Papez circuit:
An anatomical study by cadaveric dissection

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Abstract
Objective: This study was done to completely study the Papez circuit by cadaveric dissection and it's relation to ventricles and other related anatomical structures.

Methods: Eight formalin fixed cerebral hemispheres were microscopically dissected for Papez circuit. Klinger's technique of fibre dissection was adopted. The circuit was dissected from medial and superior-lateral cerebral surfaces. Bilateral hemispheric dissection was done simultaneously in intact brain from superior-lateral surface in two brains (4 hemispheres). During and after dissection it's relation with lateral ventricles and other related structures were studied.

Results: Papez circuit was demonstrated by total dissection. Fibres leave the hippocampal formation and proceed through the fornix; most of these fibres have been shown to terminate in the mammillary nuclei of the hypothalamus. From here, the mammillothalamic tract ascends to the anterior group of thalamic nuclei. This group of nuclei projects to the cingulate gyrus through the anterior limb of internal capsule to anterior cingulated gyrus. From the cingulate gyrus there is an association bundle; the cingulum, which connects the cingulate gyrus with the parahippocampal gyrus part of the limbic lobe. The parahippocampal gyrus projects to the hippocampal formation and circuit is completed. Relation of different parts of the circuit with surrounding structures were also clearly seen.

Conclusion: Knowledge of the microsurgical anatomy of the Papez circuit is not only important for understanding memory mechanism and other limbic functions but also very important in management of lateral and third ventricular lesions, in transcallosal, transventricular, supraseller and temporal lobe surgery, and for psycho-neurosurgery.

Key words: *Papez circuit, fornix, mammillothalamic tract, hippocampus, parahippocampal gyrus, cingulated gyrus and microsurgical anatomy.*

Introduction

Neoplastic, vascular and other pathological lesions in ventricular system (lateral and third ventricle) can produce clinical neuropsychiatric problems by involving the facets of Papez circuit or by pressure over it. Different lesions in hippocampus can produce intractable epilepsy where surgical treatment is needed. One must not forget the role of psychosurgery in intractable psychiatric illness involving the Papez circuit. When a neurosurgeon finds himself dealing with the above mentioned pathologies he must be aware of the microsurgical anatomy of the Papez circuit, ventricular system and other related neural structures to maintain integrity of the circuit so that the patient does not suffer postoperative neurological deficit/s.

In this study, we attempted to dissect the Papez circuit completely and to evaluate the anatomical relation of the circuit to surrounding neuro-structures and ventricular system. This type of cadaveric study appears rarely in the literature.

Materials and methods

Eleven cerebral hemispheres that were formalinated for 3 - 6 months were taken for dissection of Papez circuit in the Department of Neurosurgery, King Edward Memorial Hospital, Mumbai, India during the author's fellowship in that Department. The circuit was dissected using Klinger's fibre dissection method under operating microscope. Dissection was done by bamboo made small spatula surgical dissector and sharp cutting instruments.

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Dissection was started from superior and lateral surfaces of cerebral hemispheres in an intact brain simultaneously on both hemispheres. The part of the brain above the corpus callosum was transected and removed. Body, trigone, frontal and occipital horn of lateral ventricle was opened carefully by dissecting and removing the corpus callosal fibres under microscope. Whole corpus callosum was removed dissecting and separating underlying fornix, septum pellucidum and hippocampal commissure, except the most anterior part of genu and most posterior part of splenium. Extreme care was taken not to damage the caudate nucleus. Then temporal horn was exposed by removing its roof (tapetum and optic radiation). Choroid plexus was removed from foramen of Monro to choroidal point in temporal horn. The following structures were dissected out and identified sequentially, septum pellucidum, fornix with its commissure and hippocampus, stria medullaris, stria terminalis, caudate nucleus and thalamus. An oblique incision was made from a point 3.5 cm lateral to frontal pole to head of caudate nucleus just lateral to the anterior part of stria terminalis, then the incision extended posteriorly up to the fimbria of fornix just lateral to stria terminalis. The incision was deepened inferiorly and part of the caudate nucleus, thalamus, corona radiata, internal capsule, lantiform nucleus and part of upper midbrain were removed to expose the fimbria, sabiculm, dentate gyrus and parahippocampal gyrus. Uncus was identified and amygdale was dissected out anterior-medio-superior to head of hippocampus and choroidal point.

