VINYON “N” AS A DURAL SUBSTITUTE
AN EXPERIMENTAL STUDY IN THE MONKEY*

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In the last six decades numerous materials have been used experimentally and clinically as dural substitutes. They include metallic materials such as gold, platinum, silver, aluminum, and nickel foils, and tantalum and stainless steel plate or screen. Biological tissues, including fascia, fat, periosteum, amniotic, human or animal allantoic, Cargile membranes, amnioplastin, gelfoam, and plasma fibrin films have all been used. Other substances such as rubber sheets, parchment, mica, cellophane, olive oil, polyvinyl alcohol plastic, and polythene sheets have also been employed.

The chief purpose of using a dural substitute in neurosurgery is to prevent adhesion between the exposed brain and the overlying soft tissues rather than to fill the defect in the severed dura mater. It is generally believed that the meningocerebral adhesions that follow injury or surgery are responsible for the post-traumatic or postoperative convulsive disorders.

The dural substitute must possess specific qualities, such as nontoxicity, inertness in tissue, nonabsorbability, resistance to disintegration, favorable tensile strength, soft consistency, easy maneuverability for wrapping over the surface of the brain, and ease in sterilization. None of the above-mentioned materials fulfills all these requirements. This probably accounts for the long and continuous search for suitable dural substitutes in neurosurgery.

This communication concerns a new synthetic material, Vinyon “N” cloth, which has been used experimentally as a dural substitute in the monkey.

MATERIAL AND METHOD

Vinyon “N” Cloth. Vinyon “N” is a synthetic fabric woven in cloth form with a construction of 144 warps and 90 filling yarns per square inch. The woven pattern, consistency and color are those of China silk. It is nontoxic, inert, and nonabsorbable when buried in animal tissue. It has a smooth surface. Its tensile strength is similar to that of silk. Furthermore, it can readily and repeatedly be sterilized in boiling water without any appreciable damage. Autoclaving stiffens it.

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Experimental Animals and Operative Technic Used. Two series of animals were studied. The first series consisted of 6 adult monkeys including 1 Rhesus cynomologus and 5 Macaca mulatta, weighing from 2.5 to 5.8 kg.

On each of these 6 monkeys a craniotomy was performed using sterile technic. A left frontoparietal bone flap was turned down under intravenous sodium nembutal anesthesia, 18 mg. per pound of body weight. In 4 of these 6 monkeys (Animals 1, 2, 3 and 4), the cerebral cortex was left intact, while in 2 (Animals 5 and 6) a piece of the cerebral cortex in or close to the motor area was excised. In each animal, a piece of dura mater measuring approximately 1 by ½ inch was removed and replaced by a piece of Vinyon “N” cloth. The edges of the dural substitute and the dura

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**Fig. 1.** Diagram illustrating the result of three different methods of anastomosis of dura mater and Vinyon “N” dural substitute. (A) Edge-to-edge (end-to-end) anastomosis with the formation of meningo-cerebral cicatrix along the line of approximation (crosshatch). (B) Anastomosis by everted sutures. Meningocerebral adhesions were prevented. (C) Tuck-under method shows no meningo-cerebral adhesions.

- Broken line = Vinyon “N” dural substitute
- S = Suture
- Crosshatch = Adhesion formation
- DMA = Dura mater and arachnoid
- PC = Pia and cortical surface
- SA = Subarachnoid space
- MC = Meningocerebral cicatrix
mater were approximated by edge-to-edge (end-to-end) suturing with 00000 silk (Fig. 1 A) or eversion of the edges (Fig. 1 B). A second series of 5 monkeys (Animals 7, 8, 9, 10 and 11) were studied by another group of investigators for electrical stimulation of the frontal and occipital eye fields. The operative procedure employed was similar to that described above. In 3 of the 5 monkeys, the reactive area for contralateral conjugate ocular deviation was excised. In each animal a piece of Vinyon “N” dural substitute was used to cover the exposed cerebrum. The edges of the dural substitute were tucked under the edges of the dura mater with or without one through-and-through anchoring stitch on each side (Fig. 1 C). After completion of the anastomosis of the dura mater and dural substitute in each animal, the wound was closed in layers with silk sutures.

