Morphologic analysis of the hippocampal formation in *Elephas maximus* and *Loxodonta africana* with comparison to that of human

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SUMMARY: The hippocampal formation (HC) of mammals is a component of the limbic system of the brain hidden deep within the cerebral hemispheres in close association with the medial temporal lobe. Although the HC has been well studied in primates, little anatomic information is available concerning the detailed anatomy of the HC in the elephant, a large mammal proverbial for its powers of memory. We present an anatomic analysis of the HC in an Asian elephant *Elephas maximus* (female, age 34 years) and in an African elephant *Loxodonta africana* (female, age 46 years). Our investigations include macroscopic descriptions of the HC and microscopic analysis of histologic preparations.

1. Introduction

The hippocampal formation (HC) of mammals is a component of the limbic system of the brain hidden deep within the cerebral hemispheres in close association with the medial temporal lobe. The HC is believed to play an important role in learning and memory and may as well, through its limbic connections, play a role in the control of emotional behaviors and neuroendocrine functions. In higher mammals manifesting complex behaviors, such as cetaceans, proboscideans, and primates, the HC is small relative to the large size of the cerebrum. Although the HC has been well studied in primates, relatively little detailed anatomic information is available concerning the anatomy of the HC in the elephant (Dexler 1907; Haug 1970; Janssen & Stephan 1956; Koikegami *et al.* 1941). Our objectives have been to study the anatomical homologies between the HC of the elephant, a large mammal proverbial for its powers of memory, and of the human and to infer possible functions based on knowledge from the human HC. The pathologic involvement of the human HC in neurodegenerative diseases associated with old age such as Alzheimer's disease raises the question of the occurrence of similar changes in elderly elephants.

2. Materials and Methods

We present an anatomic analysis of the HC in formaldehyde-fixed brain specimens obtained from an Asian elephant *Elephas maximus* (female, age 34 years) and an African elephant *Loxodonta africana* (female, age 46 years).

Our investigations include macroscopic descriptions of the HC and microscopic analysis of histologic preparations using paraffin-embedded material sectioned at 10u and stained with Luxol fast blue/cresyl violet, hematoxylin and eosin, and Bielschowsky methods and 30u sections stained with cresyl violet alone.

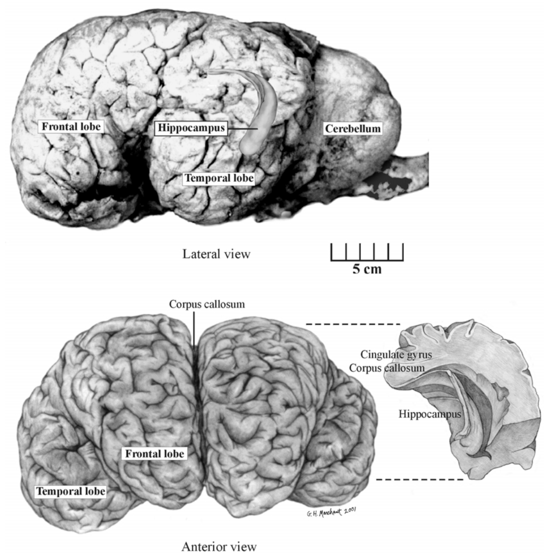


Fig.1 - Location and orientation of the hippocampus in the medial temporal lobe (*Elephas maximus*).

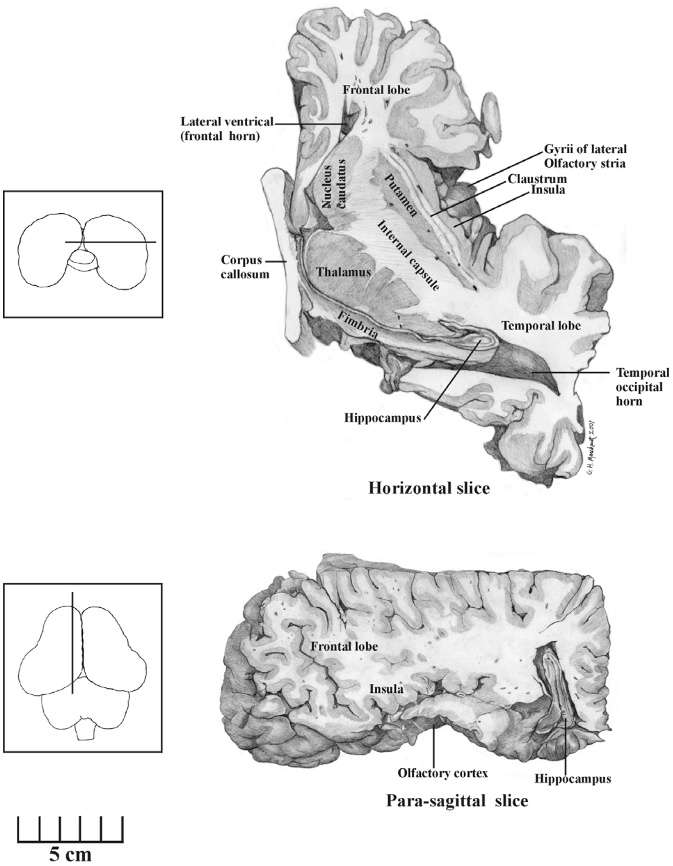


Fig.2 - Location and orientation of HC (*Loxodonta africana*). Note relationship of HC to medial wall of lateral ventricle.