Before commencing medial dissection, brain was bisected into two symmetrical halves by cutting strictly in the midline with sharp instrument. Dissection started from foramen of Monro. Column of fornix was dissected down to mammillary body lateral to ependymal lining through hypothalamus. Precommissural fibres of fornix to septal area were dissected and preserved. Anterior commissure was identified between pre- and postcommissural fibres of fornix. Mammillothalamic tract was traced from mammillary body that passes superio-laterally and posteriorly through the thalamus to anterior group of nucleus. Anterior thalamic radiation, projected anteriorly and anterio-superiorly, that passed lateral to head of caudate nucleus to join the anterior limb of internal capsule were dissected out. These fibres curved superio-medially and pass through the fibres of corpus callosum to end in anterior part of cingulated gyrus. Gray mater and short association fibres of cingulate gyrus were removed and cingulum fascicle was dissected out throughout the whole cingulated gyrus to parahippocampal gyrus. Fibres passing to hippocampus through dentate gyrus from parahippcampus were then dissected out.

Results

In our study we dissected out all parts of the Papez circuit by superior-lateral and medial surface dissection of cerebral hemisphere. In our dissection, parts of the circuit are (sequentially) hippocampus - fornix - mammillary body - mammillothalamic tract - anterior group of thalamic nucleus - anterior thalamic projection to cingulate gyrus - cingulum-parahippocampus - dentate gyrus - hippocampus. Parts are shown in Figure 1.

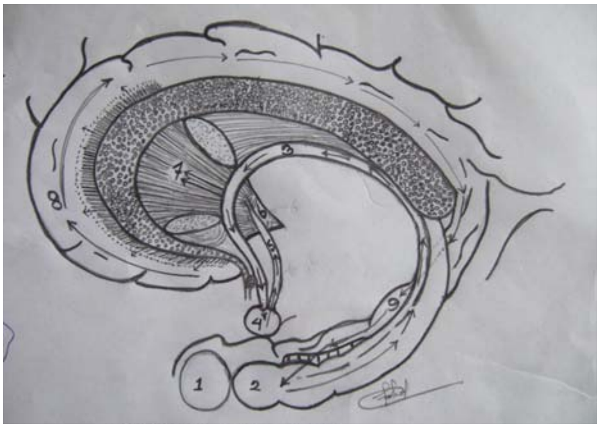

Figure 1 - Papez circuit and amygdale: (1) amgdala, (2) hippocampus, (3) fornix, (4) mammillary body, (5) mammillothalamic tract, (6) anterior thalamic nuclei, (7) anterior thalamic radiation, (8) cingulate gyrus, (9) parahippocampal gyrus and dentate gyrus.

Hippocampus (Figs. 2-5): This is thought to be the centre (nucleus) of Papez circuit. The circuit starts and ends here. It is situated in the floor of temporal horn lateral to it is collateral eminence. Anterior to head of hippocampus is amagdala. It is separated medially from thalamus by choroids fissure and choroids plexus of temporal horn. It has head, body and tail (from anterior to posterior). Tail is continued as fimbria of fornix posteriorly. The hippocampus is connected with septal area, hypothalamus and thalamus of the same side by foniceal fibres and by commissural fibres to opposite side. It is also connected with parahippocampal gyrus and cingulated gyrus through dentate gyrus. Hippocampus, sabiculum and dentate gyrus are together called hippocampal formation.

