REGENERATION OF DURAL DEFECTS
A REVIEW

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The belief that it is necessary to fill every dural defect with some type
of membrane has been the basis of much of the experimental work on
dural deficiency as well as the surgical treatment of dural defects. On
the other hand, there is the opinion, based on clinical experience and some
experimental studies, that the dura mater takes good care of its own defects.

In 1924, Trotter had observed that if a segment of cerebral dura mater were
excised and the overlying subcutaneous tissues of the scalp were left in con-
tact with the brain a neomembrane would form from the scalp which would
be indistinguishable from the old dura mater within a few weeks. He was of
the opinion, further, that every element of the nervous system should be kept
from contact with somatic tissue, either by dura mater or neurilemmal
sheaths, and he stressed the insulating function of the dura mater. He
reached the same conclusions regarding the regeneration of dura mater as
Sayad and Harvey, who based their conclusions on experimental work.
Davis compared the regeneration of the dura mater to that of peritoneum
and warned against the introduction of foreign materials to fill in dural de-
fects. He believed that the regenerated dura mater was far more protective
than any artificial membrane and, also, that it regenerated very rapidly.
Penfield in 1942 expressed the opinion that neurosurgeons still needed an
ideal membrane which would be absorbable and would disappear, after
having prevented cross circulation and formation of adhesions. As recently
as 1955, Huertas and Teng and Feigin expressed opposing views regarding
the indications for repair of dural defects: Huertas, in a report on a dural
substitute stated, “The continuity of the dura mater is a prime necessity;”
and Teng and Feigin in a similar report stated, “The chief purpose of using
a dural substitute in neurosurgery is to prevent adhesions between the ex-
posed brain and the overlying soft tissues rather than to fill the defect in the
severed dura mater.”

The dural defect has been dealt with in numerous and varied reports,
and the multiformity of the therapy described would indicate that an ideal
successful therapy has yet to be presented.

A deficiency of the dura mater may result from many causes—cranio-

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cerebral trauma;\textsuperscript{17,29} surgical removal;\textsuperscript{15,20,45,57} neoplastic destruction;\textsuperscript{11,18} inflammatory destruction;\textsuperscript{2,20} hydrocephalus;\textsuperscript{11,16,58} or congenital absence. Occasionally dural defects lead to serious sequelae. Probably the most important of these is the frequent complication of meningitis and/or cerebral abscess in association with the dural defects of cranionasal or cranio-otic fistulae.\textsuperscript{11,18,29} These fistulae are usually accompanied by cerebrospinal fluid rhinorrhea or otorrhea. O’Connell\textsuperscript{49} said that the herniation of brain tissue in “cerebral fungus” formation following an injury is caused primarily by a dural defect and that the superficial extent of the “fungus” is determined by the size of the dural defect, not by the size of the cranial defect.

Pneumocephaalus\textsuperscript{19} may result from a dural defect associated with a cranionasal or cranio-otic fistula. It is also frequently accompanied by meningitis.

A less serious, though very important, sequela is the development of erosion of the skull in an area corresponding to an underlying dural defect. This condition, aptly termed “craniocerebral erosion”\textsuperscript{14,15} has been known and is still known under a wide variety of terms,\textsuperscript{16,53} though its true nature is still not well understood.

\section*{EXPERIMENTAL WORK}

In 1923 Sayad and Harvey\textsuperscript{61} recorded the first experimental study concerned primarily with the regeneration of the dura mater. In addition to their report, there is an extensive literature on the subject of duraplasty and prevention of meningocerebral adhesions.

Interest in the surgical treatment of dural defects arose originally from a desire to prevent the return of meningocerebral adhesions following excision of the dura mater and the meningocerebral cicatrix in cases of epilepsy (Beach,\textsuperscript{6} 1890). This interest has been confined chiefly to that of finding a dural substitute that closely resembles the normal membrane.

The search for dural substitutes has taken two principal routes: inorganic materials such as metal foils; and animal membranes such as homologous and autologous tissue grafts.

The subject of duraplasty has been reviewed by von Saar\textsuperscript{50} (1910), Buné\textsuperscript{10} (1933), Glaser and Thienes\textsuperscript{25} (1938), and Pudenz and Odom\textsuperscript{47} (1942). The large number of substitutes that have been advocated bears witness to the continued confusion concerning the proper treatment of dural defects.

