all cases. Therefore it
14 was determined that CT-scan measurements could be used for sex assessment
15 based on the published osteometric studies.
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24 *Test of the applicability of published studies in Germans*

25 Using Scheuer and Elkinghton's [7] formulae for MTC 1 all samples (G1, G2, G3)
26 were classified as male while for MTC 5 all samples were classified as females
27 (Supplementary Table 1). So these two equations need to be considered with
28 caution. Falsetti's [8] formula could not be tested for G3 because not all
29 measurements were available in this randomly selected group of patients. The
30 combination of the remaining equations gave correct group assessment for the vast
31 majority of individuals from Group 2 and 3 and therefore was used in the
32 estimation of the mummified hands. For example Individual G1.1 is a male and is
33 classified as male in 35/50 equations used. In addition G2.1 is a female and is
34 classified as female in all 4 equations that could be applied. G1.5 is the only
35 individual which was misclassified as male in 28/50 equations.
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50 *Prediction of sex for the unknown mummified hands.*

51 Sex for G1 was assessed taking into consideration the correct sex assessment of the
52 tested formulae for the validation groups (G2 and G3) and the overall prediction
53 using all available formulae. Table 1 shows the results of metacarpals and first
54 proximal phalanx. As seen in Table 1 it is very likely that the unknown sample
55 consists of five males (Münster, Erkeln, HWI 2641, Legden, Lunow), one female
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(Goslar) and one of ambiguous sex (HWI 4019).

Group 1: Prediction of sex for the unknown hands using CT measurements. (SE: Scheuer and Elkinghton, F: Falsetti, S: Stojanowski, Bar:Barrio).

	SE	Fal	Bar	Stojanowski							SE	Fal	Bar	Stojanowski						
				1	2	3	4	5	6	7				1	2	3	4	5	6	7
	Münster										Erkeln									
MTC1	M		M	M	M	M	M	M	M	M	M		M	F	M	M	M	M	M	M
MTC II	M	M	F	M	F	M	M	M	M	M	M	M	M	M	F	F	F	M	M	M
MTC III	M		M	F	M	F	M	M	M	M	M	M		M	M	M	M	M	M	M
MTC IV	F	F	F	F	F	F	M	M	M	M	M	M	M	M	M	M	M	M	M	M
MTC V	F	M	M	M	M	F	M	M	M	M	M	F	M	M	M	M	F	M	M	
p1	M											M								
mid	M											M								
	HWI 2641										Goslar									
MTC II	F	M	F	M	M	M	M	M	M	M	M	M	M	F	F	F	F	M	M	
MTC III	M		M	F	M	M	M	M	M	M	M	M		M	M	F	F	M	M	
MTC IV	M	M	M	M	M	M	M	M	M	M	M	M	M	F	M	F	F	M	M	
MTC V	F	M	M	M	M	M	M	M	M	M	M	F	M	M	M	F	M	M	M	
mid												F								
	HWI 4019										Lunow									
MTC I	M		M	F	M	F	F	F	M	M	M		M	M	M	M	M	M	M	
MTC II	M	M	F	F	F	F	M	M	M	M	M	M	M	M	F	F	M	M	M	
MTC III	M		F	F	F	F	F	F	F	F	M		M	M	F	M	M	M	M	
MTC IV	M	M	M	M	M	M	M	M	M	M	M	M	F	M	M	M	M	M	M	
MTC V	F	M	M	F	F	F	F	F	F	F	M		M	M	M	M	M	M	M	
p1	M											M								
mid	M											M								
	Legden																			
MTC I	M		F	F	M	F	F	F	F	F										
MTC II	M	M	M	M	M	M	M	M	M	M										
MTC III	M		M	M	F	M	M	M	M	M										
MTC IV	M	M	M	M	M	M	M	M	M	M										
MTC V	F	M	M	M	M	M	M	M	M	M										
p1	M																			
mid	M																			

Discussion

In order to understand the social significance of the hands through history either appearing as Leibzeichen, or signs of corporal punishment, it is essential to discover the identity of the individuals. As noted above, demographic data was not available for sexing these remains. It was assumed that these individuals were of European descent, and most probably Germans, due to the geographic locations where these remains were found. Therefore, the current literature was used in order to estimate the sex of the remains, with the reservation that these studies are not based on the German population.

