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Article

Citation (please note it is advisable to refer to the publisher's version if you intend to cite from this work)

Borrini, M (2022) Overcoming the chaotic numerology of osteometry. A proposal for a univocal numeric coding system for osteometric measurements of the human skeleton. Archivio per l'Antropologia e la Etnologia, 152. pp. 17-31. ISSN 0373-3009

Archivio per l'Antropologia e la Etnologia - Vol. CLII (2022)
www.antropologiaetnologia.it
ISSN 0373-3009

Published: November 1, 2022

Data Availability Statement: All relevant data are within the paper.

Overcoming the chaotic numerology of osteometry. A proposal for a univocal numeric coding system for osteometric measurements of the human skeleton

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Abstract. Osteometric measurements have a critical role particularly in forensic anthropology. They allow the objective quantification of morphological characteristics when developing the biological profile of unknown skeletons, rather than relying purely on qualitative descriptions that are often subjective. Various coding systems for anthropometric measurements have been developed across the years and countries. Currently, there is not a shared classification for the most commonly applied measurements in osteometry. For a scientific community becoming ever more global and international, the lack of a common language can create impasses and lead to miscommunications between scientists. The problem could become more relevant in mass fatalities and international scenarios. In order to develop a new communal codification model, some imperfections in traditional classifications have been identified and overcome. The new proposed coding is based on a three-number taxonomy. The three cyphers, separated by a dot (#.#.#), indicate the anatomical area of which the measurement is referred (e.g. cranium, upper limb), the single bone (e.g. humerus) or the topographic region (e.g. neurocranium) measured, and the specific measurement. The third number, an arithmetic progression that identifies every measurement, has been designed to allow the scientific community to introduce new measurements without scrambling the entire series.

Keywords: anthropometry, forensic anthropology, standards, reliability, guidelines, quality control.

Introduction

Osteometry is not only one of the most historical and essential parts of physical anthropology; skeletal measurements still have a very relevant role in forensic anthropology because they allow the objectification of morphological characteristics, outlining the biological profile of unknown skeletal remains and understanding human physical variation (Bass, 1987; France, 1998; Scheuer and Black, 2000; Dabbs and Moore-Jansen, 2010; Plochocki, 2011).

Over the decades (Rollet, 1888; Hrdlicka, 1952; Olivier, 1960), various methods have been developed using different coding systems for measurements, each being used by different researchers, but none reaching a universal consensus. Especially in Europe, one of the most popular codifications is from Martin-Saller (1957); other codes often used in the USA are by Howells (1973) and by Buikstra and Ubelaker (1994). A non-shared language can create an impasse and miscommunication between scientists and forensic practitioners in the scientific community, which is becoming ever more global and international.

However, forensic sciences urgently require standard analytic methods and data collection: the Frye and Daubert principles, the Joint POW/MIA Accounting Command (JPAC) experience, and recent AAFS meetings (Bono, 2011) all stressed the importance of scientific evidence based on the requirements of relevance, reliability and validity. The use of quality assurance is essential where a high degree of reliability is required, and therefore a univocal and standardized coding system should be introduced into physical/forensic anthropology (Byrd and Sava, 2009; Byrd, 2009).

Similar problems have been faced by odontologists who are involved in mass fatalities and international casework. The odontological community has solved this problem with the FDI World Dental Federation notation ISO 3950, where quadrants are numbered from 1 to 4 in permanent and from 5 to 8 in deciduous dentition. The numbers proceed clockwise from the upper right quadrant to the lower right, and the teeth are numbered from the midline to the posterior.

Imperfections of the traditional coding systems

In order to develop a new shared codification model, some imperfections in the traditional coding systems must be overcome.

First of all, one obstacle in the Martin-Saller system (Martin and Saller, 1957) is that all measurements are divided into chapters corresponding to single bones and are numbered with an arithmetic progression. This system can be ambiguous because the numbers are not univocal. For example, measurement number 1 (MS 1) can indicate the maximum length of the skull, the femur and all the other long bones.

Howells coding identifies the measurement by an abbreviation in capital letters of its description; this system presents a problem when a long or complex name identifies a measurement or if new measurements are created.

The USA Standards by Buikstra and Ubelaker (1994) has poor proactivity because measurements are numbered in a non-interrupted sequence from the skull to the calcaneus; therefore, new measurements cannot be simply introduced to the sequence without creating confusion.