Postoperatively, each animal was observed daily until the time scheduled to be sacrificed. The animals were sacrificed after 91, 91, 380, 428, 305, 327, 21, 35, 42, 49, and 365 days, respectively.

Before each animal was sacrificed, the operative wound was re-opened under anesthesia and the situation on the outer surface of the dural substitute was first examined. Then a large dural flap which included all of the anastomosed dural substitute was reflected. The line of anastomosis, the under surface of the dural substitute, and the condition of the underlying cerebral cortex were examined. Thereafter, the animal was killed by giving it a large dose of intravenous sodium amytal. In the first series of 6 animals, the brain and its coverings as well as the dural substitute were removed en masse and fixed in 20 per cent formalin solution. After the fixation, blocks of specimen were taken from the operated area and embedded in paraffin. Sections were cut at 8μ and stained with hematoxylin and eosin, and, in some cases, with the azocarmine, phosphotungstic acid hematoxylin, Nissl, Romanes (axon) and Mahon (myelin) technics. The requirements of the physiological experiments for which the second series of animals were primarily used, precluded microscopic examination of the tissues.

OBSERVATIONS AND RESULTS

CLINICAL OBSERVATIONS

In none of these 11 monkeys have postoperative convulsions been noted. There were no abnormal neurologic findings. All animals were active and appeared normal. The wound was well healed in 10 animals and was infected in 1 (second series, Animal 9).

PATHOLOGICAL OBSERVATIONS

Animal 1 was sacrificed 91 days after the operation. The periosteum of the inner aspect of the bone flap was thickened. The dural substitute appeared grossly normal. It lay in close contact with the underlying pia and brain, so that no cerebrospinal fluid was observed. It was very easily separated from the underlying cortex, revealing only a few delicate connecting strands along the line of suture between dura mater and dural substitute. Microscopically, the periosteal and dural tissues were entirely normal except at the point of the end-to-end anastomosis. Here, fragments of suture material were noted, surrounded by a few lymphocytes and foreign body giant cells. Similar cells were present in the dural substitute, extending along its entire length. Beneath this, much more delicate connective-tissue strands of the leptomeninges were noted which revealed only a minimal proliferation of arachnoid cells. The underlying cortex appeared entirely normal.
Animal 2 was sacrificed 91 days after operation. Reflection of the dural substitute left the cortex entirely smooth. Microscopically, the dura mater at the site of the anastomosis (end-to-end) was involved in a granulomatous process like that described for Animal 1, and this process extended into the dural substitute as well. The underlying leptomeninges were thin and delicate except for two small focal areas beneath the suture line, where moderate lymphocytic infiltration and moderate fibrosis were noted. The underlying cortex appeared entirely normal, including that beneath the focal areas of leptomeningeal change.

Animal 3 was sacrificed 380 days after operation. The dural substitute was in close apposition to the cortex, but was separated from it with ease except in one small focal area along the line of end-to-end anastomosis. Here, fibrous tissues were seen extending from the epidural space and the severed edge of the dura mater through the line of suture. The adhesions were dense and firmly attached to the underlying cortex so that separation resulted in tearing. Microscopically, the point of anastomosis (end-to-end) between dura mater and dural substitute revealed a moderate granulomatous reaction like that previously described. The dural substitute contained a small number of collagen fibers, but there was no inflammatory cellular infiltration. The leptomeninges showed no essential changes. The underlying cortex was entirely normal except for the small area immediately beneath the suture line, where an adhesion to the granulomatous tissue was noted.

Animal 4 was sacrificed 428 days after operation. The dural substitute was easily separated from the underlying cortex. Microscopic sections of the anastomotic area (end-to-end) revealed a granulomatous reaction like that described above. The adjacent segments of dural substitute were similarly infiltrated and there was a dense partially hyalinized connective tissue containing a few lymphocytes and a few pigment-containing phagocytes on its inferior aspect. The leptomeninges at this site were also involved, but those beneath the dural substitute at a distance from this site revealed almost no change. The underlying cortex appeared normal.