Abbe\textsuperscript{1,2} (1895) first reported on the use of an artificial membrane for a dural defect. He used rubber tissue in two patients with post-traumatic epilepsy operated on with removal of meningocerebral cicatrices. Prior to this, Beach\textsuperscript{6} had suggested the use of gold foil for the prevention of meningocerebral adhesions. However, he did not report its use until 1897.\textsuperscript{7} McCosh\textsuperscript{26–28} in 1898 reported on the surgical treatment in 14 cases of epilepsy. He used rubber tissue and silver foil in an effort to prevent the post-operative return of meningocerebral adhesions. The use of silver foil was suggested by Ray\textsuperscript{48} (1901) and Harris\textsuperscript{26} (1904). Both rubber tissue and metal-
lic foil were popular at the turn of the century, but by the end of the first decade of the twentieth century their general use had been discontinued.

Follow-up reports on the clinical cases in which the metallic foils were used were very rare or scanty in detail. No experimental work was recorded and there is no clear indication from the literature, at that time, as to why the interest in them declined. However, recent experimental work by Chao et al., Pudenz and Odom, and Delarue et al. revealed that the metallic foils produce a fairly intense cellular reaction and thick encapsulation.

The only report of an experimental study on rubber tissue as a dural prosthesis was made by Giangrasso. His studies revealed that the rubber membrane became encapsulated but that with time this capsule diminished in size until it began to resemble the normal dura mater. He used 6 dogs and the protocols have only little information on the autopsy findings.

By 1909 Kirschenauer had carried out the first experimental studies on the use of autoplastic fascia-lata grafts for dural defects. The following year, Körte reported the first human case in which autoplastic fascia lata had been used for a dural defect. Finsterer used homoplastic hernia-sac membrane for a dural defect in man. Autoplastic dura mater, fat, periosteum, and fascial transplants were all recommended and used clinically prior to 1920.

The diversity of opinions based chiefly on clinical observations necessitated experimentation in dural regeneration. In 1923, Sayad and Harvey studied the healing of dural defects placed under unilateral decompression craniectomies in 8 dogs. The brain and leptomeninges were left uninjured. The animals were sacrificed at 2, 7, 14, 15, 22, 28, 35, and 43 days. A carotid perfusion of formalin was carried out. The operative area was removed intact and studied both grossly and microscopically. Their description of the process of dural regeneration was as follows:

"The operative defect is filled at once by blood clot which on its inner face is lightly adherent to the arachnoid and on its outer intimately adherent to the exposed temporal muscle. The process of organization of the clot commences at once and takes place much in the same manner as it would elsewhere in the body. There is an immediate invasion of phagocytes, followed almost at once by wandering and polyblastic cells and then in time by fibroblasts. These all appear to come in large part from the overlying temporal muscle and to be evenly distributed throughout the clot. Those reaching the inner surface adjacent to the arachnoid membrane become arranged in a plane tangential to that surface, and at sixty hours there is a distinct skeletal arrangement of the cells corresponding to the future architecture of the dura. In something less than a week certain of these cells are arranging themselves along the inner face of the blood clot in contact with the arachnoid, so that one begins to see a limiting membrane resembling the endothelial lining of the normal dura. . . .

"This surface is then complete in about a week and at this time the clot loses its fibrinous adhesions to the arachnoid. From this time on the process is largely one of growth and condensation of connective tissue behind the lining cells. These
bundles of fibroblasts are laid down in a plane tangential to the arachnoid and the newly formed endothelial layer."

They concluded from their experiment that dural defects in the dog without injury to the arachnoid heal rapidly in from 1 to 2 weeks and without formation of adhesions.