Fornix (Figs. 2-9): The fornix consists mainly of hippocampomammillary and hippocamposeptal fibres. Forniceal white fibres arise from the hippocampus, subiculum and dentate gyrus. It wraps the thalamus in the wall of lateral ventricle. The fornix is C-shaped. It has four parts: fimbria, crus, body, and columns of fornix.

Fimbria starts from tail of hippocampus and forms the posterior medial part of floor of temporal horn. Fimbriodentate sulcus separates it from dentate gyrus and it is separated from the geniculate body, optic and auditory radiations by the choroidal fissure.

Figure 2 - Parts of Papez circuit, right lateral ventricular parts and other related structures are shown after exposure of whole ventricle from above, part of caudate nucleus and thalamus removed: (1) foramen of Monro, (2) choroid plexus of body of lateral ventricle, (3) fornix, (4) anterior horn of lateral ventricle, (5) septum pellucidum, (6) rostrum of corpus callosum, (7) caudate nucleus, (8) thalamus, (9) pineal region, (10) splenium, (11) cerebellum, (12) occipital horn of lateral ventricle, (13) trigone of lateral ventricle, (14) temporal horn of lateral ventricle, (15) hippocampus, (16) uncinate fascicle and (17) temporal pole.

Figure 3 - Parts of Papez circuit, right lateral ventricular parts and other related structures are shown after exposure of whole ventricle from above bilaterally by removing necessary parts of hemisphere and corpus callosum, thalamus, caudate nucleus, lantiform nucleus, internal capsule and crus cerebri: (1) amygdala, (2) head of hippocampus, (3) fimbria fornix, (4) dentate gyrus, (5) collateral eminence in temporal horn, (6 and 7) occipital horn of lateral ventricle, (8) occipital lobe, (9) cerebellum, (10) splenium, (11) choroid plexus, (12) trigone of lateral ventricle, (13) body of fornix, (14) septum pellucidum, (15) foramen of Monro, (16) thalamus, (17) head of caudate nucleus, (18) frontal horn of lateral ventricle, (19) rostrum of corpus callosum, (20) frontal lobe, (21) parahippocampal gyrus and (22) temporal pole.

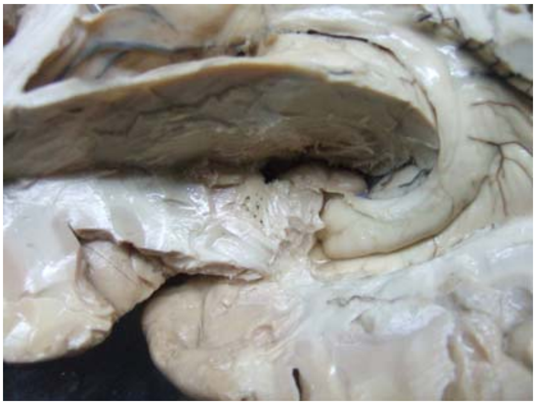

Figure 4 - Parts of Papez circuit, right lateral ventricular parts and other related structures are shown after exposure of whole ventricle from above by removing necessary parts of hemisphere and corpus callosum, thalamus, caudate nucleus, lantiform nucleus, internal capsule and crus cerebri with special focus on temporal horn structures: (1) frontal area, (2) temporal pole, (3) uncinate fascicle, (4) anterior perforated substance, (5) internal capsule, (6) amygdala, (7) hippocampus, (8) fimbria, (9) dentate gyrus, (10) parahippocampal gyrus, (11) uncus, (12) choroid fissure, (13) crus fornix, (14) optic radiation, (15) foramen of Monro, (16) thalamus, (17) septum pellucidum and septal vein, (18) rostrum of corpus callosum and (19) body of fornix.

