

Appendix D

Zooarchaeological identification of *Equidae* from the ancient Near East An overview of previous research

Introduction


This is an overview of identification methods suggested for identifying and differentiating the equid species present in the Near East in the Bronze Age (c. 3000-1200 BCE). The following species have been included: *E. asinus*, *E. caballus*, *E. hemionus*; where data are available, crosses between these are added; *E. africanus* is also added when comparative information is available (for additional species of *Equidae* of other areas and periods, and for measurement guides, see also the extensive resources on the website of Vera Eisenmann: vera-eisenmann.com). It is very important to note here that this is *not* an atlas or guide to identification, but rather an overview of some of the criteria suggested by various scholars and experts since such studies first began. All the methods are not necessarily reliable or systematically and extensively tested; they should be applied with great caution. There is considerable overlap between species, and unknown factors as a result of extinct/rare species and chronological development. The most fruitful results are likely to be based on complete or large parts of skeletons, but these are also the ones least likely to appear in archaeological contexts. In practice, overall size is still the most common criteria used for identification. Dental morphology is commonly used, but entails a significant degree of uncertainty. Drawings accompanying each identification method mark the location of the specific feature: they are not themselves diagnostic, and are all based on *E. caballus* bones. Where available, comparative images occur at the end of each section.

The skull

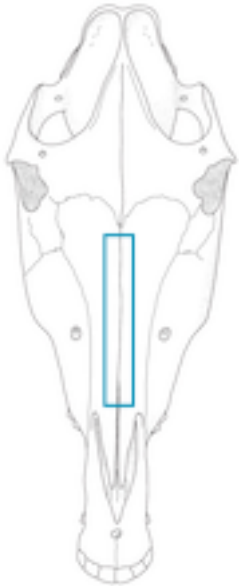
For age-related changes in equines skulls, see Arloing (1882).

Maxilla

Anterior nasal spine	
<i>E. asinus</i>	More robust and protruding
<i>E. caballus</i>	Lower and crossed by furrow
<i>E. hemionus</i>	No data
Source: Barone 1976: 103. Wilkens 2003.	



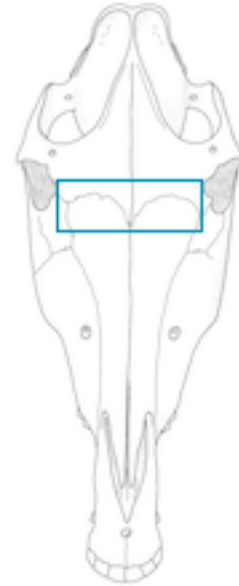
Profile between forehead and nose (longitudinal, posterior/anterior view)	
<i>E. asinus</i>	Concavity in nasal region, longer more pronounced depression
<i>E. caballus</i>	Straight, sometimes convex, less pronounced depression
<i>E. hemionus</i>	Variable
<i>E. africanus</i>	Concavity in nasal region
Source: Barone 1976: 90. Groves & Willoughby 1981: 338-9.	



Naso-frontal suture

<i>E. asinus</i>	Runs straight across
<i>E. caballus</i>	No data
<i>E. hemionus</i>	No data
<i>E. africanus</i>	Does not run straight across

Source: Groves & Willoughby 1981: 340.




Supraorbital foramen


<i>E. asinus</i>	Single
<i>E. caballus</i>	Single
<i>E. hemionus</i>	Multiple

Source: Bökönyi 1972: 13-14; 1986: 306. Eisenmann 1986: 74.

Comment: In young hemiones, single foramen may occur. Horse and donkey can occasionally have two. There may also be a tendency for multiple foramina in Przewalski horses (Johnstone 2004: 172).



Zygomatic process		
<i>E. asinus</i>	More laterally extended; orientated for more forward vision	
<i>E. caballus</i>	Less laterally extended; orientated for peripheral vision	
<i>E. hemionus</i>	No data	
<p>Source: Arloing 1882: 243. Barone 1976: 71-2. Johnstone 2004: table 4.2. Hanot & Bochaton 2018: 14.</p>		

Orbit		
<i>E. asinus</i>	Back border more squared; wider and lower	
<i>E. caballus</i>	Back border more rounded; narrower and higher	
<i>E. hemionus</i>	No data	
<i>E. asinus x E. caballus</i>	Back border more squared	
<p>Source: Arloing 1882: 246. Barone 1976: 129. Wilkens 2003.</p>		
<p>Comment: Arloing notes some variation in this feature, and found rounded back borders on donkey skulls as well (1882: 246).</p>		

Temporal fossa: anterior margin

<i>E. asinus</i>	Thicker and blunted
<i>E. caballus</i>	Bordered by sharp crest prolonging temporal line
<i>E. hemionus</i>	No data

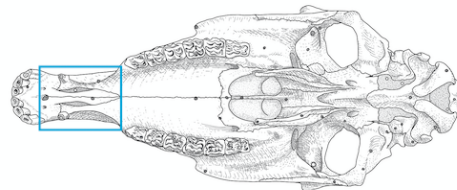
Source: Hanot & Bochaton 2018: 15. Cf. Barone 1976: 72.

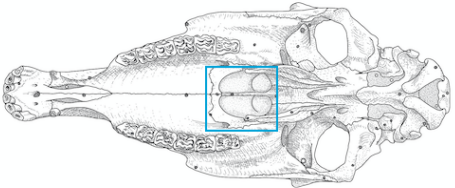


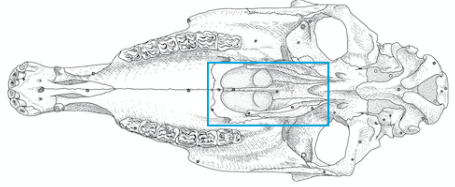
Anterior incisive bone

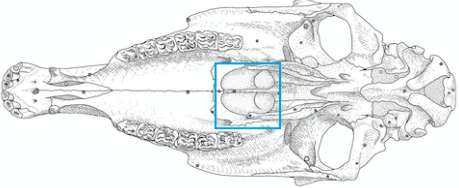
<i>E. asinus</i>	Intra-alveolar borders more parallel and straight; narrow area of incisors, only slightly wider than diastema / muzzle enlarged in the middle
<i>E. caballus</i>	Intra-alveolar borders arched; wider area of incisors, open in semicircle
<i>E. hemionus</i>	No data
<i>E. asinus</i> x <i>E. caballus</i>	Muzzle enlarged in the middle

Source: Eisenmann 1986: 73-4. Wilkens 2003. Johnstone 2004: table 4.2. Hanot & Bochaton 2018: 14. Cf. Groves & Willoughby 1981: 339.



Bony palate: palatine process and suture		
<i>E. asinus</i>	Does not extend as far as for hemione; suture curves along border of choanae	
<i>E. caballus</i>	Extends further back: reaches posterior third of M2 to as far as halfway along M3; suture wider, irregular curves along border of choanae	
<i>E. hemionus</i>	Extends only as far as halfway along M2	
<i>E. africanus</i>	Does not extend as far as for hemione	
Source: Groves & Willoughby 1981: 339. Barone 1976: 103. Wilkens 2003.		

Vomer		
<i>E. asinus</i>	Long	
<i>E. caballus</i>	Short	
<i>E. hemionus</i>	Long	
<i>E. asinus</i> x <i>E. caballus</i>	Long	
Source: Eisenmann 1986: 73-4. Johnstone 2004: table 4.2.		

Choanal opening		
<i>E. asinus</i>	Oval	
<i>E. caballus</i>	Horseshoe-shaped	
<i>E. hemionus</i>	Horseshoe-shaped	
<i>E. africanus</i>	Oval	
Source: Groves & Willoughby 1981: 339-40.		