3. Results

In both elephant specimens, the HC was identified in the medial temporal lobe oriented parallel to the long axis of the lobe (Fig. 1) and forming part of the medial wall of the inferior horn of the lateral ventricle (Fig. 2). The HC was approximately the same size as the human HC but small relative to the overall size of the elephant cerebrum. The shape was similar to the human HC but the digitationes hippocampi were indistinct.

The gyrus dentatus was relatively broad and flat and the fimbria was also relatively broader and thinner than the human fimbria. The white matter of the parahippocampal gyrus formed a prominent bulge on the medial floor of the temporal horn (Fig. 3). The elephant HC showed a similar pattern of folding to the human HC, but the folding was less compact in the end folium. The three-layered archicortical pattern was easily observed (Fig. 4), but the neuronal packing density appeared generally less than in the human HC and there was a clear distinction between the three-layered pyramidal area CA3 along the lateral border of the fascia dentata (FD) and a layer of loosely arranged pyramidal neurons (CA4) within the end folium running

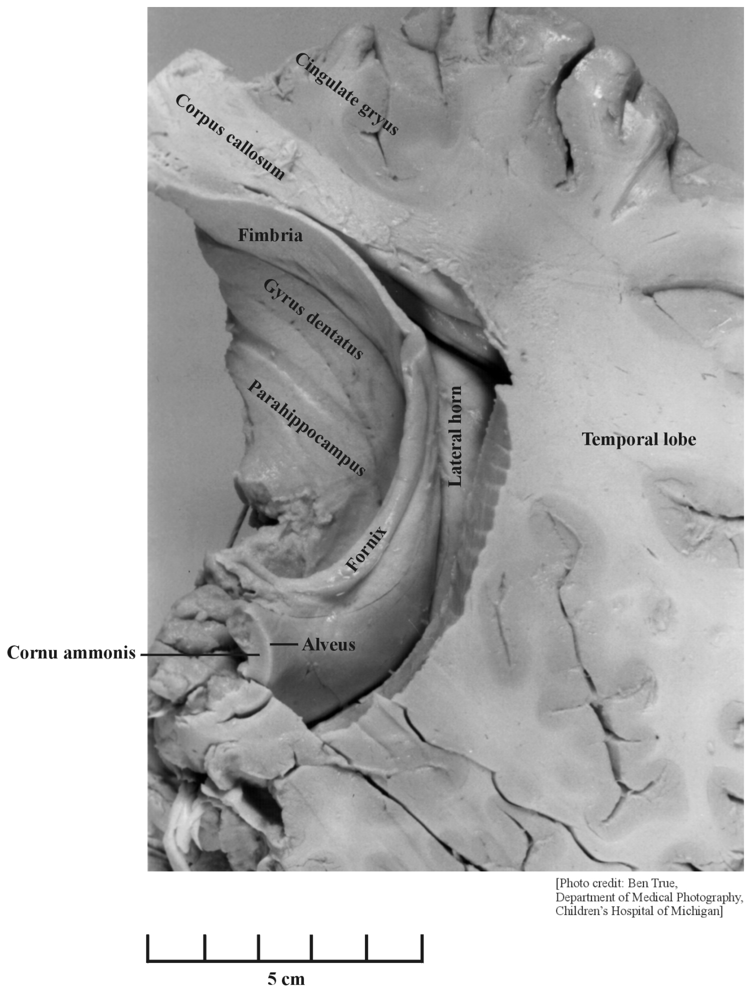
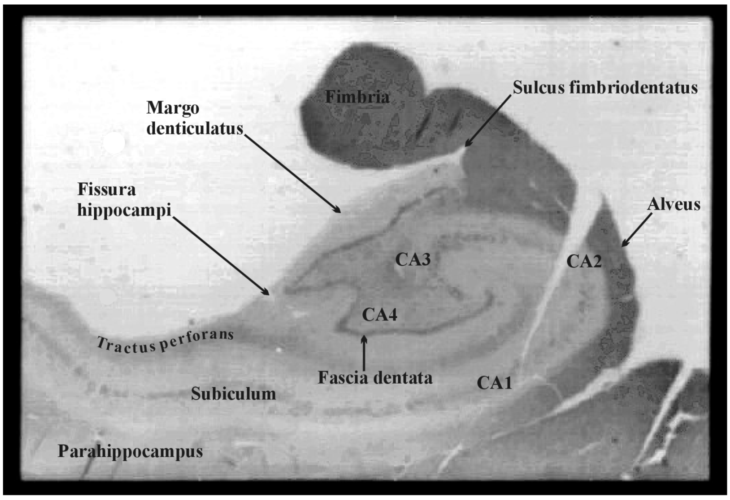


Fig.3 - Detailed photograph of HC (*Elephas maximus*). The anterior portion of the *pes hippocampi* has been damaged. The fascia dentata is broad and flat. (Photographer: Mr. Benjamin True, Medical Photography).