Penfield41 in 1924, in an experimental study on meningocerebral adhesions, performed bilateral osteoplastic skull flaps in 20 dogs. In some animals he replaced the bone flap and in others he left a bone defect. The underlying dura mater was excised and on one side squares of celluloid and celloidin were placed side by side in the defect and held in place with silk-sutures ties to the edges of the defect. On the other side squares of fat, excised dura mater, and fascia, respectively, were placed over the dural defect. Brain wounds and excision of cortex were performed on both sides. In other animals stab wounds and implantation of strips of dura mater were made into the brain on one side and large wounds of the cortex, covered with sheets of fascia or fascia and fat, were made on the other side. When the bone flap was replaced and the brain was uninjured, he found that a membrane did form in the dural defect, but that it was much thinner than that which was formed beneath temporal muscle and scalp. He noted that this membranous formation under the bone was thicker over a laceration of the brain or foreign substance than over uninjured brain. His findings were in agreement with those of Sayad and Harvey.51 He also noted a rapid regrowth of a neomembrane in dural defects under temporal muscle and absence of arachnoidal adhesions when the brain was uninjured.

It was Penfield's41 observation that: "If there has been injury to the brain, adhesions form, no matter what the covering." He concluded that the thickness of the neomembrane, formed after removal of the old dura mater, varied according to the available blood supply. Erosion of the skull in the areas of dural deficiency was not noted.

Lear and Harvey56 (1924) carried out a study, also on dogs, on the regeneration of the leptomeninges in a continuation of the work begun by Sayad and Harvey.51 Unilateral decompressive craniectomies were made and brain wounds were placed under dural flaps in 11 animals which were sacrificed from 8 to 40 days. In 1 animal, which was sacrificed at 39 days, a dural flap was turned and replaced without injury to the underlying brain. These workers observed that where there is an injury to the pia-arachnoid and cortex, even though the overlying dura mater is uninjured, dense adhesions between all three layers of the meninges and the cortex are formed. They concluded that the longer the period of healing, the greater the density of the adhesions; and that injuries to the pia-arachnoid and underlying cortex lead to formation of adhesions with the overlying normal dura mater and that these adhesions persist. They concluded further that the lining cells of the leptomeninges are more stable than those of the dura mater which are
mesothelium derived from mesenchyme and which will enter into any inflammatory reaction.

In 1938, Glaser and Thienes\textsuperscript{35} carried out a study on three groups of dogs, in which comparison was made on fascia lata, animal membrane, and a blank opening in repair of dural defect.

They found, in all three groups, that the gross appearance of the newly formed dura mater was the same. They found no adhesions to the underlying uninjured brain. Sections taken through the underlying brain were reported to be normal. When the dural defect was left blank, a thin clot was present in 24 hours and was replaced by a thick clot within 3 days. A definite neodura mater was first visible within 7 days and was quite apparent by the 10th day. They noted that the microscopic picture indicated that the process of regeneration consisted of the formation of granulation tissue and the outgrowth of fibroblasts from the muscle and dural edges. They also noted a clinical case of neodural formation of 6 weeks' duration in which the newly formed fibroblasts seemed to arise from the muscle and dural mater, not from the blood clot. Their observations indicated that the heteroplasic animal membrane was as efficient as the autoplasic fascial graft for the repair of dural defects. They concluded, without further qualification, that the use of a graft for the repair of dural defects is entirely unnecessary.

In 1940, Chao et al.\textsuperscript{13} started extensive experimental work in the cat on the use of "amnioplastin," a specially prepared human amniotic membrane, and allantoic membrane as possible dural substitutes. They also studied mica, aluminum foil, silver foil, nickel plate, stainless steel plate, cellophane, Cargile membrane, fat, plain catgut, and fascia lata. On the basis of this study, they recommended the use of amnioplastin to replace defects in the dura mater that may occur for any reason. They concluded that the boiled amnioplastin prevented adhesions and that it was completely absorbed within a period of 30 days. Later, Penfield\textsuperscript{42} warned against the use of amnioplastin until further experimental work had been done. He suggested that formation of adhesions with the dry amnioplastin might be caused by the presence of fat. In the investigations carried out by Pudenz and Odom\textsuperscript{47} (1942) and Cone et al.\textsuperscript{14} (1942), amnioplastin was studied in the viable, attenuated and fixed forms. Cargile membrane, allantoic membrane, tantalum foil, and films of polyvinyl alcohol were also studied. Their observations revealed that both the viable and attenuated forms of amniotic membrane survived and that the viable form, instead of suppressing, stimulated the formation of adhesions. They concluded that none of the materials tested could be considered ideal for the prevention of meningocerebral adhesions. All the materials tested stimulated some degree of cellular reaction, became encapsulated, and some allowed the formation of adhesions. They concluded that tantalum foil provoked the least intense cellular reaction, encapsulation and formation of adhesions and advocated its use until something better should be discovered.
That same year Hicks et al.\textsuperscript{27} reported an experimental study on the use of amnioplastin as a dural substitute in dogs. They used 5 dogs as controls in which dural defects were made with underlying brain wounds, and overlying decompressions allowing the galea and temporal muscle to come in direct contact with the brain wound. It was noted that the marked formation of adhesions observed at 5\(\frac{1}{2}\) weeks and at 3 months markedly decreased by the fourth and fifth months. They found a well-marked neodural formation by 5\(\frac{1}{2}\) weeks. In addition to the control study, they used “dry” amnioplastin, “boiled” amnioplastin, and “defatted” amnioplastin in dural defects. They found adhesions formed between the brain and reformed dura mater when the brain was injured and when amnioplastin, whether dry, boiled or “defatted,” was used to cover the dural defect. They also noted that for the first 7 weeks these adhesions were not so tough as those formed when no membrane was used for the dural defect. After 7 weeks, they observed that there was little difference in the adhesions; and that there was increasing solidity and contraction of adhesions in all the groups. They expressed surprise at the difference of their results on dogs from those of Chao et al.\textsuperscript{13} who had performed their experimentations on the cat.