The new coding system

The new coding system proposed is based on a three-number codification, where numbers are divided by full stops (i.e. #.#.#). The first number will indicate the anatomical area to which the measurement refers:

1 – cranium
2 – upper limb
3 – lower limb
4 – rachis
5 – thoracic girdle
6 – pelvic girdle

The second number will indicate the single bone or the topographic region in the cranium, as shown in Table 1.

1 – cranium	2 – upper limb	3 – lower limb
1.1 neurocranium 1.2 facial skull 1.3 orbital skeleton 1.4 nasal region 1.5 maxillary area 1.6 mandible	2.1 humerus 2.2 ulna 2.3 radius	3.1 femur 3.2 tibia 3.3 fibula 3.4 patella
4 – rachis	**5 – thoracic girdle**	**6 – pelvic girdle**
4.1 vertebrae 4.2 atlantoaxial joint 4.3 sacrum	5.1 scapula 5.2 clavicle 5.3 sternum	6.1 os innominatum 6.2 pelvis

Tab. 1. *The first two numbers of the coding system refer to the anatomical area and the bone to which the measurement refers. For the cranium, the second number indicate the anatomical region.*

The first two numbers of the code rapidly identify which area of the body and on which bone the anthropometrical data is recorded. The third and final number is an arithmetic progression that identifies each measurement, allowing future researchers to introduce new measurements without scrambling the entire series.

Tables from 2 to 21 present a selection of measurements and their correspondence with the new coding system and previous codifications, including British (Brothwell, 1981) and Fordisc® systems. The proposed selection includes only some of the measurements in Howells (1973) or Buikstra and Ubelaker (1994), but it also provides for new ones, most of which come from Martin and Saller (1957) or recent forensic scientific literature (Baker *et al.*, 1990). All the measurements reported in the present proposal are included in the «*Forensic Protocol for anthropometric measurement of human skeletal remains*» developed in Italy (Borrini, 2011). This new protocol has been developed with detailed instructions which provide standard operating procedures (SOP) for measuring human bones. The measurements are mostly from Martin and Saller (1957), but they have been rewritten as SOP, providing clear, detailed and explicit directions on how to record each measurement and from which landmark. Anatomical reference points have been thorough specified, and the measuring technique has not been presented as mere definitions as in the past literature. Instead, each action (e.g., placement and movements of the callipers) has been described in short sentences, and the protocol includes step-by-step instructions for the operator, which indicate in a clear, unambiguous and precise manner how to record each measurement, from which landmark to proceed, and which instrument to use. Consequently, a further benefit of this protocol is overcoming the problems related to the lack of universal consensus on recording osteometric measurements.

Conclusion and future developments

The author presents to the scientific community of biological and forensic anthropologists a proposal for a new measurement coding in order to create a shared system for osteometry.

The proposed system is an integral part of the «*Forensic Protocol for anthropometric measurement of human skeletal remains*» developed at the University of «Tor Vergata» (Borrini, 2011). The coding and the protocol have been successfully applied to various historical (Franchi *et al.*, 2000; Pintaudi *et al.*, 2012; Gnes *et al.*, 2018; Baldoni *et al.*, 2018) and Italian forensic cases (Borrini, 2015) in a five-year research project at the University of Florence.

Currently, this protocol is used by various Italian and international (Valoriani, 2019) Universities and expert witnesses appointed by the Italian State Prosecutor Office. It is hoped that the proposed system will enable researchers and practitioners to speak the same language and communicate their findings. A scientific community with a common language will be more inclusive and allow the comparison of data from different skeletal populations and pursuing justice around the world.