Figure 5 - Parts of Papez circuit, right lateral ventricular parts and other related structures are shown after exposure of whole ventricle from above bilaterally by removing necessary parts of hemisphere and corpus callosum, thalamus, caudate nucleus, lantiform nucleus, internal capsule and crus cerebri: (1) frontal pole, (2) rostrum of corpus callosum, (3) head of corpus callosum, (4) septum pellucidum, (5) foramen of Monro, (6) body of fornix, (7) crus fornix, (8) hippocampal commissure (9) striaterminalis, (10) splenium, (11) fimbria, (12) hippocampus, (13) amagdala, (14) thalamo-caudate sulcus, (15) dentate gyrus, (16) collateral eminence in temporal horn, (17) occipital horn of lateral ventricle, (18) optic radiation, (19) cerebellum, (20) occipital lobe, (21) insula and external capsule

The crus of the fornix is the posterior continuation of fimbria that covers the posterior surface of the pulvinar in the medial part of the atrium and arches superio-medial toward the lower surface of the splenium. It forms the medial part of anterior wall of atrium. Thin sheet of white fibre that interconnects medial edge of both crus below the splenium is known as hippocampal commissure.

Body of the fornix is formed by the joining of both crus in midline at the junction of body and atrium of lateral ventricle. Passing forward above the thalami superiorly it blends with lower edge of the septum pellucidum and forms the medial wall of the body of the lateral ventricle.

Column of fornix begins when body of fornix separates into a pair of columns at the anterior pole of the thalamus; the columns that arch anterior-inferiorly to form the superior and anterior margins of the foramen of Monro. Then they blend into the lateral walls of the third ventricle and pass down behind the anterior commissure through the hypothalamus to mammillary body.

The part of the thalamus lateral to the body of the fornix forms the floor of the body of the lateral ventricle and the part medial to the fornix forms part of the lateral wall of the velum interpositum and third ventricle. The crus of the fornix crosses the pulvinar approximately midway between the medial and lateral edge of the pulvinar. The part of the pulvinar lateral to the crus of the fornix forms part of the anterior wall of the atrium. The lower border of the fornix forms the upper border of the choroidal fissure and the lower border of choroid fissure is formed by stira medullaris; choroids plexus is attached here. The septum pellucidum stretches across the interval between the anterior parts of the corpus callosum and the body of the fornix. It is composed of paired laminae and separates the frontal horns and bodies of lateral ventricles.

Mammillary body and mammillothalamic tract (Figs. 6-9): Mammillary bodies are egg-shaped paired structures in the floor of the third ventricle situated on the both sides of midline behind the pituitary stalk and can easily be seen both from ventricular and inferior surface of the brain. Column of fornix ends and mammillothalamic tract originates from here. Mammillothalamic tract ascends superio-laterally and posteriorly through the thalamus to anterior group of nucleus. Some fibres of the tract also go to dorso-medial nucleus of thalamus.

Anterior group of thalamic nuclei (Figs. 7-9): Anterior thalamic group of nuclei lies anteriorly near the foramen of Monro. They receive mammillothalamic tract and project anterior thalamic radiation.

Anterior thalamic projection (Figs. 7-9): Fibres from anterior group of thalamic nucleus project anteriorly and anterior-superiorly passing lateral to head of caudate nucleus and links to anterior limb of internal capsule. These fibres curve superio-medially and pass through the fibres of orpus callosum to end in anterior part of cingulate gyrus. Some fibres of the anterior thalamic projection are seen to end in head of caudate nucleus and some fibres are seen to be passed through the lateral part of caudate nucleus. Small portion of this radiation is also passed to prefrontal cortex.

Cingulate gyrus (Figs. 6-9): This is on the medial cerebral surface, just above the corpus callosum. It begins anterior to rostrum of corpus callosum and septal area. It follows the curvature of callosum, below and behind the splenium and it continues with parahippocampal gyrus through isthmus. Anteriorly, it receives anterior thalamic radiation. The cingulum within the cingulate gyrus contains long and short association fibres that follow the curve of the cingulate gyrus and corpus callosum. Cingulum ends in parahippocampal gyrus.