External auditory meatus	
<i>E. asinus</i>	Larger
<i>E. caballus</i>	Smaller
<i>E. hemionus</i>	Smaller
<i>E. africanus</i>	Larger
<p>Source: Groves & Willoughby 1981: 339. Wilkens 2003. Johnstone 2004: table 4.2. Cf. Barone 1976: 72.</p>	
<p>Comment: Arloing is not able to identify this as a diagnostic feature (1882: 247).</p>	



Basal bone between occipital condyles	
<i>E. asinus</i>	Thin and sharp
<i>E. caballus</i>	Broader and less sharp
<i>E. hemionus</i>	No data
<p>Source: Barone 1976: 58. Wilkens 2003. Cf. Arloing 1882: 241.</p>	


















External occipital process: posterior extension	
<i>E. asinus</i>	Higher, more developed protuberance folded back
<i>E. caballus</i>	Less developed
<i>E. hemionus</i>	No data
<p>Source: Arloing 1882: 240-1. Barone 1976: 58. Wilkens 2003. Hanot & Bochaton 2018: 14. Cf. Groves & Willoughby 1981: 341.</p>	



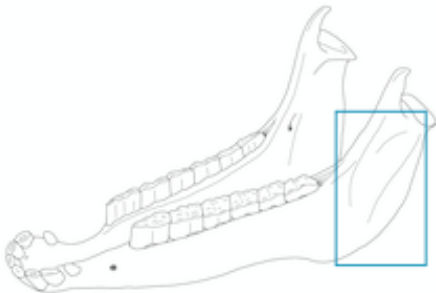
Occipital indices	
<i>E. asinus</i>	Mean 43.9, standard range 36-52
<i>E. caballus</i>	Mean 29.45 (Przewalski 35.5), standard range 22-37
<i>E. hemionus</i>	Mean 52.4, standard range 43-62
<i>E. africanus</i>	Mean 44.2, standard range 36-52
Source: Groves & Willoughby 1981: 338. Cf. Bennett 1980.	
Comment: Measure and compare to index. Occipital index: vertex length - condylobasal length x 100 / occipital crest width. The index is primarily useful for distinguishing horses from other equids. In practical terms, horse skulls 'stand when set on their caudal end, which other groups will not' (Groves & Willoughby 1981: 338, following the work of Bennett 1980).	

Ratio indices	
<i>E. asinus</i>	Measure and compare to index
<i>E. caballus</i>	Measure and compare to index
<i>E. hemionus</i>	Measure and compare to index
<i>E. africanus</i>	Measure and compare to index
Source: Arlioni 1882. Bökönyi 1972: 13-14. Groves & Willoughby 1981: 334-5. Eisenmann 1981a. Eisenmann & Kuznetsova 2004.	
Comment: Groves & Willoughby (1981) devised 20 cranial indices, comparing basal length to various other cranial features. Some may be useful for distinguishing species, but seem more varied than the postcranial indices. For a recent method using 3D geometric morphometrics with potential for differentiating <i>E. asinus</i> , <i>E. caballus</i> and hybrids, see Hanot et al. 2017.	

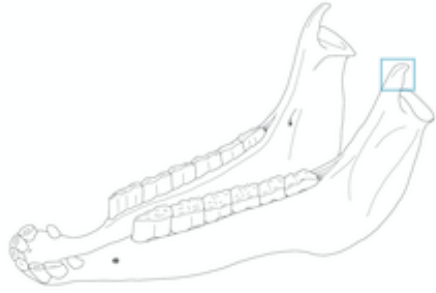
Maxilla: comparative images				
				
				
				
<i>E. asinus</i>	<i>E. caballus</i>	<i>E. hemionus</i>	<i>E. hemionus</i> (m) x <i>E. asinus</i> (f)	<i>E. asinus</i> (m) x <i>E. caballus</i> (f)
Images courtesy of Vera Eisenmann (vera-eisenmann.com)				

Mandible


External surface of ascending ramus	
<i>E. asinus</i>	Elongated depression, sometimes well-marked
<i>E. caballus</i>	Depression not well-marked
<i>E. hemionus</i>	Elongated depression, sometimes well-marked
<i>E. africanus</i>	Elongated depression, sometimes well-marked
Source: Groves & Willoughby 1981: 340.	



Coronoid process	
<i>E. asinus</i>	Dorsal extremity triangular
<i>E. caballus</i>	Dorsal extremity rounded or truncated
<i>E. hemionus</i>	No data
Source: Barone 1976: 106. Hanot & Bochaton 2018: 15.	
Comment: Arloing notes great variation in this feature in both donkeys and horses (1882: 243-4).	





Mental foramen	
<i>E. asinus</i>	Medial orientation, laterally deeper
<i>E. caballus</i>	Posterior orientation resulting in medial border
<i>E. hemionus</i>	No data
Source: Hanot & Bochaton 2018: 15.	



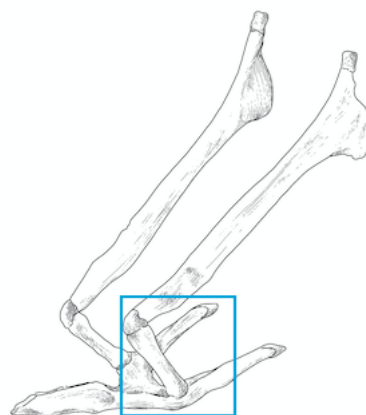
Incisor area	
<i>E. asinus</i>	Narrower, low incisive zone
<i>E. caballus</i>	Wider, opens like fan, rising incisor zone
<i>E. hemionus</i>	No data
Source: Wilkens 2003.	



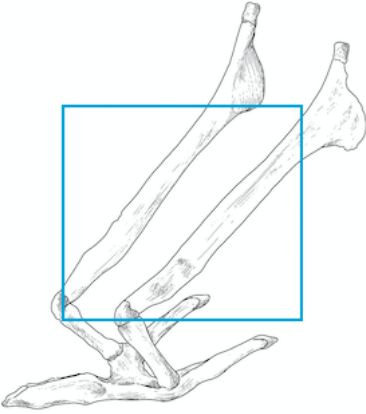
Mandible: comparative images	
	
<i>E. asinus</i>	<i>E. caballus</i>
Images courtesy of Barbara Wilkens	

Hyoid

Thyrohyoid	
<i>E. asinus</i>	Thyrohyoid form a U-shape; curved slightly upward
<i>E. caballus</i>	Thyrohyoid form a V-shape
<i>E. hemionus</i>	No data
Source: Barone 1976: 110.	



Stylohyoid and epihyoid	
<i>E. asinus</i>	Epihyoid more developed; stylohyoid narrower
<i>E. caballus</i>	Epihyoid less developed; stylohyoid broader
<i>E. hemionus</i>	No data
Source: Barone 1976: 110.	



Teeth

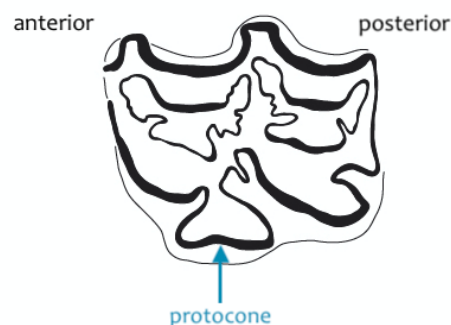
Equid teeth continue to erupt throughout their lives. The enamel patterns change through wear. Very young and very old individuals are therefore not reliable for species identification. According to Payne, occlusal length, minimum distance between external and internal sulci and greatest length of postflexid increase with wear, greatest length of double knot remains constant, the double knot index increases, postflexid index decreases (1991).

There has been much criticism of the use of teeth to identify equid species due to the great variability. Many of the criteria listed here have been tested on ancient teeth by Twiss et al. 2017, with significant differences in identification between seven zooarchaeologists. They conclude that these criteria are not reliable; the same conclusion is reached by Chuang & Bonhomme (2019). See also earlier assessments and doubts in Davis (1980: 295), Baxter (1998: 15), and Gilbert (1991: 98).

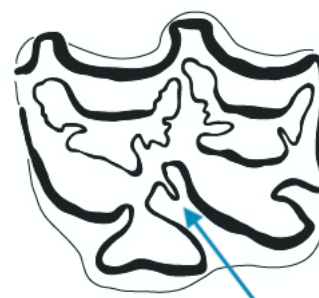
Overall size	
<i>E. asinus</i>	Smallest
<i>E. caballus</i>	Largest
<i>E. hemionus</i>	Intermediate
<i>E. asinus</i> x <i>E. caballus</i>	Second largest
Source: Weber 2006: 183-4.	