1.1 NEUROCRANIUM						
Measurement name	**New code**	**Martin & Saller code**	**USA Standards code**	**Howells code**	**British code**	**Fordisc code**
maximum length of the neural skull	1.1. 1	MS 1	1	GOL	L	Maximum Ln
glabella-inion length	1.1.2	MS 2	--	--	--	--
glabella-lambda length	1.1.3	MS 3	--	--	--	--
cranial base length	1.1.4	MS 5	5	BNL	LB	Basion-Nasion Ln
maximum neurocranial breadth	1.1.5	MS 8	2	XCB	B	Max Cranial Br
biauricular breadth	1.1.6	MS 11	9	AUB	--	Biauricular Br
biasterionic diameter	1.1.7	MS 12	--	ASB	Biast B	Biasterionic Breath
bimastoid breadth of the cranial base	1.1.8	MS 13	--	--	--	--
basion-bregma height	1.1.9	MS 17	4	BBH	H'	Basion-Bregma Ht
total height	1.1.10	MS 18	--	--	--	--
porion-bregma height	1.1.11	MS 20	--	--	--	--
porion-vertex height	1.1.12	MS 21	--	--	--	--
horizontal cranial circumference	1.1.13	MS 23	--	--	--	--
horizontal cranial circumference above-ophryon	1.1.14	MS 23-a	--	--	U	U
transverse curve	1.1.15	MS 24	--	--	BQ'	BQ'
total longitudinal arch	1.1.16	MS 25	--	--	--	--
nasion-bregma arch	1.1.17	MS 26	--	--	S_1	S_1
parietal longitudinal arch	1.1.18	MS 27	--	--	S_2	S_2
occipital arc	1.1.19	MS 28	--	--	S_3	S_3
nasion-bregma chord	1.1.20	MS 29	19	FRC	S'_1	Frontal Chord
bregma – lambda chord	1.1.21	MS 30	20	PAC	S'_2	Parietal Chord
lambda-opisthion chord	1.1.22	MS 31	21	OCC	S'_3	Occipital Chord
foramen magnum length	1.1.23	MS 7	22	FOL	FL	Foramen Magnum Ln
foramen magnum breadth	1.1.24	MS 16	23	--	FB	Foramen Magnum Br

Tab. 2. *Correspondence between the proposed coding system and the traditional classifications for neurocranial measurements.*

1.2 FACIAL SKULL						
Measurement name	**New code**	**Martin & Saller code**	**USA Standards code**	**Howells code**	**British code**	**Fordisc code**
length of the face	1.2.1	MS 40	6	BPL	--	Basion-Prosthion Ln
minimum frontal breadth	1.2.2	MS 9	11	--	B'	Minimum Frontal Br
maximum frontal breadth	1.2.3	MS 10	--	XFB	--	--
upper facial breadth	1.2.4	MS 43	12	FMB	G'H	--
bizygomatic facial breadth	1.2.5	MS 45	3	ZYB	J	Bizygomatic Br
maximum bimaxillary breadth of the midface	1.2.6	MS 46	--	ZMB	GB	Zygomaxillary Br
morphological height of the face	1.2.7	MS 47	--	--	--	--
height of the upper face	1.2.8	MS 48	10	NPH	--	--

Tab. 3. Correspondence between the proposed coding system and the traditional classifications for facial measurements.

1.3 ORBITAL SKELETON						
Measurement name	**New code**	**Martin & Saller code**	**USA Standards code**	**Howells code**	**British code**	**Fordisc code**
biorbital breadth	1.3.1	MS 44	17	EKB	--	Biorbital Br
interorbital breadth from dakryon	1.3.2	MS 49-a	18	DKB	O'_1	Interorbital Br
interorbital breadth	1.3.3	MS 50	--	--	DC	--
orbital breadth	1.3.4	MS 51	15	OBB	--	Orbital Br
orbital height	1.3.5	MS 52	16	OBH	--	Orbital Ht

Tab. 4. *Correspondence between the proposed coding system and the traditional classifications for orbital measurements.*

1.4 NASAL SKELETON						
Measurement name	**New code**	**Martin & Saller code**	**USA Standards code**	**Howells code**	**British code**	**Fordisc code**
nasal breadth	1.4.1	MS 54	14	NLB	NB	Nasal Br
nasal height	1.4.2	MS 55	13	NLH	NH'	Nasal Height
nose-malar chord	1.4.3	MS 44-a	--	--	--	--
nose-malar breadth	1.4.4	MS 44-1	--	--	--	--

Tab. 5. *Correspondence between the proposed coding system and the traditional classifications for nasal measurements.*

1.5 MAXILLARY SKELETON						
Measurement name	**New code**	**Martin & Saller code**	**USA Standards code**	**Howells code**	**British code**	**Fordisc code**
maxillo-alveolar length	1.5.1	MS 60	8	--	--	--
maxillo-alveolar breadth	1.5.2	MS 61	7	--	--	--
palate length	1.5.3	MS 62	--	--	G'_1	G'_1
palate breadth	1.5.4	MS 63	--	--	G_2	G_2

Tab. 6. *Correspondence between the proposed coding system and the traditional classifications for maxillary measurements.*

