# HR Mice Model and Experimental Measurements for Bones 

Alberto Arturo Castro
Gerald C. Claghorn Hannah Rabitoy


$$
\begin{gathered}
\text { MICRO-TOMOGRAPHIC } \\
\text { ATLAS OF THE } \\
\text { MOUSE SKELETON }
\end{gathered}
$$



Itai Bab • Carmit Hajbi-Yonissi Yankel Gabet • Ralph Müller
(i) Springer


Figure 1. Rostral view of mouse femur.


## ImageJ

## Image Processing \& Analysis in Java



## Set Scale

Draw a line from 0 to 2 on the ruler.
Click on analyze > set scale


1. Make sure the calibration is correct: measure the distance from the " 0 " to the " 1 " in the ruler and press " M ". Check if the distance calculated by the program is 10 mm .


Femur length, \#1 of Kelly et al (2006):
2. femoral length, dorsal tip of femoral head to distalmost end of medial condyle;

Gerald Claghorn's notes and recommendation: All bones need to be clear of cartilage between the condyles (the one here is ok). Draw a line by starting at the most distal part of the medial condyle (remember that the femur head is medial and orient accordingly) and then drag the cursor to the furthest point on the head of the femur.

3. femoral length, dorsal tip of greater trochanter to distalmost end of lateral condyle;

4. lateral-medial width of femoral head, using widest distance between two hypothetical parallel lines

5. femoral width at third trochanter, widest point


Femur least width, \#5 of Kelly et al (2006):
6. femoral least width, at its least constriction and distal to the third trochanter; Drawn perpendicular to main axis of bone at that point

6. femoral distal width femoral distal width: greatest distal width of the femur at the medial and lateral epiheads


Greater Trochanter Width (Samuels et al 2008) Greatest lateral medial width of the greater trochanter

transverse femoral width, medio-lateral diameter at midpoint of bone shaft (Kelly et al. 2006 and Samuels et al. 2008)

Not always at same location; calculated by taking the average of the shaft and tracing up that point. Not counting the greater and lesser trochanter, femoral heads, and epicondlyles.


69: Tibia: Length: distance from the superior articular surface of the lateral condyle to the tip of the medial malleolus.

Gerald's notes and recommendation: All the photos should be taken such that the medial side is closest to the camera, and the lateral side is closest to the table. Draw a line at the distal point (closest to the camera, then drag the cursor to the center of the proximal end.


69: Tibia: Length: distance from the superior articular surface of the lateral condyle to the tip of the medial malleolus.

Gerald's notes and recommendation: All the photos should be taken such that the medial side is closest to the camera, and the lateral side is closest to the table. Draw a line at the distal point (closest to the camera, then drag the cursor to the center of the proximal end.

2) tibial proximal width: greatest medio-lateral distance across the proximal end of the tibia and parallel to tibial groove, includes little spike on fibular side. Kelly et al. 2006

tib/fib least width: least width (medio-lateral) across tibia and fibula. Kelly et al. 2006

tib/fib distal width: greatest width at the distal end of the tibiafibula. Kelly et al. 2006


TF midshaft diameter: Not always at same location; calculated by taking the average of the shaft and tracing up that point. Easiest way is to use a ruler. (Kelly et al. 2006 Samuels and Van Valkenburgh 2008)



Figure 3. Lateral (left) view of mouse pelvic girdle.

Greatest Pelvis Length: Ramus of ischium to the most proximal end of iliac crest ( make sure to zoom in to not overestimate iliac crest).


Greatest Proximal Width of ilium: (not exactly a straight line can be at angles) Not always at the same spot make sure to check.


Least Distal Width of ilium: ( Not exactly at a straight line can be at angles) Not always at the same spot make sure to check.


Lower Ilium Length. Lower end of the proximal ilium to the most lateral tip of the ilio-pectineal eminence modified from (Tague 2003; Lewton et al. 2019)


Ischium Length: The most lateral point of the ischium to the midline point of the acetabulum (most lateral point because the tuberosity of the ischium is more variable, harder to find, mid-line point because we don't want to overestimate where the acetabulum starts dipping inwards) modified from Dumire 1955


Greatest Distal Width of Ischium Shaft: Start at the most lateral point of the tuberosity of ischium; but greatest width is not a straight-line check by moving angle in most medial direction but make sure not to go too much into the pubis. (There is a change in position because some pelves are shorter but thicker; so be careful!)


