3D segmentation of the brain of the domestic goat (*Capra hircus domestica*): Comparative white matter, grey matter, and subcortical volumes

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Abstract

Over the last 10 years there has been increasing interest in the cognitive abilities of domestic species. Domestic goats have received much attention given their remarkable abilities to read human communicative cues which parallel observations also seen for other domestic species such as dogs. This shared behavioral trait is suggestive of a convergence in morphology between the domestic Artiodactyla and Canidae. Using high resolution magnetic resonance imaging aimed at providing much needed quantitative insight to these behavioral observations, we quantified select cortical and subcortical structures in the goat brain. Scanning was performed on one postmortem brain specimen and resultant white matter; grey matter and subcortical limbic structures were manually segmented before being compared through allometric analyses with published mammalian data.

Introduction

The domestic goat, often dismissed as the 'poor mans cow', has played an important role in human prehistory with accumulating evidence indicating that wild goats (*Capra aegagrus*) were the first herbivorous species to be domesticated. Archeological evidence (Zeder & Hesse, 2000) points to a domestication event in the Neolithic (~10 000 years ago) in the region known as the Fertile Crescent (i.e., Persian Gulf, Iraq, Syria, Lebanon, Jordan, Israel and northern Egypt). While goats have long been the subject of human study and manipulation, no detailed studies have been completed of the goat brain even though goats possess some complex behavioral patterns (Nawroth et al., 2016)

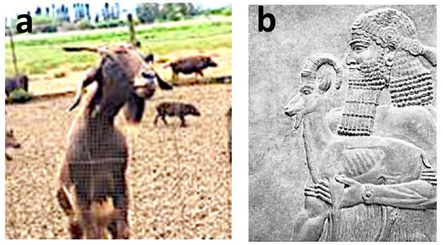

Figure 1: a- A curious goat peering over his enclosure (Image courtesy of MAS); b- A 3rd Century Mesopotamian stone carving of a man carrying a goat (displayed in Louvre Museum)

Methods

Magnetic resonance (MR) imaging was performed on the donated postmorten whole brain of an adult goat (*Capra hircus domestica*) obtained through collaboration with Iowa State University (Veterinary Medicine). The specimen was initially used in the small animal dissection lab and was embalmed in 4% paraformaldehyde before use in instruction. There was a 6 months post-fixation interval prior to the brain being removed by MAS. MR imaging of the brain was performed in the Department of Radiology, Icahn School of Medicine at Mount Sinai, New York. Before scanning the specimen was rinsed and placed in Fomblin solution for MR image acquisition on 7 T Bruker Biospec MR System. A 3D FLASH sequence with the following parameters was used for scanning: TR=36ms, TE=23ms, Flip angle=15 degrees, FOV=8cm, matrix size 384*384*384, 20 averages. Resulting dicoms were converted to nifty format and loaded into ITKSNAP for post processing and image analysis. Using the Region of Interest (ROI's) and editing tools the image intensity was optimized for visualization and the scan data was inverted (T2 to T1 scan). Every 10th image slice was saved to the workstation and placed within a Powerpoint file for identification and labelling. 3D surface files were also created in ITKSNAP. For white matter imaging we used a Diffusion Tensor Imaging (DTI) sequence with 515 b-directions/values: TR=25,000ms, TE=32.6ms, maximum bvalues=0-8000s/mm2, FOV=8cm, matrix size 128x128x80. The total acquisition time was 14hs for the specimen. Fractional anistotropic (FA) maps and vector files were generated and tensor files were imported into DTI-Query for tractography of select fiber tracts. Hippocampal and caudate volume were compared with brain mass using published data (Manger, Spocter, Patzke, 2015) from a mammalian regression line computed in CurveExpert 1.6.

Methods

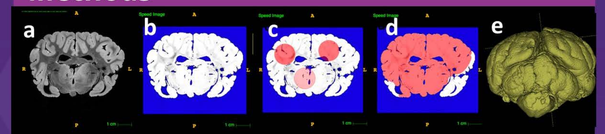

Figure 2: Overview of the MRI segmentation process used for mesh extraction in the software package ITKSNAP. a-unprocessed structural scan; b-thresholding; c-initialization; d-contour evolution; e- generated 3d mesh