Upper

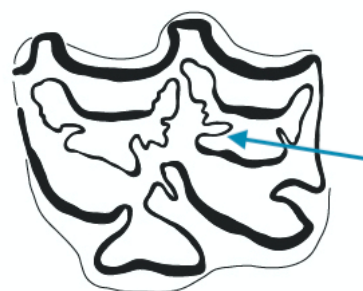
Protocone	
<i>E. asinus</i>	Short and symmetrical, triangular or oval shape, mesial arm c. 40%
<i>E. caballus</i>	Asymmetrical, longish form, elongated to posterior
<i>E. hemionus</i>	Symmetrical, shorter and oval but still elongated to posterior
<i>E. africanus</i>	Symmetrical, short and oval, mesial arm c. 40%
<i>E. asinus</i> x <i>E. caballus</i>	Symmetrical triangular shape, resembling donkeys
Source: Davis 1980: 294. Bökönyi 1986: 307. Zeder 1986: 390. Buitenhuis 1991: 41-2. Baxter 1998: 7. Johnstone 2004: table 4.1.	
Comment: A protocone index allows for comparison between sizes: $PL \times 100/OL$, with PL = protocone length, OL = mesio-distal occlusal length (Payne 1991; Baxter 1998: 7).	

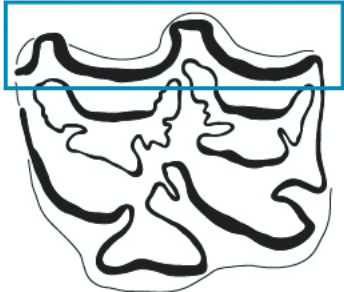


Pli cabellin	
<i>E. asinus</i>	Missing entirely or poorly developed
<i>E. caballus</i>	Very distinctive in molar and premolar
<i>E. hemionus</i>	Missing entirely or poorly developed
<i>E. asinus</i> x <i>E. caballus</i>	Intermittent or reduced
Source: Bökönyi 1986: 306. Zeder 1986: 390. Baxter 1998: 7. Johnstone 2004: table 4.1.	
Comment: Absent in 5-10% of horses. The criteria is considered of little use by some (e.g. McGrew 1944: 58, Davis 1980: 294), but as Baxter writes, 'While its absence, particularly in isolated teeth, cannot exclude attribution to <i>E. ferus/caballus</i> , the presence of well developed pli cabellin would be untypical of a donkey.' (1998: 7).	

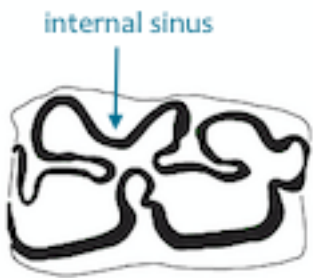


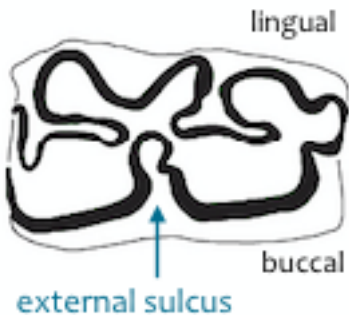
Fossette folds	
<i>E. asinus</i>	Small and simple
<i>E. caballus</i>	Complex
<i>E. hemionus</i>	No data
<i>E. asinus</i> x <i>E. caballus</i>	Variable
Source: Johnstone 2004: fig. 4.1.	

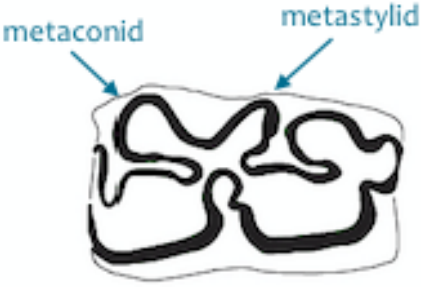


Buccal region		
<i>E. asinus</i>	Abrupt transition from interstylar surfaces to columns, with pronounced angles forming a flat U-shape	
<i>E. caballus</i>	Deep, ditch-like and narrow interstylar profile and thick styles	
<i>E. hemionus</i>	Enamel surface between styles tend to be concave with gradual transition to columns; frequent thickening and doubling	
Source: Bökönyi 1986: 307. Baxter 1998: 7.		
Comment: Davis considers this criteria 'too variable for species separation.' (1980: 294).		

Lower

Internal sinus / medial valley / lingual fold		
<i>E. asinus</i>	V-shape, shallow	
<i>E. caballus</i>	U-shape, deep	
<i>E. hemionus</i>	Wider V-angle	
<i>E. africanus</i>	V-shape	
<i>E. asinus</i> x <i>E. caballus</i>	Wider V-angle and sharper outline than horse; as deep as horses	
Source: Davis 1980: 293-4. Bökönyi 1986: 307. Zeder 1986: 387. Baxter 1998: 8. Johnstone 2004: table 4.1.		
Comment: Davis does not agree with the assessment of a wider v-angle in <i>E. hemionus</i> , noting that 'examination of recent asses and hemiones indicate that the angle is rather variable.' (1980: 294).		

External sulcus / lateral valley / penetration of buccal fold		
<i>E. asinus</i>	Shallow; no penetration of fold	
<i>E. caballus</i>	Very deep / partial penetration, nearly touching enamel on other side	
<i>E. hemionus</i>	Shallower than horse, deeper than donkey	
<i>E. africanus</i>	Less deep	
<i>E. asinus</i> x <i>E. caballus</i>	Deep; as much as or deeper penetration than horse	
Source: Bökönyi 1986: 307. Zeder 1986: 387. Baxter 1998: 8. Johnstone 2004: table 4.1.		
Comment: Index to measure depth of penetration of internal sulcus: $Bei/B3$, where Bei = minimum distance between external and internal sulci, $B3$ = maximum distance across protoconid and metaconid (Zeder 1986; Baxter 1998).		

Double knot of metaconid and metastylid		
<i>E. asinus</i>	Some symmetry, but not consistent, 'stenonien', metaconid often larger than metastylid	
<i>E. caballus</i>	Asymmetry, metastylid often long and narrow, 'hemionienne', metaconid often angular, metastylid triangular	
<i>E. hemionus</i>	Some asymmetry, but inconsistent, 'stenonien' or 'hemionienne'	
<i>E. asinus</i> x <i>E. caballus</i>	Asymmetry, metastylid often long and narrow	
Source: Eisenmann 1981b: 144-8. Zeder 1986: 387. Johnstone 2004: table 4.1.		
<p>Comment: Index to calculate degree of symmetry: $B3/B4$, where $B3$ = maximum distance across protoconid and metaconid, $B4$ = maximum distance across metastylid and hypoconid (Zeder 1986; Baxter 1998). Index suggested by Payne (1991): $100 \times Lnd/OL$, where Lnd = greatest length of double knot, OL = mesio-distal occlusal length. P2 and M3 with little or much wear are not useful for identification. The characteristics are based on the permanent teeth: for deciduous teeth, see Eisenmann 1981b. Eisenmann defines three types of 'double knot'. 'Type sténonien': Convex metastylid and metaconid, generally deep lingual groove between two convex faces, bottom of lingual groove usually sharp (esp. premolars) can be flattened in contact with vestibular groove (esp. molars). 'Type hémionien': Metastylid and metaconid are convex at lingual posterior and anterior extremities; lingual furrow is shallow, large and regularly rounded. 'Type caballin': Anterior of metastylid is convex, posterior of metaconid is concave; lingual furrow is generally shallow, resembling small Greek letter 'nu'.</p>		