The selected formulae are deriving mostly from studies based on British [7], Spanish [10], European-American [8], and combined European and African American [9] samples that are expected to give diverse results when applied to individuals of different descent. A short description of their methodology and results is considered essential in order to evaluate the sex assessment that was attempted.

In a study carried out with an autopsy sample of 60 individuals of British origin six measurements from five metacarpals and the first proximal phalanx were taken and tested on 20 specimens [7]. Results provided an accuracy rate ranging from 74% to 94%, with MTC I demonstrating the highest degree of sexual dimorphism.

Falsetti (1995) also tested the measurements proposed by Scheuer and Elkington (1993), plus anteroposterior and mediolateral midshaft breadths for sexual dimorphism. In this study, the Terry collection was used and differences between European and African-Americans were tested. Accurate classification ranged from 77% for the 2nd digit, 80% for the 4th to 85% for the 5th.

Stojanowski (1999) also studied sexual dimorphism of the hand bones using the proposed six dimensions by Scheuer and Elkington (1993) and developed 35 functions with the aim of determining sex of individuals with pathological conditions and poor preservation. He studied a pooled sample of European and

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4 African-Americans all born after 1900. Sex accuracy ranged from 75-95% with MTC
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6 IV providing the highest degree of sexual dimorphism. It should be stressed
7
8 though that the female validation sample was small and caution must be taken
9
10 validating the error rate for female classification.

11
12 Barrio and coworkers (2006) also investigated metacarpal bones in a
13
14 contemporary Spanish population and obtained 81 to 91% classification accuracy,
15
16 with the highest rate for left MTC II.

17
18 A validation study testing three of the above mentioned methods [7-9] used
19
20 a small sample (N=23) of recent European-American skeletons [14]. The
21
22 discouraging results support the theory of population specific differences in
23
24 osteometric values. On the other hand, a test of population-specific equations
25
26 deriving from a sample from the same country also gave poor classification results
27
28 for some formulae [15]. Other validation studies report a secular trend of declining
29
30 bone robusticity [16], which indicates a greater chance of misclassification in
31
32 females when archaeological samples are employed.

33
34 The review of the literature clearly demonstrates that sex estimation using
35
36 formulae developed from different populations and chronology require special
37
38 methodological consideration. This is especially difficult when there are no criteria
39
40 for the population the unknown remains may have derived from. To simplify the
41
42 potential problem in this study several steps were taken.

43
44 The sex of the hands forming G1 were estimated after a few general
45
46 assumptions were made deriving from the classification of G2 and G3 and the
47
48 literature review. Scheuer and Elkinghton's [7] formula for metacarpal V classified
49
50 all samples (G1-3) as female probably due to population differences or typos in the
51
52 equation; hence it was not used for sex estimation. Additionally, Equation 1 gave
53
54 male values for all samples in the same study; thus it was not taken into account in
55
56 samples that were indicating a female value using other formulae. In contrast
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58 Barrio's [10] equations seem to have the best accuracy rate in correct classification
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60 for G2 and G3, while Stojanowski [9] predicted more accurately than expected in a
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4 validation sample of another study [14]. It must be stressed that these remarks
5 don't represent a testing of accuracy of the other studies but to find a logical way
6 to evaluate the complex results produced in table 1 for the specific sample under
7 study.
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10
11 In this regard, one can suggest that G1 consists most likely of 5 male and 1
12 female individuals as seen in Table 1. Among them the Goslar hand represents a
13 rather controversial case that is difficult to classify either way (see table 1). It could
14 be suggested that that it is more likely to be a female individual based on the
15 appearance of female values in the formulae produced by Barrio [10] and
16 Stojanowski [9] that seem to be more accurate in classifying females, and on the
17 expected misclassification of females as males in archaeological samples as noted
18 above [16]. Naturally this assumption is expressed with reservation due to the
19 diversity of the predicted values for that case.
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30 Misclassification of sex in these remains enhances the danger of misquoting
31 the social and legal aspects of life during Middle Ages. For example, if all
32 *Leibzeichen* are classified as male, one could assume that only the male hands are
33 brought to court. Consequently, in order to reconstruct the archaeological scene
34 and interpret these findings a DNA-investigation along with radiocarbon dating is
35 needed.
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42 In conclusion, estimation of sex from metacarpals using CT scan
43 measurements is a novelty and requires a well calibrated population-specific
44 sample, especially when applied to archaeological and mummified specimens.
45 Bearing this in mind, it would be preferable to create a database of known sex in
46 the medieval German population in order to assess sex for the mummified hands
47 of G1 with better accuracy. Clearly the need for further investigation and DNA
48 analysis of these hands to verify the preliminary morphometric sex assessment.
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57 **Acknowledgments**