Parahippocampal gyrus (Figs. 3-5,8,9): This is the most medial gyrus on the inferior surface of the temporal lobe. It receives cingulum and projects to hippocampus through the dentate gyrus.

Dentate gyrus (Figs. 3-5): A short narrow gyrus can only be seen to adequate lateral retraction of parahippocampal gyrus by its characteristic appearance. It connects parahippocampal gyrus to hippocampus.

Figure 6 ← Medial surface of cerebral hemisphere showing: (1) mammillary body, (2).optic nerve, (3) anterior commissure, (4) column of fornix, (5) foramen of Monro, (6) head of caudate nucleus, (7) septal area, (8) precomisural fornix, (9) rostrum of corpus callosum, (10) cingulate gyrus, (11) splenium, (12) posterior commissure, (13) habinular commissure, (14) thalamus, (15) thalamohypothalamic sulcus, (16) tectum and (17) midbrain.

Figure 7 - Medial surface of cerebral hemisphere showing white fibre dissection for parts of Papez circuit: (1) mammillary body, (2) post commissural fornix, (3) mammillothalamic tract, (4) column of fornix, (5) rostrum of corpus callosum, (6) splenium (7) stria terminalis, (8) precommissural fornix, (9) anterior commissure, (10) septal area, (11) anterior thalamic radiation, (12) head of caudate nucleus and (13) cingulate gyrus.

Figure 8 - Medial surface of cerebral hemisphere showing white fibre dissection for parts of Papez circuit after removal of brain stem, cerebellum and part of thalamus and caudate nucleus: (1) mammillary body, (2) post commissural fornix, (3) mammillothalamic tract, (4) anteror thalamic nuclei, (5) body of fornix, (6) stria terminalis, (7) caudate nucleus, (8) anterior thalamic radiation, (9) crus fornix, (10) fimbria fornix, (11) uncus, (12) parahippocampal gyrus, (13) cingulum, (14) rostrum of corpus callosum and (15) temporal pole.

Figure 9 - Medial surface of cerebral hemisphere showing white fibre dissection for parts of Papez circuit after removal of brain stem, cerebellum and part of thalamus and caudate nucleus: (1) mammillary body, (2) mammillothalamic tract, (3) fornix, (4) anteror thalamic nuclei, (5) anterior thalamic radiation, (6) rostrum of corpus callosum, (7) cingulum, (8) crus fornix, (9) parahippocampal gyrus, (10) trigone of lateral ventricle, (11) thalamus, (12) caudate nucleus, (13) uncus, (14) splenium, (15) body of lateral ventricle and (16) temporal pole.

Discussion

In 1937 James Papez described a pathway involving some limbic and cortical structures and associated pathways.[10] These, he postulated, formed the anatomical substrate for emotional experiences.[10] The pathway forms a series of connections, which has since been called the Papez circuit or medial limbic circuit.[2,3,7] Defense reaction circuit and baso-lateral circuit are the other two circuits of limbic lobe.[2,3] The parts of Papez circuit includes, hippocampus, fornix, mammillary body, mammillothalamic tract, anterior group of thalamic nucleus, anterior thalamic projection to cingulate gyrus, cingulum, parahippocampal gyrus, and the dentate gyrus.[1,2,7,9] In our study we dissected the above mentioned parts to identify the circuit anatomically and in our dissection we also found that anterior thalamic projection communicates not only cingulate gyrus but also to prefrontal cortex and caudate nucleus. Through precomissural fibres of fornix the circuit also has connection with septal area (Fig. 7). There is also communication between hippocampus and amygdala.