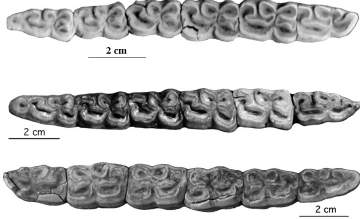
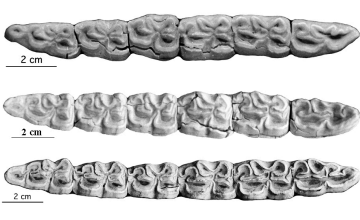
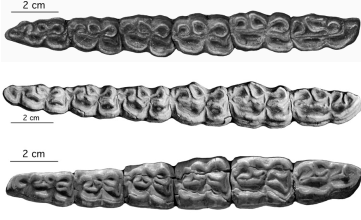
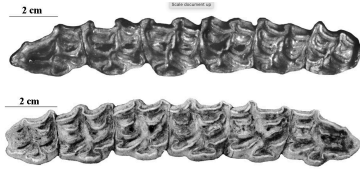
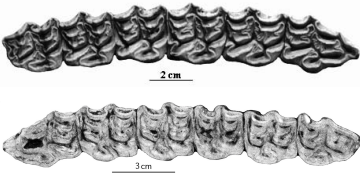
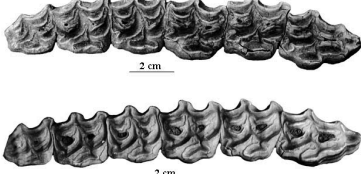
Postflexid index	
<i>E. asinus</i>	Measure and compare to index
<i>E. caballus</i>	Measure and compare to index
<i>E. hemionus</i>	Measure and compare to index
<i>E. africanus</i>	Measure and compare to index
<i>E. asinus</i> x <i>E. caballus</i>	Measure and compare to index
<i>E. asinus</i> x <i>E. hemionus</i>	Measure and compare to index
Source: Payne 1991. Baxter 1998.	
<p>Comment: As presented by Payne (1991) and used by Baxter (1998): $100 \times LF/OL$, where LF = greatest length of postflexid, OL = mesio-distal occlusal length.</p>	

Biometric	
<i>E. asinus</i>	Shortest
<i>E. caballus</i>	Longest (but shorter than przewalski)
<i>E. hemionus</i>	Occlusal length as for africanus; medium width
Source: Eisenmann 1981b: 144-148.	
Comment: See Eisenmann (1981b: 149-58) for tables and diagrams with measurements and comparisons.	

Incisors

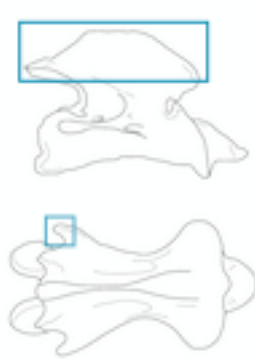
Incisors	
<i>E. asinus</i>	Narrowest
<i>E. caballus</i>	Widest
<i>E. hemionus</i>	Broader, more hypsodont than donkeys
Source: Bökönyi 1986: 306.	

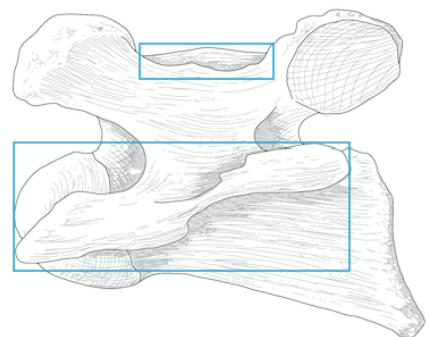
Teeth: comparative images

		
		
<i>E. asinus</i>	<i>E. caballus</i>	<i>E. hemionus</i>
Images courtesy of Vera Eisenmann (vera-eisenmann.com)		

Postcranial skeleton: axial

Vertebrae

Axis		
<i>E. asinus</i>	Border of spinous process more parallel to body; caudal end of transverse process often longer	
<i>E. caballus</i>	Border of spinous process more curved; caudal end of transverse process shorter	
<i>E. hemionus</i>	No data	
Source: Barone 1976: 160. Wilkens 2003. Cf. Arloing 1882: 258.		

Cervical vertebrae		
<i>E. asinus</i>	Transverse process less elongated; lower spinous process	
<i>E. caballus</i>	Transverse process more elongated; higher spinous process	
<i>E. hemionus</i>	No data	
Source: Barone 1976: 160.		

Lumbar vertebrae	
<i>E. asinus</i>	Usually 5
<i>E. caballus</i>	Usually 6
<i>E. hemionus</i>	Usually 5
<i>E. asinus</i> x <i>E. caballus</i>	Mule usually 6
Source: Groves & Willoughby 1981: 332. Evans & Crane 2018: 130. Wilkens 2003.	

Vertebrae: comparative images

*E. asinus**E. caballus*

Images courtesy of Barbara Wilkens

Thorax

Ribs

<i>E. asinus</i>	Less curved, especially caudally; dorsal extremity of sternal ribs more flattened
<i>E. caballus</i>	More curved; dorsal extremity of sternal ribs less flattened
<i>E. hemionus</i>	No data

Source: Barone 1976: 187.

Pelvis***Os coxae***

Differences in the os coxae are complicated by those related to sex. Arloing also notes that this is one of the least useful bones for identifying species (1882: 270).

Os coxae

<i>E. asinus</i>	Rectus groove shallow
<i>E. caballus</i>	No data
<i>E. hemionus</i>	Rectus groove can be developed or very shallow

Source: Uerpmann 1986: 258. Weber 2006: 186.

Os coxae placed ventrally on horizontal surface

<i>E. asinus</i>	High and narrow
<i>E. caballus</i>	Low and broad
<i>E. hemionus</i>	High and narrow

Source: Groves & Willoughby 1981: 328.

Ilium

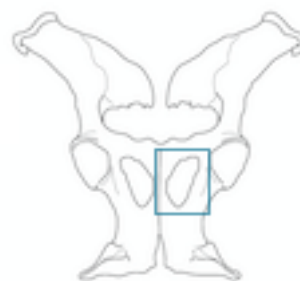
<i>E. asinus</i>	Shaft narrower, wings more markedly curved
<i>E. caballus</i>	Shaft wider, wings less curved
<i>E. hemionus</i>	No data



Source: Barone 1976: 246. Wilkens 2003.

Obturator foramen

<i>E. asinus</i>	Triangular shape
<i>E. caballus</i>	More oval
<i>E. hemionus</i>	No data



Source: Barone 1976: 246. Wilkens 2003. Cf. Arloing 1882: 271.

Sacrum

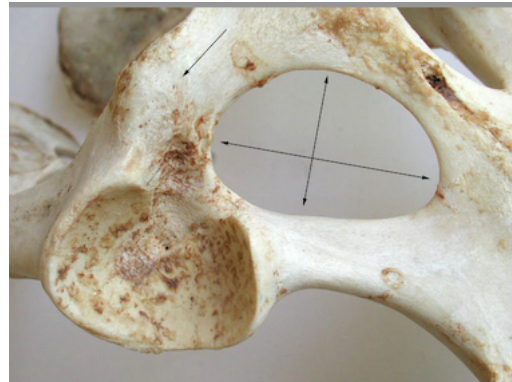
Sacrum

<i>E. asinus</i>	More elongated, narrower cranial part; first vertebra transverse process more lateral, articulated facet wider; from ventral side almost flat
<i>E. caballus</i>	Less elongated, broader cranial part; first vertebra bent towards skull, articular facet more elongated; from ventral side bend towards spinous process
<i>E. hemionus</i>	No data

Source: Barone 1976: 175. Wilkens 2003.



Pelvis: comparative images



E. asinus


E. caballus

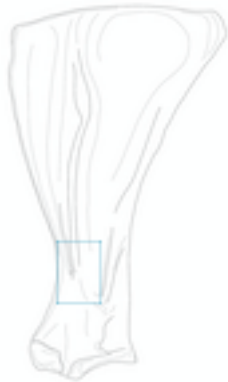
Images courtesy of Barbara Wilkens

Postcranial skeleton: appendicular


Scapula

Scapula	
<i>E. asinus</i>	Triangular, wider, longer edge and narrower neck
<i>E. caballus</i>	Less triangular, narrower, shorter edge and broader neck
<i>E. hemionus</i>	No data
<i>E. asinus</i> x <i>E. caballus</i>	Hinny resembles donkey, sometimes even shorter; mule resembles horse
Source: Arloing 1882: 264-5. Barone 1976: 199. Wilkens 2003.	

Tuberosity of spine	
<i>E. asinus</i>	Less developed; ovoid
<i>E. caballus</i>	Elongated
<i>E. hemionus</i>	More strongly developed, overhanging in caudal direction
Source: Uerpmann 1986: 257. Hanot & Bochaton 2018: 15.	
	

Distal end	
<i>E. asinus</i>	Presence of small acromion-like edge near distal end
<i>E. caballus</i>	No data
<i>E. hemionus</i>	Absence of small acromion-like edge near distal end.
Source: Uerpmann 1986: 257. Uerpmann 1991: 27.	
Comment: Present in most donkeys studied by Uerpmann, but not all.	
	