Pubis Length: Most lateral point of the descending ramus of pubis to the mid-line acetabulum (mid-line point because we don't want to overestimate where the acetabulum starts dipping inwards) Might shift in position due to changes in length and width (but remember the 1, 2,3 rule) modified from Dumire 1955


1: llio-pectineal eminence
2: at the end of the ascending ramus of pubis
3: Angle of pubis
4: Where you measure (Descending ramus of pubis)

Smallest Width of Pubis: Dumire 1955 Can be at a slight angle and not always in the same position


Hindfoot bone Dorsal View Left

$3^{\text {rd }}$ Metatarsal Length or Greatest Metatarsal length: $3^{\text {rd }}$ or greatest metatarsal bone length Garland and Freeman 2005; Kelly et al. 2006 ;Samuels et al. 2013; where small bony bits (ankle bones) end to where the phalanges begin


## Rostral (superior) angle

Superior process of spine
Supraspinous fossa

## Scapular spine

## Metacromion process

Acromion proces
Infraspinous fossa
Coracoid process Neck

Caudal (inferior) angle

Greatest Scapula breadths: Greatest superior-inferior breadth of the scapula (not always same position check); Green et al. 2012


Scapula length: Medial-lateral length of the scapula (acromion and spine damaged in a lot of specimens, why Alberto chose coracoid process instead); Green et al. 2012


Greater tubercle Proximal growth plate

Deltoid tuberosity

## Supinator crest

Coronoid-Olecranon notch

Articular surface for sesamoid bone

Lateral epicondyle

## Proximal nutrient foramen

## Shaft

Olecranon fossa

Medial epicondyle

Humerus Length: From Humeral head to the trochlea (Samuels and Van Valkenburgh 2008; Samuels et al. 2013)


Humerus Head Width: Medial-lateral width of the humeral head (analogous to Garland and Freeman 2005)


Humeri Distal Width: epicondyle breadth of distal humerus; lateral to medial epicondyles (Samuels and van Valkenburgh 2008; Samuels et al. 2013)


Humerus Midshaft Diamter: Not always at same location; calculated by taking the average of the shaft and tracing up that point. Easiest way is to use a ruler. Do not use distal and proximal ends (Samuels and Van Valkenburgh 2008; Samuels et al. 2013)


Radius and ulna like the tibia-fibula they will be measured together Caudal-medial view


Articular facet for Radius
Semilunar notch
Head of Radius
Neck of Radius
Radial tuberosity
Proximal ulnar nutrient foramen

Interosseous space
Radial ridge
Shaft of Radius

## Shaft of Ulna

Distal growth plate

Styloid process of Radius

Ulnar length: length of ulna from olecranon to styloid (Samuels and Van Valkenburgh 2008; Samuels et al. 2013)

length of olecranon (Samuels and Van Valkenburgh 2008; Samuels et al. 2013)


Radius length: from head of radius to styloid (Samuels and Van Valkenburgh 2008; Samuels et al. 2013)


Ulna midshaft diameter Not always at same location; calculated by taking the average of the shaft and tracing up that point. Easiest way is to use a ruler (Samuels and Van Valkenburgh 2008; Samuels et al. 2013)


Styloid width: width of distal end of articulated radius and ulna (Morris and Carrier 2016)


Hand bone left and dorsal view

$3^{\text {rd }}$ or Greatest Metacarpal Length: length of metacarpal at the $3^{\text {rd }}$ or greatest bone (Samuels et al. 2013; Samuels and Van Valkenburgh 2008), These bones are really small Wrist bones to where phalanges end

Caliper Measurements

## Calcaneus length



Caliper Measurements

Femoral Head to third Trochanter muscle scar


Caliper Measurements

Greater Trochanter Height


## Functional Index based on

 Samuels, Van Valkenburgh, and Morris: Hindlimb Forelimb- Intermembral index (IM) Functional lengths of the humerus and radius divided by lengths of the femur and tibia [(HL 1RL)/(FL 1 TL)]. Indicates the length of the forelimb relative to the hind limb.
- Forelimb proportions index Length of proximal forelimb relative to length of distal forelimb ((Scapula length + Humerus length)/(Radius length + Metacarpal length)). Indicates degree of morphological specialization for producing large outforces in the forelimb (Hildebrand and Goslow 2001).