In 1942 Penfield\textsuperscript{43} retracted his statements published in 1940\textsuperscript{13} in regard to amnioplastin, and agreed with Cone et al.\textsuperscript{14} that no animal membrane should be used to cover brain, spinal cord, or peripheral nerves. He also noted two human cases in which he had used amnioplastin to repair dural defects and in both cases at re-operation, 7 months and 1 year respectively, dense adhesions had formed.

Delarue et al.\textsuperscript{22} (1944), provoked by the report of Cone et al.\textsuperscript{14} (1942), carried out an experimental study on the use of tantalum foil in the subdural space of 12 dogs. They observed a marked thickening of the overlying dura mater in 12 animals and a slighter, reactive thickening of the arachnoid. On the basis of this study one of the authors (McKenzie) concluded that the use of tantalum foil in the human brain was contra-indicated. However, Robertson and Peacher\textsuperscript{49} (1945), in a clinical report describing the use of tantalum foil subdurally in 45 recorded human cases, plus an undetermined additional number of unrecorded cases, concluded that tantalum foil was well adapted to subdural use in human beings, contrary to the conclusions of McKenzie.\textsuperscript{22}

Next in this long list of dural substitutes was fibrin film, which was studied in the monkey and used clinically.\textsuperscript{4,5,20,31} In 1947, Ingraham et al.\textsuperscript{29} and Brown et al.\textsuperscript{8,9} began studies on polyethylene film as a dural substitute. Scheuerman et al.\textsuperscript{52} in 1951 reported studies on Gelfoam film. They stated that it was absorbed in 80 to 90 days and that it was effective as a dural substitute in that it prevented adhesions from developing between the wounded cortex and dura mater with practically no tissue reaction. Their study was limited to 2 dogs.

In 1955, two studies were reported on the use of synthetic fabric materials as dural substitutes. Huertas\textsuperscript{28} used Orlon in 7 monkeys. He placed Orlon
prostheses in dural defects over injured and uninjured brains. The bone flaps were wired back in all cases. He reported that no envelope was found around the prostheses and that the neighboring tissues did not show any foreign-body reaction. No cerebromembranous adhesions were found. Teng and Feigin\textsuperscript{14} reported a similar study using Vinyon-N in dural defects in monkeys. They reported also that no fibrous capsules were found around the prostheses in animals observed from 21 to 428 days. No cerebromembranous adhesions were found in any case when the prosthesis was sutured to the edge of the dural defect with everted sutures. Slight meningocerebral adhesions were found in 2 of 4 animals in which end-to-end sutures were used.

In an attempt to contribute to the clarification of this important clinical problem, the author has initiated extensive experimental studies in animals on the regeneration of dural wounds and loss of dural substance. These studies will be reported at a later date.

**SUMMARY**

A review of the literature on dural regeneration and the repair of dural defects is made. The conflicting opinions, outlined in the review, bear witness to the need that exists for further experimental work.

**REFERENCES**

33. Körte, W. Cited by Krause and Schum. 24