The circuit may be affected by various pathologies, such as degenerative (Alzheimer's disease), deficiency condition (Vitamin B1 deficiency, Korsakoff psychosis[4]), vascular (infarction, AVM, angioma), hypoxia (temporal mesial sclarosis[6,8]) neoplastic (intrinsic to Papez circuit-glioma, extrinsic to the circuit-glioma, meningioma, colloid cyst, craniopharyngioma, choroids plexus papilloma, and other tumours), trauma, iatrogenic (postsurgical), psychiatric illness.[2] These patients may present with defective functions of Papez circuit such as memory disturbance (especially recent), personality changes, changes in emotional behaviour, loss of spontaneity and initiative, affective disorders, hallucinations, intractable epilepsy with or without features of intracranial space occupying lesion.[5] Various investigations including neuro-imaging can identify these conditions with ease.

Surgical intervention is needed in neoplastic, vascular, intractable epilepsy and intractable psychiatric conditions. Appropriate surgical approach and peroperative identification and preservation of Papez circuit along with other related vital structures are essential for a good outcome in these surgeries. Lesion making surgeries in psychiatric illness should be done only after definite indications with extreme caution.[2] In case of intractable epilepsy where mesial temporal excision is planned, the opposite mesial temporal lobe's function should be kept intact, otherwise postoperatively patient may become disastrously disabled.[7] The hippocampal formation is one of the critical structures for memory. This function of the hippocampal formation became understood because of an individual known in the literature as H.M., who has been extensively studied by neuropsychologists. H.M. had surgery several decades ago for a valid therapeutic reason - the removal of an epileptic area in the temporal lobe of one side, which was the source of intractable seizures. Most importantly, the surgeons did not know, and could not know according to the methods available at that time, that the contralateral hippocampal area was also severely damaged. This surgery occurred, unfortunately, before the functional contribution of this area to memory formation was not known. Since the surgery, H.M. has not been able to form any new memory for events or facts, although he has been taught new motor skills (called procedural memory).[7]

We now know that bilateral damage or removal of the anterior temporal lobe structures, including the amygdala and the hippocampal formation, leads to a unique condition in which the person can no longer form new declarative or episodic memories, although older memories are intact. The individual cannot remember what occurred moments before. Therefore, the individual is unable to learn (i.e., to acquire new information) and is not able to function independently.[7]

Conclusion

Knowledge of the microsurgical anatomy of the Papez circuit is not only important for understanding memory mechanism and other limbic functions but also very important in management of lateral and third ventricular lesions, in transcallosal, transventricular, supraseller and temporal lobe surgery, and psycho-neurosurgery.

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References

1. Carpenter MB (ed): Core Text of Neuroanatomy, 4 Ed. Baltimore, Williams & Wilkins 1991, pp 375-383
2. Feldman RP, Alterman RL, Goodrich JT: Contemporary psychosurgery and a look to the future. J Neurosurg 2001, 95(6): 944-956
3. Goldenberg PL: Functional neurosurgery. In: Schmidek HH, Sweet WH (eds), Operative Neurosurgical Techniques: Indications, Methods and Results, 2 Ed. Orlando, Grune & Stratton 1988, Vol. 2, pp 1035-1068
4. Haberland C (ed): Acquired neurometabolic disease. In: Clinical Neuropathology: Text and Color Atlas. New York, Demos Medical Publishing 2007, pp 199-211
5. Haberland C (ed): Basics of Neuropathology. In: Clinical Neuropathology: Text and Color Atlas. New York, Demos Medical Publishing 2007, pp 7-30
6. Haberland C (ed): Cerebral hypoxia. In: Clinical Neuropathology: Text and Color Atlas. New York, Demos Medical Publishing 2007, pp 33-41
7. Hendelman WJ (ed): The limbic system. In: Atlas of Functional Neuroanatomy, 2nd Ed. New York, CRC Press 2006, pp 202-238
8. Hogan RE: Mesial temporal sclerosis: Clinicopathological correlations. Arch Neurol 2001, 58(9): 1484-1486
9. MacLean PD: The limbic system ('visceral brain') and emotional behavior. Arch Neurol Psychiatry 1955, 73(2): 130-134
10. Papez JW: A proposed mechanism of emotion. Arch Neurol Psychiatry 1937, 38(4): 725-743