Distal end: neck and caudal border




<i>E. asinus</i>	Ridge remains of caudal rim, giving sharp appearance all the way to insertion for tricep muscle	
<i>E. caballus</i>	Compare to mule/hinny	
<i>E. hemionus</i>	Muscular line continuing sharp edge of thoracic margin runs on lateral side of neck, leaving caudal rim rounded or	
<i>E. asinus</i> x <i>E. caballus</i>	Compared to horses: slight torsion of axis in distal end and stronger bend of <i>Margo caudalis</i>	
Source: Uerpmann 1986: 257. Peters 1998: 162, pl. 53.		


Scapula: comparative images


	
<i>E. asinus</i>	<i>E. caballus</i>
Images courtesy of Barbara Wilkens	


Humerus

On age-related changes occurring in the humerus that may influence on species identification see Arloing (1882: 265).

Head and proximal articular surface		
<i>E. asinus</i>	No U-shaped depression; anterior point at level of intermediate tubercle	
<i>E. caballus</i>	Shallow U-shaped depression; anterior point at level of inter tubercular groove	
<i>E. hemionus</i>	U-shape can occur, but less marked	
Source: Groves & Willoughby 1981: 330-1. Hanot & Bochaton 2018: 15.		
Proximal end: tubercles		
<i>E. asinus</i>	Intermediate tubercle is lower or equal to the others in height; weakly extended in anterior direction	
<i>E. caballus</i>	Intermediate tubercle exceeds the others in height; well-extended in anterior direction	
<i>E. hemionus</i>	Intermediate tubercle tends to be lowest	
Source: Barone 1976: 205. Groves & Willoughby 1981: 329-30. Wilkens 2003. Hanot & Bochaton 2018: 15.		
Proximal end: Lesser tubercle		
<i>E. asinus</i>	Rectangular shape, well-extended in anterior direction	
<i>E. caballus</i>	Anterior rounded and weakly extended in anterior direction	
<i>E. hemionus</i>	No data	
Source: Hanot & Bochaton 2018: 15.		

Diaphysis		
<i>E. asinus</i>	Thin but clearly marked muscular line on cranial side of distal half of shaft running down midline and ending in small tuberosity dividing the fossa supratrochlearis into smaller medial and larger lateral portion; straight and	
<i>E. caballus</i>	Twisted and at an angle to the distal end	
<i>E. hemionus</i>	Tuberosity more ridge-like, muscular line on shaft not developed at all, or if visible, not parallel to axis of bone	
<i>E. asinus x E. caballus</i>	Straight and perpendicular to distal end	
Source: Barone 1976: 205. Uerpmann 1986: 257-8. Johnstone 2004: table 4.3. Cf. Arloing 1882: 265-6.		

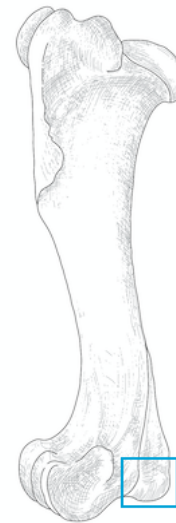
Distal end		
<i>E. asinus</i>	Border usually slopes down on lateral side, but exceptions especially in domestic	
<i>E. caballus</i>	No data	
<i>E. hemionus</i>	Proximal border of articular surface of trochlea is almost straight, forming small backwards projections towards epicondyle on lateral side	
Source: Barone 1976: 205. Uerpmann 1986: 257.		
Comment: Least reliable indicator, according to Uerpmann.		

Distal end: lateral epicondyle		
<i>E. asinus</i>	Sharper, pointed shape of crest	
<i>E. caballus</i>	Blunted, rounded shape of crest	
<i>E. hemionus</i>	No data	
Source: Hanot & Bochaton 2018: 15.		

Distal end: medial epicondyle

<i>E. asinus</i>	More descended; placed standing, the bone will usually stay balanced on the two epicondyles and the articular surface
<i>E. caballus</i>	Less descended; not in balance when placed standing
<i>E. hemionus</i>	No data

Source: Barone 1976: 205.



Humerus: Comparative images



Humerus: Comparative images

*E. asinus**E. caballus*

Images courtesy of Barbara Wilkens

Radius and ulna

Radius and ulna

<i>E. asinus</i>	Generally thinner; radius more curved
<i>E. caballus</i>	Stronger structure; radius less curved
<i>E. hemionus</i>	No data

Source: Barone 1976: 213. Wilkens 2003.

Ulna: olecranon tuber, lateral view

<i>E. asinus</i>	Expanded and elongated in ventral direction
<i>E. caballus</i>	Rounded
<i>E. hemionus</i>	No data

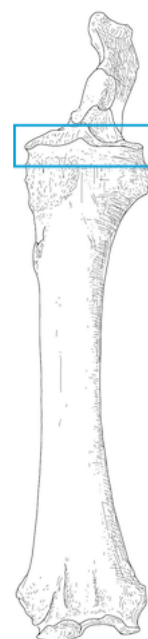
Source: Hanot & Bochaton 2018: 15. Cf. Arloing 1882: 268.



Radius: proximal end, dorsal view

<i>E. asinus</i>	Straighter; medial margin flared
<i>E. caballus</i>	No data
<i>E. hemionus</i>	Offset laterally; medial margin rounded

Source: Weber 2006: 185.



Interosseus space

<i>E. asinus</i>	Usually ossified, with complete fusion of radius and ulna
<i>E. caballus</i>	Not ossified - gap between radius and ulna
<i>E. hemionus</i>	No data

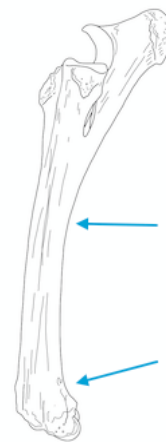
Source: Barone 1976: 213-4. Hanot & Bochaton 2018: 15.



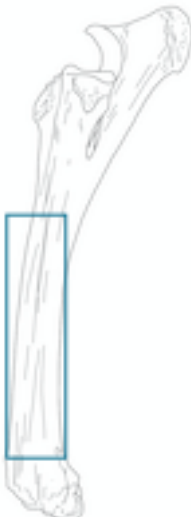
Diaphysis

<i>E. asinus</i>	More angular edges; ulna diaphysis often extends in thin line to distal diaphysis
<i>E. caballus</i>	More rounded; ulna diaphysis does not extend as far
<i>E. hemionus</i>	No data


Source: Arloing 1882: 268. Wilkens 2003.




Diaphysis: dorsal longitudinal ridges	
<i>E. asinus</i>	Ridges look evenly spaced
<i>E. caballus</i>	No data
<i>E. hemionus</i>	Lateral ridge set further apart
Source: Uerpmann 1986: 258.	





Diaphysis: tendon attachment, volar	
<i>E. asinus</i>	More marked and larger
<i>E. caballus</i>	Less marked
<i>E. hemionus</i>	No data
<i>E. asinus</i> x <i>E. caballus</i>	More marked and larger
Source: Peters 1998: 162, pl. 54.	




Distal end: volar trochlea	
<i>E. asinus</i>	No data
<i>E. caballus</i>	Flat or even slightly convex
<i>E. hemionus</i>	No data
<i>E. asinus</i> x <i>E. caballus</i>	Slightly concave
Source: Peters 1998: 162, pl. 54.	

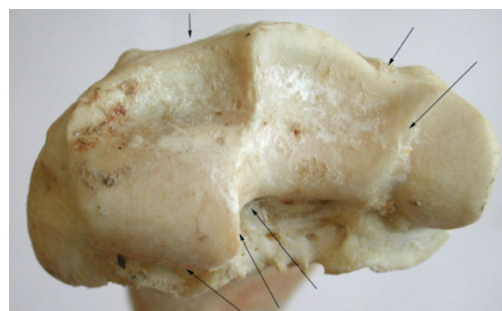


Distal articular surface		
<i>E. asinus</i>	Presence of marked suture line, extending all the way through	
<i>E. caballus</i>	No data	
<i>E. hemionus</i>	No suture line or line only extending up to a third way through	
Source: Helmer 2000: 236, fig. 3.		
Comment: To be used in conjunction with measurement indices by Uerpmann 1986.		