Animal 5 was sacrificed 305 days after operation. In this case, the dural substitute was used to cover a surgical wound in the cortex. The dura mater and dural substitute were sutured after eversion of the edges, as in Fig. 1 B. The dural substitute was reflected with ease, there being no adhesions at the site of the cortical lesion, or in any other area (Fig. 2). Microscopically, a granulomatous reaction was not ob-
served on the inner aspect of the junction of dura mater and dural substitute, where this covered the brain. The external aspect was infiltrated by mononuclear and lymphocytic cells. There were no adhesions between the dural substitute and the surgical wound, which was covered by fibrotic leptomeninges showing an arachnoid cell proliferation. The wound itself showed a loss of tissue, microglial proliferation and marginal astrocytosis (Figs. 3 and 4).

Animal 6 was sacrificed 327 days after an operation identical with that used for

![Image](image.png)

**Fig. 3. Animal 5.** The cortical wound with leptomeninges, above which is the layer of dural substitute (arrows). (A) Epidural fibrous tissue. (B) Cross-section of Vinyon “N” fibers. (C) Crator of cerebral wound. There is no meningocerebral adhesion nor fibrous capsule on the under surface of the dural substitute. Hematoxylin and eosin stain, ×26.

Animal 5. The dural substitute was easily removed, there being no adhesions at the site of the cortical lesion or in any other area. Sections through that portion of the everted anastomosis between dura mater and dural substitute in which silk sutures had been placed, revealed a small focus of granulomatous reaction like that described above. At a distance from the site of anastomosis, there were only a few collagenous fibers and no cellular reaction (Fig. 5) except at two small foci, one containing lymphocytes, the other a few foreign body giant cells. The leptomeninges were slightly thickened, but showed no inflammatory reaction except in one focal area, where a granuloma, which included giant cells, surrounded two fragments of bone wax. The cortex was entirely normal in this and adjacent areas. Sections through the brain wound, and its covering leptomeninges were inadvertently lost.
Fig. 4. *Animal 5*. Higher magnification of edge of cortical wound in Fig. 3, showing absence of meningoencephalic adhesions. (C) Crater of cortical wound, surgically produced. Hematoxylin and eosin stain, X86.5.

Fig. 5. *Animal 6*. Section through the dural substitute which had remained overlying a cortical lesion for 327 days shows minimal connective tissue on the under surface. (A) Epidural scars. Arrows indicate cross-section of Vinyon “N.” Hematoxylin and eosin stain, X86.5.
Observations on the second series of animals were limited to gross examination. There were no fibrous capsules about the dural substitute. There were no adhesions between the dural substitute and the cortex, including the 3 instances in which a cortical excision had been performed. In 1 animal, a wound infection with epidural abscess had developed, which extended to the outer surface of the dural substitute. When examined on the 42nd postoperative day, the inner aspect of the dural substitute was smooth, and not adherent to the underlying cortex which appeared normal.

**DISCUSSION**

A material to replace an excised portion of dura mater is not often required. However, it is necessary in craniocerebral lacerations, and in cases of leaking of cerebrospinal fluid through a wound connecting with the subarachnoid space. In the latter circumstance, an artificial dura mater would seal the opening and prevent leakage of the cerebrospinal fluid. In instances of penetrating craniocerebral injuries, an artificial membrane is desired primarily to reduce the incidence of meningoencephaloclastic and subsequent post-traumatic epilepsy. It is also desired to cover the cerebral wound after the excision of a meningoencephaloclastic scar which had caused seizures.

Heavy metals induce a fibrous reaction of varying thickness and with a varying intensity of cellular reaction, when used as dural substitute. These depend on the extent and character of corrosion.18 Chao et al.7 and Pudenz and Odom18 have made a comparative study of various materials used as dural substitute, such as Cargile membrane, fat, aluminum, and silver foil, mica, nickel and stainless steel plate, cellophane, fascia lata, plain catgut membrane, allantoic membrane, human amnion, vinyl alcohol film, amnioplastin and tantalum foil. All were unsatisfactory. Tantalum caused the least reaction concerning the formation of fibrous tissue.

Ingraham and Bailey11 in 1944 reported that fibrin film is easy to handle, translucent, flexible, and when used as dural substitute, was gradually replaced by a neomembrane of fibrous tissue without formation of meningoencephaloclastic adhesions. The absorption of the fibrin film was almost complete at 3 months and no film remained at 5 or 6 months after operation.