[Photo credit: W. J. Kupsky]

Fig.4 - Low-magnification photomicrograph of mid-portion of HC sectioned perpendicular to the long axis of the HC. The f*ascia dentata* and zones of the *cornu ammonis* (CA) are marked. (Luxol fast blue/cresyl violet, 1x original magnification).

parallel to the FD. The FD consisted of a broad lamina moleculare, a compact lamina granulare of small bipolar neurons, and a narrow lamina plexiforme containing small cells. In the end folium, the distinct CA4 layer surrounded a central hilum of myelinated fibers devoid of neurons.

There was a distinct transition to pyramidal layer CA3. Ectopic pyramidal neurons in various orientations were prominent in both the lamina moleculare and lamina plexiforme. Pyramidal layers CA1 and the subiculum were distinguished by the presence of discrete sublaminae, with a compactly arranged layer of pyramidal cells forming the top of layer 2. Scattered large pyramidal neurons were relatively abundant in layer 1. Layer 3 included more abundant pyramidal neurons intermixed with small horizontally oriented neurons, most prominent in the subiculum.

No evidence of Alzheimer-type changes (senile plaques, neurofibrillary tangles-NFT, Hirano bodies, or granulovacuolar degeneration) or other aging changes such as prominent accumulation of lipofuscin, mineralization of the HC microvasculature, or vascular sclerotic change was noted in either hippocampal specimen.

4. Conclusions

HC structures in the elephant appear grossly and histologically to have the same basic structural components and anatomic disposition as in the human HC. The elephant HC, however, is about the same size as the human HC and is therefore smaller in proportion to the overall brain size (Fig. 5). The homologies have possible implications for similar functions (learning, memory, control of behavior). The absence of HC degenerative changes of the Alzheimer type (senile plaques, NFT, Hirano bodies, granulovacuolar degeneration.), which occur in the HC of many elderly humans as well as in humans with Alzheimer's disease is of uncertain significance.

Degenerative changes were not noted in three older elephant brains examined by Cole & Neal (1990). Although the ages of the elephants we examined (34 and 46 years) may only represent somewhat more than half of their maximal life span potential, the African elephant did show rare NFT in the substantia nigra, a non-limbic brainstem structure involved with NFT in other forms of human neurodegenerative disease. This basic research is part of a long-term systematic study of ele-

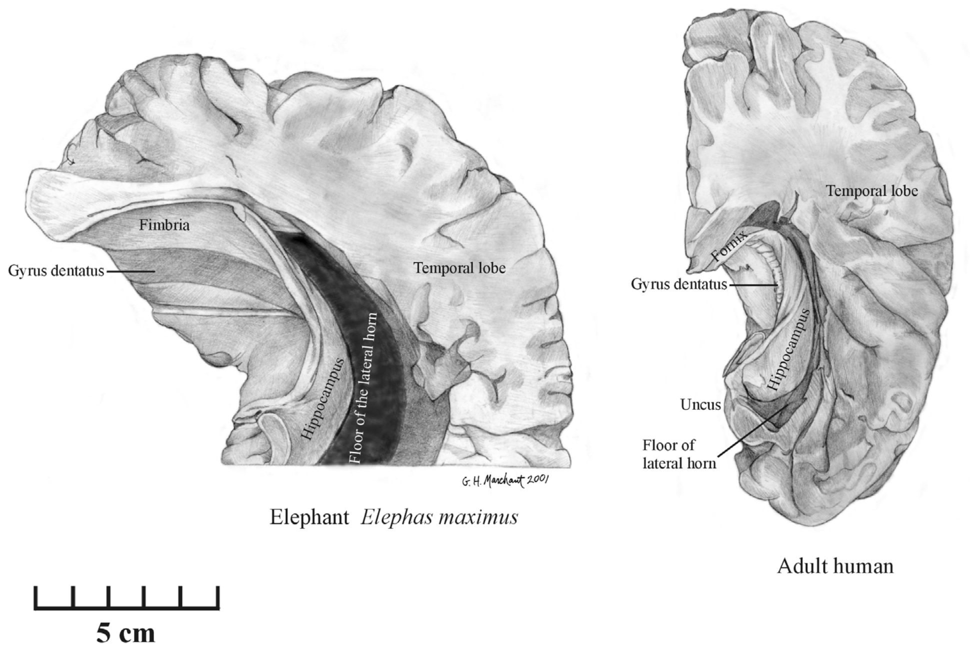


Fig.5 - Comparison of elephant and human hippocampus drawn to same scale.

phant brain anatomy from both a macroscopic and microscopic perspective whose goal is to fill in missing or misunderstood information using a holistic approach to gain knowledge on the largest living land mammal.

5. References

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