Distal articular surface: breadth/depth ratio		
<i>E. asinus</i>	Mean above 75%	
<i>E. caballus</i>	No data	
<i>E. hemionus</i>	Mean below 75%	
<i>E. africanus</i>	Mean above 75%	
Source: Uerpmann 1991: 20-1.		
Comment: Index expressed as breadth as percentage of depth: Bx100/D.		

Distal articular surface: transversal crest in distal view		
<i>E. asinus</i>	Interrupted by irregular incision	
<i>E. caballus</i>	Interrupted by regular rounded incision	
<i>E. hemionus</i>	No data	
<i>E. asinus</i> x <i>E. caballus</i>	Interrupted by irregular incision	
Source: Barone 1976: 213. Peters 1998: 162, pl. 54. Hanot & Bochaton 2018.		

Radius and ulna: comparative images

*E. asinus**E. caballus*

Images courtesy of Barbara Wilkens


Femur

Femur


<i>E. asinus</i>	Narrower, more delicate
<i>E. caballus</i>	More robust
<i>E. hemionus</i>	No data

Source: Barone 1976: 255. Wilkens 2003.


Head	
<i>E. asinus</i>	Semi-spherical and not laterally elongated
<i>E. caballus</i>	No data
<i>E. hemionus</i>	Articular surface tends to become cylindrical and elongated towards the
<i>E. africanus</i>	Semi-spherical and not laterally elongated
Source: Uerpmann 1991: 26.	




Greater trochanter	
<i>E. asinus</i>	Rounded, shorter
<i>E. caballus</i>	Pointed/triangular
<i>E. hemionus</i>	No data
Source: Wilkens 2003. Hanot & Bochaton 2018: 15.	




Greater trochanter: convexity	
<i>E. asinus</i>	Medial extension of tuberosity on anterior margin
<i>E. caballus</i>	Well-delimited dorsal tuberosity extending along anteroposterior axis
<i>E. hemionus</i>	No data
Source: Hanot & Bochaton 2018: 15.	



Greater and third trochanter: crest between (lateral view)	
<i>E. asinus</i>	No crest, smooth area
<i>E. caballus</i>	Well-marked crest linking them
<i>E. hemionus</i>	No data
Source: Hanot & Bochaton 2018: 15.	



Intertrochantric crest

<i>E. asinus</i>	Medial margin thin and sharp	
<i>E. caballus</i>	Medial margin thick and blunted	
<i>E. hemionus</i>	No data	
Source: Hanot & Bochaton 2018: 15.		

Lesser trochanter

<i>E. asinus</i>	Absent or weakly marked crest in dorsal extension	
<i>E. caballus</i>	Well-marked crest in dorsal extension	
<i>E. hemionus</i>	No data	
Source: Barone 1976: 255. Wilkens 2003. Hanot & Bochaton 2018: 16.		

Diaphysis

<i>E. asinus</i>	Straight
<i>E. caballus</i>	Twisted
<i>E. hemionus</i>	No data
<i>E. asinus</i> x <i>E. caballus</i>	Straight
Source: Johnstone 2003: table 4.3. Cf. Arloing 1882: 272-3.	

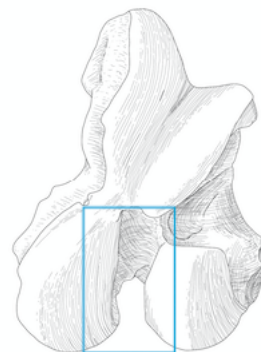
Distal end: deep groove separating condyles, shallow cranial extension where reaching articular surface of trochlea

E. asinus Borderline between articular surface and groove roughly evenly curved

E. caballus No data

E. hemionus Borderline between articular surface and groove notched or otherwise irregular

Source: Uerpmann 1986: 258.



Femur: Comparative images



Femur: Comparative images

*E. asinus**E. caballus*

Images courtesy of Barbara Wilkens

Patella

Ratio: transverse dm x anterior-posterior dm

<i>E. asinus</i>	Equal to or lower than 1
<i>E. caballus</i>	No data
<i>E. hemionus</i>	Higher than 1

Source: Helmer 2000: 236.


Tibia

Tibia


<i>E. asinus</i>	Narrower, more elongated
<i>E. caballus</i>	Stronger structure
<i>E. hemionus</i>	No data

Source: Wilkens 2003.


Proximal articular surface: protruding facet	
<i>E. asinus</i>	Reduced
<i>E. caballus</i>	Well-developed
<i>E. hemionus</i>	No data
Source: Wilkens 2003.	



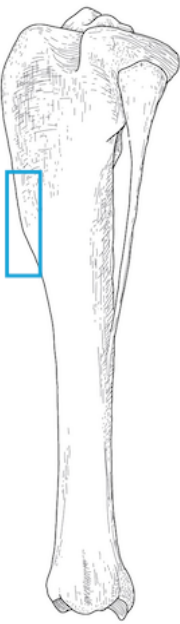
Proximal articular surface: medial condyle	
<i>E. asinus</i>	Medial articular surface does not extend to margin; angular margin
<i>E. caballus</i>	Rounded posteromedial margin
<i>E. hemionus</i>	No data
Source: Hanot & Bochaton 2018: 16.	



Proximal articular surface: lateral condyle	
<i>E. asinus</i>	Posterior extremity constricted and pointed
<i>E. caballus</i>	Posterior extremity enlarged
<i>E. hemionus</i>	No data
Source: Hanot & Bochaton 2018: 16.	



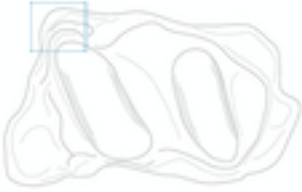
Tuberosity of tibial crest

<i>E. asinus</i>	More developed	
<i>E. caballus</i>	Weakly developed	
<i>E. hemionus</i>	No data	
Source: Arloing 1882: 274. Barone 1976: 264. Hanot & Bochaton 2018: 16.		

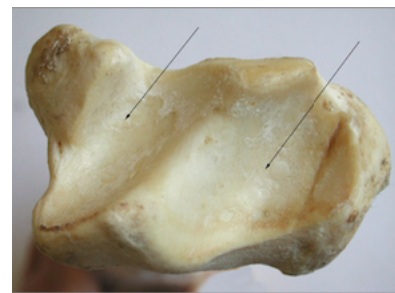
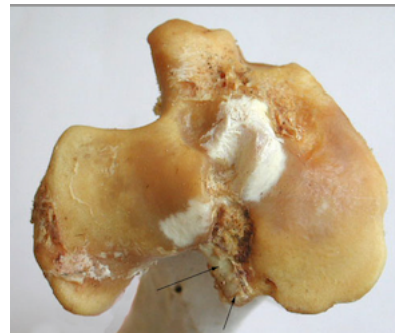
Distal articular surface: medial malleolus

<i>E. asinus</i>	Articular surface curves out medially farther than in hemione, only blunt ridge left between articular surface and rest of malleolus
<i>E. caballus</i>	No data
<i>E. hemionus</i>	Almost crest developed in area between articular surface and rest of malleolus
Source: Uerpmann 1986: 258.	

Distal articular surface: cochlea, medial

<i>E. asinus</i>	Extends, trapez-shaped	
<i>E. caballus</i>	Right-angled shape	
<i>E. hemionus</i>	No data	
<i>E. asinus</i> x <i>E. caballus</i>	Extends, trapez-shaped	
Source: Peters 1998: 162, pl. 55. Hanot & Bochaton 2018: 16.		
Comment: Arloing further notes that for donkeys, the tibia might be placed on its distal end and almost stand on its own, while this is not possible for horse (1882: 274).		