Similar results have been reported by Scheuerman and associates21 on gelfoam film as a dural substitute. It was absorbed in 40 to 70 days after inducing the formation of a thin fibrous capsule. Nevertheless, they stated that the inner layer was continuous with the intact dura mater, making it impossible to determine the point of regeneration. There were no adhesions between the newly formed dura mater and the cortex either in the intact or in the traumatized cortex. Microscopically they found no giant cell reaction. The chief objections to these two materials are their cost, the requirement for special storage and handling, and the difficulty in sterilization.

Polythene sheet4,5,10 has been described as the least irritating substance
among those nonabsorbable materials that have been tried as a dural substitute. Like fibrin and gelfoam film, it also caused the formation of a connective-tissue capsule, although it was thin and nonadherent to the underlying brain tissue. Its disadvantages are its nonmolding nature and its wide difference in tensile strength from the suturing material commonly used.

In our experiments with Vinyon “N” as a dural substitute, the observations were extended more than 1 year to be certain that they would reflect the ultimate degree of reaction. The evidence shows that this material placed intracranially in the monkey for a period as long as 428 days remained unabsoberd, and was comparatively inert. It did not induce the formation of a gross fibrous capsule. In 9 of the 11 animals, it completely prevented the formation of adhesions between the cortex and the overlying connective tissues even in instances in which a cortical wound had been surgically induced. In 1 (Animal 1), a few easily separable strands of tissue were noted. In the other (Animal 3) dense meningocerebral adhesions were found in one focal area along the line of end-to-end anastomosis of dura mater and dural substitute.

Microscopically, evidence of a granulomatous reaction was present about the silk sutures used to approximate the dura mater to the dural substitute, and in 2 animals this extended diffusely among the fibers of the dural substitute. In 2 other instances, fibrotic lesions were limited to that portion of the dural substitute adjacent to the anastomotic area, the distant areas being normal in 1, and showing only two small foci of inflammatory change in the other. In a fifth animal, the meshes of the dural substitute contained a few collagen fibers and inflammatory cells on its external, but not internal aspect. In the 2 animals of the first series in which a cortical wound was produced, the leptomeninges were thickened and fibrotic over the wound in 1, and most probably in the other, for which sections were not available. Other portions of the leptomeninges which lay beneath the dural substitute were entirely normal in 1, and normal except for a small focal granuloma surrounding fragments of bone wax in the other. In the 4 animals in which no parenchymal wound was created, the leptomeninges were entirely normal in 2, normal except for some granulomatous tissue beneath the anastomotic area in 1, and two small focal chronic inflammatory zones in the other. The neural parenchyma in all cases was entirely normal except for the surgical wounds produced experimentally.

These studies have shown that the method of dura mater-dural substitute anastomosis has a significant bearing on the formation of meningocerebral adhesions. Such adhesions were observed in 2 of the 4 animals in which the end-to-end anastomosis had been used. Connective tissues were seen extending from the epidural space through the suture line onto the underlying cerebral cortex in 1 of these. No such adhesions were noted in any of the other animals in which alternative methods of anastomosis had been employed. This suggests that these adhesions would have been avoided if the eversion or tuck-under technic (Fig. 1 B and C) had been substituted in
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these animals. Of these two latter technics, the tuck-under method is the simpler and is the one recommended for clinical trial in using Vinyon "N" cloth as a dural substitute.

SUMMARY

1. Vinyon "N," a synthetic material in cloth form, has been used experimentally in the monkey as a dural substitute. The period of observation was 21 to 428 days.

2. This material is relatively inert and nontoxic. It is not absorbed and has a tensile strength like that of China silk. It can be sterilized by boiling in water.

3. Various methods of dura mater-dural substitute anastomosis and their relation to the formation of meningoencephalic adhesions have been discussed. Meningoencephalic adhesions were found along the suture line in edge-to-edge anastomosis in 2 of 4 cases in which it was used. They did not occur in any case in which suturing was done after eversion of the edges, or when the method of tucking the edge of the dural substitute under the edge of the dura mater was used.

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REFERENCES


