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Trabecular distribution of proximal tibia in extant apes

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Extant apes are characterized by a wide range of locomotor, postural and manipulative behaviours that require each to use their limbs in different ways. In addition to external bone morphology, comparative investigation of trabecular bone can provide novel insights into bone functional adaptation. Two previous studies [1-2] have examined trabecular bone structure in the hominoid knee joint, but have focused on the distal femur only. We build upon these previous studies to characterize trabecular structure of the proximal tibia in extant apes. Here we analyze the trabecular morphology of proximal tibial epiphysis of *Homo sapiens* (N=25), *Gorilla gorilla* (N=13), *Pan troglodytes verus* (N=15), and *Pongo* spp. (N=7) to determine how variation in trabecular structure reflects differences in locomotor behaviour and to establish patterns of proximal tibia loading in extant taxa. Trabecular bone was imaged using microtomography with an isometric voxel resolution of 25-63 microns. Bone tissues were segmented using the medical image analysis (MIA) clustering method [3]. Canonical holistic morphometric analysis (cHMA) [4] was used to analyze relative bone volume fraction (rBV/TV) and patterns of rBV/TV distribution within and between taxa were investigated via principal component analysis (PCA).

A PCA of rBV/TV shows clear separation between extant ape taxa. In humans, trabecular density is similarly concentrated in circular regions in the middle of both the medial and lateral condyles, which distinguishes them from all other apes on PC1. In African apes, the trabecular bone is denser on the medial side (penetrating the entire condyle) suggesting differential loading of the tibia plateau. *Pongo* also exhibits greater density on the medial side but differs from African apes in having less rBV/TV at the margins of the condyles. Values of rBV/TV under the articulation with proximal tibia (and on the tibial plateau) are significantly higher compared to rest of the lateral condyle in all taxa. *Pongo* (positive PC2) separates from *Gorilla* (negative PC2) due to the higher rBV/TV concentration in the middle of both tibial condyles on tibial plateau. Additionally, rBV/TV concentration is the lowest in orangutans, which separates them from gorillas (PC2) as well as from chimpanzees (PC3).

Trabecular distribution in humans is consistent with an extended knee position and bipedal locomotion where the load is spread more equally between both tibial condyles. However, trabecular distribution in non-human apes is consistent with flexed knee positions compared to humans and with primarily medial loading due to the higher knee adduction moment, varus angle and ground reaction forces. The pattern of trabecular distribution in orangutans reflects their more variable knee joint postures during locomotion. These results provide the comparative context to interpret knee posture and, in turn, locomotor behaviours in fossil hominins.

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References: [1] Georgiou, L., Kivell, T.L., Pahr, D.H., Skinner, M.M., 2018. Trabecular bone patterning in the hominoid distal femur. *PeerJ* 6, e5156. [2] Sylvester, A.D., Terhune, C.E., 2017. "Trabecular mapping: Leveraging geometric morphometrics for analyses of trabecular structure," *American Journal of Physical Anthropology* 163(3), pp. 553–569. [3] Dunmore, C. J., Wollny, G., Skinner, M.M., 2018. MIA-Clustering: a novel method for segmentation of paleontological material. *PeerJ* 6, e4374. [4] Bachmann, S., Dunmore, C.J., Skinner, M.M., Pahr, D.H., Synek, A., 2022. A computational framework for canonical holistic morphometric analysis of trabecular bone. *Scientific Reports* 12, 1-13.