Tibia: comparative images

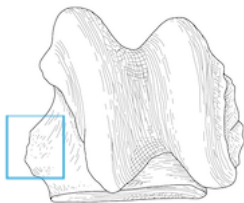
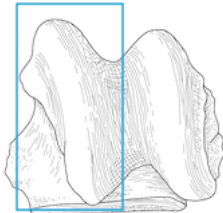
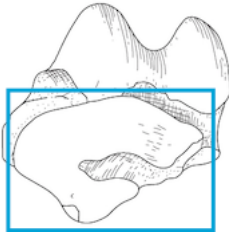


E. asinus

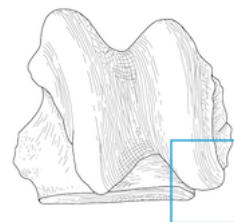
E. caballus

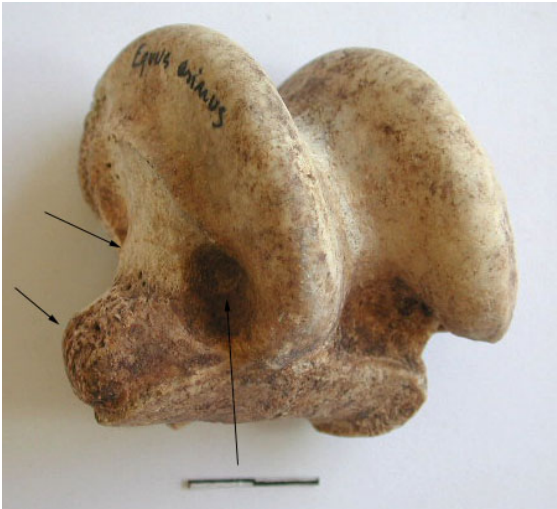

Images courtesy of Barbara Wilkens

Talus

Medial muscular tubercle		
<i>E. asinus</i>	Tubercle projects more than in hemione	
<i>E. caballus</i>	No data	
<i>E. hemionus</i>	Tubercle projects less	
<i>E. africanus</i>	Tubercle projects more than in hemione	
Source: Uerpmann 1986: 258. Uerpmann 1991: 19-20. Helmer 2000: 236. Weber 2006: 188.		
Comment: Weber also notes that this feature can be measured by comparing greatest height (GH) and greatest breadth (GB), 'Relative to hemiones, the GB in asses is greater relative to GH' (2006: 188).		
Medial trochlea (length of)		
<i>E. asinus</i>	Generally less than 50 mm	
<i>E. caballus</i>	No data	
<i>E. hemionus</i>	Generally more than 50 mm	
Source: Weber 2006: 188.		
Comment: Weber notes as 'possibly indicative of species'.		
Distal articular surface		
<i>E. asinus</i>	Wider in relation to dorso-plantar depth, looks more tipped on lateral side	
<i>E. caballus</i>	No data	
<i>E. hemionus</i>	Narrower in relation to dorso-plantar depth, looks less tipped on lateral side	
Source: Uerpmann 1986: 258.		

Distal: caudal/cranial view	
<i>E. asinus</i>	Small lateral recess is very abrupt
<i>E. caballus</i>	No data
<i>E. hemionus</i>	Small lateral recess less abrupt or not visible
Source: Helmer 2000: 236, fig. 5.	




Astragalus: comparative images	
	
<i>E. asinus</i>	<i>E. Caballus</i>
Images courtesy of Barbara Wilkens	

Metapodials

Metapodials	
<i>E. asinus</i>	Narrow-footed
<i>E. caballus</i>	Broad-footed, large distal ends
<i>E. hemionus</i>	Narrow-footed, perhaps more than donkey; Narrow distal epiphyses have very limited medio-lateral broadening in relation to diaphyses
<i>E. africanus</i>	Narrow-footed
Source: Hilzheimer 1941: 10. Eisenmann 1979. Bökönyi 1986: 309. Eisenmann 1986: 77-8, 80.	
Comment: Eisenmann's (1986) criteria are based on examination of 500 equid skulls (350 complete), and 400 modern + 400 ancient specimens for the metapodials.	


Metacarpals (MC III)


Proximal articular surface: volar edge	
<i>E. asinus</i>	Uneven and less sharp
<i>E. caballus</i>	No data
<i>E. hemionus</i>	Sharp and straight
Source: Uerpmann 1986: 258.	




Diaphysis	
<i>E. asinus</i>	Less flat
<i>E. caballus</i>	More flattened
<i>E. hemionus</i>	No data
Source: Barone 1976: 225. Wilkens 2003.	

Distal end: volar view	
<i>E. asinus</i>	Triangular depression near trochlea; also gives a more slender impression in medial view; posterior intermediate projection of condyle weakly extended - straighter
<i>E. caballus</i>	No depression; posterior intermediate projection of condyle well extended in dorsal direction - curvilinear border
<i>E. hemionus</i>	Bent slightly backward
<i>E. africanus</i>	Straight
<i>E. asinus</i> x <i>E. caballus</i>	Triangular depression near trochlea; also gives a more slender impression in medial view
Source: Uerpmann 1991: 22. Peters 1998: 162, pl. 55. Hanot & Bochaton 2018: 15.	



Distal end: lateral	
<i>E. asinus</i>	Some flattening, but less than hemione
<i>E. caballus</i>	Less flattening
<i>E. hemionus</i>	Flattening of diaphysis immediately above lower joint; epiphysis stands out more in medial/lateral view as a result
Source: Hilzheimer 1941: 9-10.	
	
<p>Comment: For an illustration comparing <i>E. Kiang</i>, <i>E. hemionus</i>, <i>E. onager hemippus</i> from Tell Asmar and <i>E. asinus somaliensis</i>, see Hilzheimer 1941: figs. 2-3. This feature is closely associated with the impression of slenderness/gracility.</p>	

Distal end: dorsal	
<i>E. asinus</i>	Gracile
<i>E. caballus</i>	Least gracile; smaller dorsal protuberance, larger medial and lateral bulges in connection with flaring epiphysis, epiphysis flaring beyond breadth of diaphysis
<i>E. hemionus</i>	More gracile than ass; protuberance on dorsal side, proximal to epiphysial line (not present on medial or lateral side, distal breadth close to dimension of diaphysis)
<i>E. asinus</i> x <i>E. caballus</i>	Broad distal articular breadth (hinny)
Source: Hilzheimer 1941: 9-10. Eisenmann/Beckouche 1986. Gilbert 1991: 96.	
	
<p>Comment: This is also related to the slenderness index (see below), with further suggested measurements in Eisenmann/Beckouche 1986.</p>	

Slenderness index and ratios

<i>E. asinus</i>	Below 13.6
<i>E. caballus</i>	Above 13.6
<i>E. hemionus</i>	Above 13.6
<i>E. africanus</i>	Below 13.6

Source: Hilzheimer 1941: 11-12. Bökönyi 192: 16. Clutton-Brock 1986: 217. Eisenmann/Beckouche 1986. Johnstone 2004: figs. 4.14-4.15.

Comment: $SD \times 100 / GL$, where SD = smallest breadth of diaphysis (Hilzheimer uses 'medial width'), and GL = greatest length. cf. Bokonyi index of $100 \times Bp / GL$ (1972). Bp = greatest breadth of proximal end. Clutton-Brock for ratio of mid-shaft width to mc length for *E. caballus* and *E. hemionus*. Bökönyi (1972: 16) high variability in onagers and overlap with horses. Johnstone notes that while it seems possible to distinguish horses and donkeys using a slenderness index, it does not seem possible to distinguish between horses and mules (2004: 184). For further measurements indicating slenderness, see

Metacarpals: comparative images



E. asinus

E. caballus

a) *E. kiang* (m), b) *E. hemionus* (m), c) *E. onager hemippus* (from Tell Asmar), d) *E. asinus somaliensis* (f)

Images courtesy of Barbara Wilkens and after Hilzheimer 1941, figs. 2-3.

Metatarsals (MT III)

Slenderness	
<i>E. asinus</i>	Slender, difference in distal proportions
<i>E. caballus</i>	Difference in distal proportions
<i>E. hemionus</i>	Slender
<i>E. asinus</i> x <i>E. caballus</i>	Slender (hinny)
Source: Barone 1976: 277. Eisenmann 1986: 77. Eisenmann/Bekouche 1986: 118.	
Comment: Can be differentiated only on the basis of distal proportions in horses and donkeys.	

Diaphysis	
<i>E. asinus</i>	Diaphysis above lower joint rather convex
<i>E. caballus</i>	No data
<i>E. hemionus</i>	Flattening of diaphysis above lower joint, almost concave; prominence of middle ridge of lower joint towards front; backward bend of lower prominent compared to donkey
<i>E. africanus</i>	Diaphysis above lower joint rather convex
Source: Hilzheimer 1941: 9.	