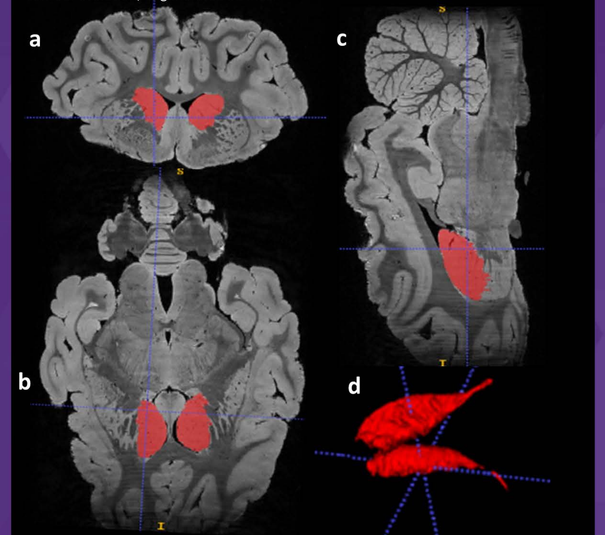

Figure 3: Select screenshots showing the T1 weighted scan of the Kudu. a- Coronal image showing the head of the caudate nucleus; b- transverse section through the caudate; c-sagittal section; d- 3D reconstruction of caudate (head + body+ tail)

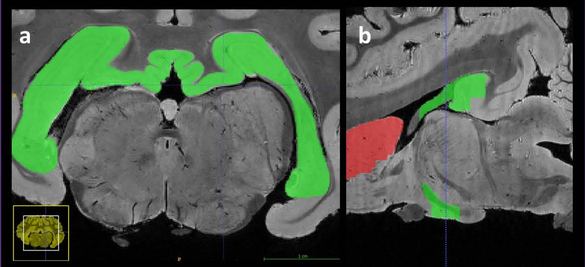

Figure 4: Screenshots showing the process of manual segmentation of the hippocampus. a – coronal section at level of midbrain; b- sagittal section showing the fornix of the hippocampus relative to caudate nucleus.

Results

Figure 5: A series of screenshots of the manually segmented caudate nucleus (RED) and hippocampus (GREEN). a- caudal view; b- lateral view; c- rostral view; d- inferior view

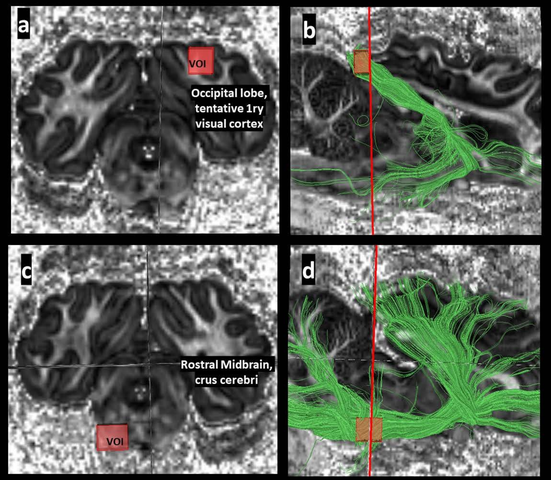

Figure 6: a-d – Results of explorative tractography (i.e., diffusion tensor imaging) of fiber pathways in the domestic goat. a & d- localization of explorative VOI (a - primary visual cortex; d- crus cerebri); b & d- Tractographic reconstruction of visual stream and corticospinal tract.

Conclusion

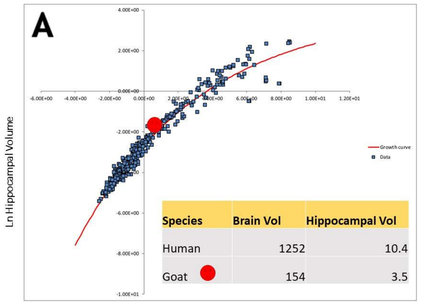

Figure 7: Regression analysis of hippocampal volume plotted against brain volume for all mammals. Superimposed on the regression line is the data point for goat used in this study. The hippocampal volume for the Kudu lies well within the prediction interval for the regression line. The regression is an Exponential Association model with an R^2 = 0.98. The model is defined by the equation $Y = a\ (b\text{-}e^{-cx})$; where a is 6.68; b is 6.03 and c is 1.38.

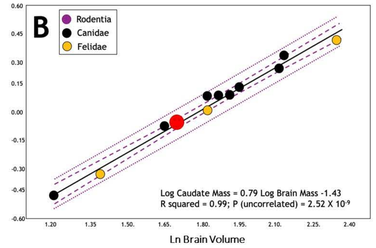

Figure 8: Regression analysis of caudate volume plotted against brain volume for all mammals. Superimposed on the regression lines is the data points for the goat used in this study.

References

Zeder MA, Hesse B. The initial domestication of goats (Capra hircus) in the Zagros mountains 10,000 years ago. Science. 2000 Mar 24;287(5461):2254-7.

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