1.6 MANDIBLE						
Measurement name	**New code**	**Martin & Saller code**	**USA Standards code**	**Howells code**	**British code**	**Fordisc code**
bicoronoid breadth of the jaw	1.6.1	MS 65-1	--	--	--	--
bigoniac breadth	1.6.2	MS 66)	28	--	Go-Go	Bigonial Br
bimental breadth	1.6.3	MS 67	--	--	ZZ	--
length of the mandibular body	1.6.4	MS 68	33	--	--	Mandibular Ln
projected length of the mandible	1.6.5	MS 68-1	--	--	ML	--
symphysial height of the chin	1.6.6	MS 69	25	--	H_1	Chin Height
corpus mandibulae height	1.6.7	MS 69-1	26	--	--	Ht at Mental Foramen
height of the corpus mandibulae to the 2nd molar	1.6.8	MS 69-2	--	--	--	--
thickness of the corpus mandibulae	1.6.9	MS 69-3	27	--	--	Br at Mental Foramen
condylar height of the ramus	1.6.10	MS 70	32	--	--	Max Ramus Ht
minimum ramus breadth referred to the height	1.6.11	MS 71	30	--	--	Minimum Ramus Br
minimum ramus breadth	1.6.12	MS 71-a	--	--	RB'	--
mandibular angle	1.6.13	MS 79	34	--	--	Mandibular Angle

Tab. 7. *Correspondence between the proposed coding system and the traditional classifications for mandibular measurements.*

2.1 HUMERUS						
Measurement name	**New code**	**Martin & Saller code**	**USA Standards code**	**Howells code**	**British code**	**Fordisc code**
maximum length	2.1.1	MS 1	40	--	--	HUMXLN
total physiological length	2.1.2	MS 2	--	--	--	--
superior epiphyseal breadth	2.1.3	MS 3	--	--	--	--
epicondilar breadth	2.1.4	MS 4	41	--	--	HUMERBR
maximum diameter in the mid diaphysis	2.1.5	MS 5	43	--	--	HUMMXD
minimum diameter in the mid diaphysis	2.1.6	MS 6	44	--	--	HUMMWD
minimum shaft circumference	2.1.7	MS 7	--	--	--	--
caput circumference	2.1.8	MS 8	--	--	--	--
maximum transverse diameter – *caput* breadth	2.1.9	MS 9	--	--	--	--
sagittal diameter - *caput* height	2.1.10	MS 10	42	--	--	HUMHDD

Tab. 8. *Correspondence between the proposed coding system and the traditional classifications for measurements of the humerus.*

2.2 ULNA						
Measurement name	**New code**	**Martin & Saller code**	**USA Standards code**	**Howells code**	**British code**	**Fordisc code**
maximum length	2.2.1	MS 1	48	--	--	ULNXLN
physiological length	2.2.2	MS 2	51	--	--	ULNPHL
minimum circumference	2.2.3	MS 3	52	--	--	ULNCIR
dorso-volar diameter	2.2.4	MS 11	49	--	--	ULNDVD
transverse diameter	2.2.5	MS 12	50	--	--	ULNTVD
upper transverse diameter	2.2.6	MS 13	--	--	--	--
upper dorso-volar diameter	2.2.7	MS 14	--	--	--	--

Tab. 9. *Correspondence between the proposed coding system and the traditional classifications for measurements of the ulna.*

2.3 RADIUS						
Measurement name	**New code**	**Martin & Saller code**	**USA Standards code**	**Howells code**	**British code**	**Fordisc code**
maximum length	2.3.1	(MS 1)	45	--	--	RADXLD
physiological length	2.3.2	(MS 2)	--	--	--	--
minimum circumference	2.3.3	(MS 3)	--	--	--	--
transverse diameter	2.3.4	(MS 4)	47	--	--	RADTVD
sagittal anterior-posterior diameter	2.3.5	(MS 5)	46	--	--	RADAPD

Tab. 10. *Correspondence between the proposed coding system and the traditional classifications for measurements of the radius.*