Distal end	
<i>E. asinus</i>	No data
<i>E. caballus</i>	No data
<i>E. hemionus</i>	Bent backwards; more pronounced than in donkeys
<i>E. africanus</i>	Bent backwards
Source: Uerpman 1991: 22.	

Metatarsals: comparative images

*E. asinus**E. caballus*

Images courtesy of Barbara Wilkens


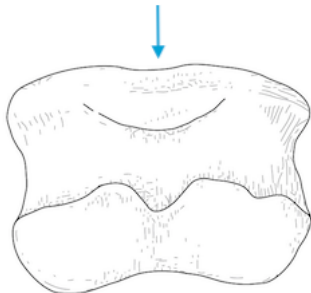
Phalanxes (thoracic and pelvic)

Proximal phalanx

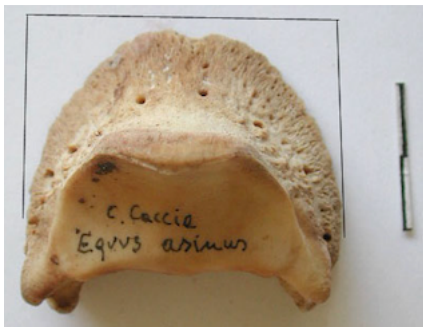
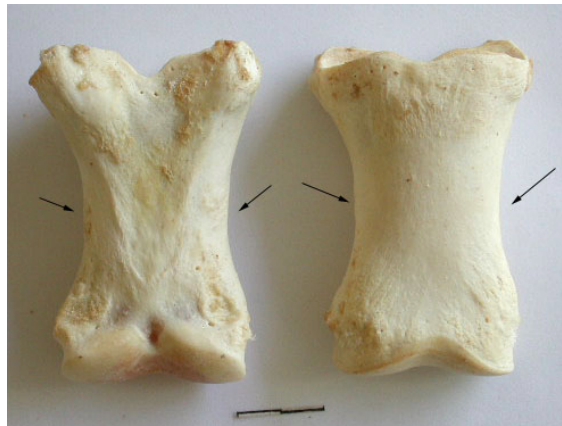
<i>E. asinus</i>	Long
<i>E. caballus</i>	Less slender, large
<i>E. hemionus</i>	No data
<i>E. asinus</i> x <i>E. caballus</i>	Slender

Source: Barone 1976: 232. Eisenmann 1986: 77. Peters 1998: 162, pl. 56.

Comment: Eisenmann's characteristics are based on Przewalski horses, but as she can detect no difference between those and *E. caballus*, they have been added here under *E. caballus*.

Proximal phalanx: trigonum phalangis		
<i>E. asinus</i>	More marked	
<i>E. caballus</i>	Less marked	
<i>E. hemionus</i>	No data	
<i>E. asinus</i> x <i>E. caballus</i>	More marked	
Source: Peters 1998: 162, pl. 56. Hanot & Bochaton 2018: 15.		
Middle phalanx, middle phalanx index		
<i>E. asinus</i>	More elongated, well-developed proximal medial tubercle	
<i>E. caballus</i>	Less elongated, less developed proximal medial tubercle	
<i>E. hemionus</i>	Measure and compare to index	
<i>E. africanus</i>	Measure and compare to index	
Source: Barone 1976: 232. Wilkens 2003. Uerpmann 1991: 19.		
Comment: Plot Bp (proximal breadth) and GL (greatest length) on X and Y axis for possible distinction between donkeys and hemiones.		
Distal phalanx		
<i>E. asinus</i>	Narrow and high	
<i>E. caballus</i>	Wider and lower	
<i>E. hemionus</i>	No data	
Source: Barone 1976: 232. Wilkens 2003.		
Comment: See also Groves & Willoughby (1981: 327) for index of plantar length vs anterior length.		

Phalanges: comparative images



E. asinus

E. Caballus

Images courtesy of Barbara Wilkens

Proportions and overall size

Limb proportions	
<i>E. asinus</i>	Less gracile than onagers
<i>E. caballus</i>	No data
<i>E. hemionus</i>	More gracile than asinines; lower legs more slender than <i>E. africanus</i>
<i>E. africanus</i>	Lower legs less slender than hemiones
Source: Uerpmann 1991: 19. Grigson 2012: 190	
Comment: With considerable overlap, especially in smaller animals.	

Limb ratio: metacarpal vs radius	
<i>E. asinus</i>	Length of metacarpal less than 70% of radius
<i>E. caballus</i>	No data
<i>E. hemionus</i>	Length of metacarpal more than 70% of radius
Source: von den Driesch & Amberger 1981: 69. Clutton-Brock 1989.	

Limb ratio: metatarsus vs humerus	
<i>E. asinus</i>	Metatarsus shorter than humerus
<i>E. caballus</i>	Metatarsus shorter than humerus
<i>E. hemionus</i>	Metatarsus longer than humerus
Source: Groves & Willoughby 1981: 328.	

Total limb length (7 forelimbs) vs basal skull length	
<i>E. asinus</i>	Total limb length less than horses
<i>E. caballus</i>	Total limb length 2.7-3.1 times basal skull
<i>E. hemionus</i>	Total limb length less than horses
<i>E. africanus</i>	Total limb length less than horses
Source: Groves & Willoughby 1981: 327-8.	

Postcranial ratio indices	
<i>E. asinus</i>	Compare to indices: especially 1-4, 6, 9, 14, 16, 17 and 19
<i>E. caballus</i>	Compare to indices
<i>E. hemionus</i>	Compare to indices: especially 6, 7, 9-13, 15, 18-20
<i>E. africanus</i>	Compare to indices: especially 1-4, 6, 9, 14, 16, 17 and 19
Source: Groves & Willoughby 1981: 326. Johnstone 2004: table 4.5. Arbuckle & Öztan 2018.	
Comment: Groves & Willoughby (1981) devised 20 indices in which various combinations of two skeletal parts feature. Most of the indices are expressed as the length of one bone as a percentage of another (e.g. humerus/scapula, scapula/radius, radius/femur etc), while others use width or composite factors. When the calculated index for each species is compared, it is possible in some cases to detect tendencies. See also Arbuckle & Öztan (2018) for biometric data concerning <i>E. caballus/ferus</i> and <i>E.</i>	

Size index / breadth vs 'standard' animal	
<i>E. asinus</i>	Plot against known assemblages; mean size greater than onager
<i>E. caballus</i>	Plot against known assemblages
<i>E. hemionus</i>	Plot against known assemblages
<i>E. asinus</i> x <i>E. caballus</i>	Plot against known assemblages
Source: Grigson 1993. Grigson 2006: 223-4, 250 Table 6.7C. Grigson 2012: 190. Uerpman 1982. Uerpman 1986.	
Comment: The method requires a fairly large assemblage. The formula for calculation is $SI = (a - \bar{X}) \times 100/4s$. a = dimension of particular element, \bar{X} = mean of that dimension at site studied, s = standard deviation at site. Details and comparisons in Grigson 1993, Grigson 2012, and Uerpman 1986.	

Overall size / breadth and width of postcranial remains	
<i>E. asinus</i>	Smallest
<i>E. caballus</i>	Biggest
<i>E. hemionus</i>	Medium
<i>E. africanus</i>	Smallest
<i>E. asinus</i> x <i>E. caballus</i>	Medium, tend to be in horse range
Source: Zeder 1986: 399. Buitenhuis 1991.	
Comment: See Buitenhuis for diagrams of each element. Caballus is usually easily distinguishable from other species (although it is harder to distinguish ponies from other species). Hemiones and asses can be distinguished, but there is significant overlap. Note also that donkeys from archaeological contexts appear to be larger than modern specimens. Ancient sizes of especially asinus and onager/hemione are not well-known. This is also the reason for the discrepancy in the relative size of <i>E. asinus</i> in this and the previous criteria.	

Note

I am extremely grateful to Barbara Wilkens and Vera Eisenmann for their generosity in sharing images and allowing me to reproduce them here. All other images have been redrawn by S. Recht based on illustrations in Barone 1976, Davis 1980, Peters 1998, Wilkens 2003, Budras et al. 2001 and 'Equine Anatomy - Illustrated Atlas of the Bones of the Horse' (www.imaio.com, accessed 10/6/2021).

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