58
59 EK would like to thank Dr. Peter Pieper for allowing access to the CT scans of the
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7 scans of patients and for allowing the use of 3D software. Special thanks to
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Supplementary table S1. Sex estimates using all equations for G1, G2 and the unknown G3.

No	sex	MTC I										MTC II										MTC III										MTC IV										MTC V										p1	mid	F	M								
		SE	S1	S2	S3	S4	S5	S6	S7	Bar	SE	Fal	S1	S2	S3	S4	S5	S6	S7	Bar	SE	S1	S2	S3	S4	S5	S6	S7	Bar	SE	Fal	S1	S2	S3	S4	S5	S6	S7	Bar	SE	Fal	S1	S2	S3	S4	S5	S6	S7	Bar	SE	SE												
G1.1	1	M	F	M	F	F	F	F	F	F	M	M	M	F	M	F	F	M	F	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	15	35
G1.2	1			M							F	M	F	F	F	M	M	M	M	F	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	6	36
G1.3	1	M	F	M	M	M	M	M	M	F	F	M	F	M	F	M	M	M	M	F	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	7	43
G1.4	2	M	F	M	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	M	M	F	F	F	F	F	F	F	M	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	46	4
G1.5	2	M	M	M	F	F	M	M	F	M	F	F	F	F	F	M	M	M	M	M	M	F	M	F	M	F	F	F	F	F	M	M	F	M	M	M	M	M	F	F	M	M	F	M	M	F	M	M	F	M	F	22	28										
G2.1	2												F							F	F							F																																	4	0	
G2.2	2	M	M	M	M	F	F	F	F				F							F	F							F			F										F																				10	4	
G2.3	2			M										F									F										F						F				F						M													5	2
G2.4	1		M											M						M	M							M			M										M																				0	7	
G2.5	1		M											M						M	M							M			M										M																				0	7	
G2.6	1	M	M	M	M	M	M	M	M	M				M						M	M							M			M							M			M							M													0	17	
Munster	UN	M	M	M	M	M	M	M	M	F	M	M	M	F	M	M	M	M	M	F	M	F	M	F	M	M	M	M	M	F	F	F	F	M	M	M	M	F	F	M	M	M	F	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	12	38	
Erkeln	UN	M	F	M	M	M	M	M	M	M	M	M	F	F	F	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	F	M	M	F	M	M	F	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	7	43	
hwi 4019	UN	M	F		F	F	F	M	M	M	M	M	F	F	F	M	M	M	F	M	F	F	F	F	F	F		M	M	M	M	M	M	M	M	M	M	M	F	M	F	F	F	F	F	F	M	M	M	M	M	M	M	M	M	M	M	M			23	24	
hwi 2641	UN										F	M	M	M	M	M	M	M	F	M	F	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	F	M	M	M	M	M	M	M	M	M													4	34	
Gosslar	UN										M	M	F	F	F	M	M	M	M	F	M	M	F	F	M	M	M	M	M	M	M	F	F	M	M	M	M	F	F	M	M	F	M	M	M	M	M	M													11	27	
Legden	UN	M	F	M	M	M	M	M	M	F	M	M	M	M	M	M	M	M	M	M	M	M	F	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	F	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	4	46	
Lunov	UN	M		M	M	M	M	M	M	M	M	M	M	F	F	M	M	M	M	M	M	M	F	M	M	M	M	M	M	M	M	F	F	M	M	M	M	F	F	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	5	45	

SE Scheuer and Elkington
 Fal Falsetti
 S Stoyanowski
 Bar Barrio