3.1 FEMUR						
Measurement name	**New code**	**Martin & Saller code**	**USA Standards code**	**Howells code**	**British code**	**Fordisc code**
maximum length	3.1.1	MS 1	60	--	--	FEMXLN
total length in natural anatomical position	3.1.2	MS 2	61	--	--	FEMBLN
maximum trochanteric length	3.1.3	MS 3	--	--	--	--
trochanteric physiological length	3.1.4	MS 4	--	--	--	--
lateral-medial transverse diameter	3.1.5	MS 7	67	--	--	FEMMTV
antero-posterior sagittal midshaft diameter	3.1.6	MS 6	66	--	--	FEMMAP
midshaft circumference	3.1.7	MS 8	68	--	--	FEMCIR
transverse sub-trochanteric diameter	3.1.8	MS 9	65	--	--	FEMSTV
anteroposterior sub-trochanteric diameter	3.1.9	MS 10	64	--	--	FEMSAP
caput femoris vertical diameter	3.1.10	MS 18	--	--	--	FEMHDD
caput femoris transverse diameter	3.1.11	MS 19	--	--	--	--
caput femoris circumference	3.1.12	MS 20	--	--	--	--
epicondylar breadth	3.1.13	MS 21	62	--	--	FEMEBR
maximum height of the intercondylar notch	3.1.14	--	--	--	--	--

Tab. 11. *Correspondence between the proposed coding system and the traditional classifications for measurements of the femur.*

3.2 TIBIA						
Measurement name	**New code**	**Martin & Saller code**	**USA Standards code**	**Howells code**	**British code**	**Fordisc code**
total condyle-malleolar length	3.2.1	MS 1	69	--	--	TIBXLN
physiological condyle-talar length	3.2.2	MS 2	--	--	--	--
maximum proximal epiphysis breadth	3.2.3	MS 3	70	--	--	TIBPEB
maximum distal epiphysis breadth	3.2.4	MS 6	71	--	--	TIBDEB
maximum midshaft sagittal diameter	3.2.5	MS 8	--	--	--	--
maximum diameter at the nutrient foramen	3.2.6	MS 8.a	72	--	--	TIBNFX
transverse midshaft diameter	3.2.7	MS 9	--	--	--	--
transverse diameter at the nutrient foramen	3.2.8	MS 9-a	73	--	--	TIBNFT
circumference at the nutrient foramen	3.2.9	MS 10.a	74	--	--	TIBCIR
minimum circumference	3.2.10	MS 10-a	--	--	--	--

Tab. 12. *Correspondence between the proposed coding system and the traditional classifications for measurements of the tibia.*

3.3 FIBULA						
Measurement name	**New code**	**Martin & Saller code**	**USA Standards code**	**Howells code**	**British code**	**Fordisc code**
maximum length	3.3.1	MS 1	75	--	--	FIBXLN
maximum midshaft diameter	3.3.2	MS 2	76	--	--	FIBMDM
minimum midshaft diameter	3.3.3	MS 3	--	--	--	--
minimum circumference	3.3.4	MS 4-a	--	--	--	--

Tab. 13. *Correspondence between the proposed coding system and the traditional classifications for measurements of the fibula.*

3.4 PATELLA						
Measurement name	**New code**	**Martin & Saller code**	**USA Standards code**	**Howells code**	**British code**	**Fordisc code**
maximum height	3.4.1	MS 1	--	--	--	--
maximum breadth	3.4.2	MS 2	--	--	--	--
maximum thickness	3.4.3	MS 3	--	--	--	--

Tab. 14. *Correspondence between the proposed coding system and the traditional classifications for measurements of the patella.*

4.1 VERTEBRAE (from C3 to L5)						
Measurement name	**New code**	**Martin & Saller code**	**USA Standards code**	**Howells code**	**British code**	**Fordisc code**
ventral vertical diameter- frontal height	4.1.1	MS 1	--	--	--	--
dorsal vertical diameter- posterior height	4.1.2	MS 2	--	--	--	--
central vertical diameter - central height	4.1.3	MS 3	--	--	--	--
cranial sagittal diameter- upper diameter	4.1.4	MS 4	--	--	--	--
caudal sagittal diameter- inferior diameter	4.1.5	MS 5	--	--	--	--
medial sagittal diameter	4.1.6	MS 6	--	--	--	--
cranial transverse diameter	4.1.7	MS 7	--	--	--	--
caudal transverse diameter	4.1.8	MS 8	--	--	--	--
transverse medial diameter	4.1.9	MS 9	--	--	--	--

Tab. 15. *Correspondence between the proposed coding system and the traditional classifications for measurements of the vertebrae from C3 to L5.*