## Functional Index based on

 Samuels, Van Valkenburgh, and Morris: Femur- Epicondylar breadth of femur divided by the functional length of the femur ( $\mathrm{FEB} / \mathrm{FL}$ ). Indicates relative area available for the origins of the gastrocnemius and soleus muscles used in extension of the knee and plantar-flexion of the pes.
- Femoral robustness index (FRI) Anteroposterior diameter of femur divided by functional length of the femur (FAPD/FL). Indicates robustness of the femur and its ability to resist bending and shearing stresses (AP diameter is used due to transverse expansion of the femora in semiaquatic rodents). This will be changed to medial-lateral since we can't get anteriorposterior in images.
- Gluteal index (GI) Length of distal extension of the greater trochanter of the femur divided by functional length of the femur (FGT/FL). Indicates relative mechanical advantage of the gluteal muscles used in retraction of the femur.
- $3^{\text {rd }} / \mathrm{F}$ Gluteus maximus muscle insertion position (Castro and Garland 2018)


## Functional Index based on

 Samuels, Van Valkenburgh, and Morris Tibia- Tibial robustness index (TRI) Mediolateral diameter of tibia divided by functional length of the tibia (TMLD/TL). Indicates robustness of the tibia and its ability to resist bending and shearing stresses.
- Tibia/Femur ratio long moment arm faster running (Van damee 2000 clumsy lizards; Biancardi and Minetti 2015); longer distal segments relative to proximal or Crural index (CI) Functional length of the tibia divided by functional length of the femur (TL/FL). Indicates relative proportions of proximal and distal elements of the hind limb (samuels et al. 2008).
- Hindlimb malleolus index: distal width of the tibia divided by functional length of tibia (Morris and Carrier 2016) infers distal robustness safety factors of the distal bone elements with increased locomotor performance


## Functional Index:Pelvis and Scapula

- Ischium mechanical Advantage Length of ischium relative to total hindlimb length (Ischium length/(Femur length + Tibia length+ Metatarsal length)). Indicates anatomical mechanical advantage of main hindlimb retractor muscles (e.g., biceps femoris, semimebranosus, semitendinosus; Evans 1993).
- SB/MLS: ratio of scapula breadth divided by scapula length is it wider than it is longer


## Functional Index Metatarsal:Femur Ratio; Many papers

- Samuels et al. 2008,2013,:Pes length index (PES)Metatarsal 3 length divided by functional length of the femur (MT3L/FL). Indicates relative proportions of proximal and distal elements of the hind limb, and relative size of the hind foot.
- Calcaneus mechanical advantage Length of calcaneus relative to Metatarsal length anatomical advantage of ankle extensors (gastrocnemius) Morris and Carrier 2016).
- Garland and Janis 1993; Garland and Freeman 2005; more economical based locomotion
- Hilebrande 1974: Longer strides and therefore speed


## Functional Index based on

 Samuels, Van Valkenburgh, and Morris Humerus- Humerus epicondyle index Humerus epicondyle width relative to humerus length (Humerus epicondyle width/Humerus length). Indicates relative surface area for attachment of wrist and digit flexor, extensor,pronator, and supinator muscles (Evans 1993; Meachen-Samuels and Van Valkenburgh 2009; Samuels et al. 2013).
- Humeral robustness index (HRI) Mediolateral diameter of humerus divided by functional length of the humerus (HMLD/HL).Indicates robustness of the humerus and its ability to resist bending and shearing stresses


## Functional Index based on

 Samuels, Van Valkenburgh, and Morris Radius/Ulna- Olecranon mechanical advantage Length of olecranon process relative to length of distal forelimb (Olecranon length/(Radius length+ Metacarpal length)). Indicates anatomical mechanical advantage of triceps brachii, an elbow extensor (Samuels et al. 2013).
- Olecranon length index (OLI) Olecranon process length divided by functional length of the ulna (ULOL/FUL). Indicates relative mechanical advantage of the triceps brachii and dorsoepitrochlearis muscles used in elbow extension. This is identical to the index of fossorial ability used by Hildebrand (1985).
- Ulnar robustness index(URI) Mediolateral diameter of ulna divided by functional length of the ulna (UMLD/FUL). Indicates robustness of the ulna and its ability to resist bending and shearing stresses, and relative area available for the origin and insertion of forearm and manus flexors, pronators, and supinators.
- Brachial index (BI) Functional length of the radius divided by functional length of the humerus (RL/HL). Indicates relative proportions of proximal and distal elements of the forelimb.

End Goal is to measure all bones
Samuels et al. 2008 and 2013
Functional index are derived from these studies looking at ecomorphological specializations of different rodents and carnivores