4.2 ATLANTO-AXIAL JOINT (C1 AND C2)						
Measurement name	**New code**	**Martin & Saller code**	**USA Standards code**	**Howells code**	**British code**	**Fordisc code**
ventral vertical diameter-height	4.2.1	MS 1a	--	--	--	--
height of the axis body	4.2.2	MS 1b	--	--	--	--
ventral vertical diameter of the atlanto-axial joint	4.2.3	MS 1c	--	--	--	--

Tab. 16. *Correspondence between the proposed coding system and the traditional classifications for measurements of the vertebrae C1 and C2.*

4.3 SACRUM (S1 to S5)						
Measurement name	**New code**	**Martin & Saller code**	**USA Standards code**	**Howells code**	**British code**	**Fordisc code**
sagittal arch-ventral curve	4.3.1	MS 1	--	--	--	--
sagittal chord	4.3.2	MS 2	53	--	--	SACHT
maximum upper breadth	4.3.3	MS 5	54	--	--	SACABR
median breadth	4.3.4	MS 9	--	--	--	--
inferior breadth	4.3.5	MS 10	--	--	--	--

Tab. 17. *Correspondence between the proposed coding system and the traditional classifications for measurements of the sacrum.*

5.1 SCAPULA						
Measurement name	**New code**	**Martin & Saller code**	**USA Standards code**	**Howells code**	**Brtish code**	**Fordisc code**
morphological breadth	5.1.1	MS 1	38	--	--	SCAPHT
anatomical length	5.1.2	MS 2	39	--	--	SCAPBR
length of the axillary margin	5.1.3	MS 3	--	--	--	--
length of the top margin	5.1.4	MS 4	--	--	--	--
infraspinous fossa morphological breadth	5.1.5	MS 5a	--	--	--	--
supraspinous fossa morphological breadth	5.1.6	MS 6a	--	--	--	--
glenoid cavity length	5.1.7	MS 12	--	--	--	--
glenoid cavity breadth	5.1.8	MS 13	--	--	--	--

Tab. 18. *Correspondence between the proposed coding system and the traditional classifications for measurements of the scapula.*

5.2 CLAVICLE						
Measurement name	**New code**	**Martin & Saller code**	**USA Standards code**	**Howells code**	**British code**	**Fordisc code**
maximum length	5.2.1	MS 1	35	--	--	CLAXLN
height of the diaphyseal curve	5.2.2	MS 2	--	--	--	--
length of diaphyseal curvature chord	5.2.3	MS 3	--	--	--	--
midshaft vertical diameter	5.2.4	MS 4	37	--	--	CLAVRD
midshaft sagittal diameter	5.2.5	MS 5	36	--	--	CLAAPD
midshaft circumference	5.2.6	MS 6	--	--	--	--

Tab. 19. *Correspondence between the proposed coding system and the traditional classifications for measurements of the clavicle.*

6.1 OS INNOMINATUM						
Measurement name	**New code**	**Martin & Saller code**	**USA Standards code**	**Howells code**	**British code**	**Fordisc code**
os coxe-pelvis height	6.1.1	MS 1	56	--	--	INNOHT
breadth of the iliac bone	6.1.2	MS 12	57	--	--	ILIABR
ilium posterior breadth - cotyle-sciatic diameter	6.1.3	MS 14.1	--	--	--	--
sciatic height	6.1.4	MS 15.1	--	--	--	--
maximum acetabulum diameter	6.1.5	MS 22	--	--	--	--
acetabulum-symphysis length	6.1.6	MS 14	--	--	--	--
cotyle-pubic breadth	6.1.7	--	--	--	--	--
ischio-acetabular length	6.1.8	--	--	--	--	--
spino-sciatic length	6.1.9	--	--	--	--	--

Tab. 20. *Correspondence between the proposed coding system and the traditional classifications for measurements of the os innominatum or os coxa.*

6.2 PELVIS						
Measurement name	New code	Martin & Saller code	USA Standards code	Howells code	British code	Fordisc code
maximum pelvic breadth	6.2.1	MS 2	--	--	--	--
anterior spinal breadth of the pelvis	6.2.2	MS 5	--	--	--	--
sagittal diameter-true conjugate	6.2.3	MS 23	--	--	--	--
transverse diameter	6.2.4	MS 24	--	--	--	--

Tab. 21. *Correspondence between the proposed coding system and the traditional classifications for measurements of the pelvis. For these measurements both the os coxae and the sacrum are articulated.*

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