REVIEW ARTICLE

Dura Mater Substitutes in Neurosurgery: A Review

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ABSTRACT

The outer layer of the meninges, known as duramater plays a critical role in protecting the brain. In cases where it is damaged due to head trauma or surgery there can be a risk of leakage that may have life threatening consequences. While suturing to repair the mater is not always feasible due to the potential for further leakage finding biomaterials capable of replacing the damaged dura becomes essential. During the 19th century initial attempts at using synthetic materials for dural replacement faced challenges as they were rejected by the immune system. However researchers have made progress by developing materials such as collagen based xenografts that undergo treatments to prevent adverse reactions. This review focuses on types of dural replacement materials, like autografts, allografts, xenografts and synthetics. It sheds light on efforts to find an ideal neurosurgical dural replacement material while also discussing associated challenges.
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INTRODUCTION

The dura mater, located as the outermost layer of the meninges, shares a close relationship with the internal tabula calvaria that safeguards the brain (1). This layer acts as a shield protecting the skull from the pulsations of the brain and helping to distribute pressure across the bones. Additionally, it helps regulate pressure changes, within the fluid surrounding the brain and spinal cord (2,3). Damage to the mater can occur due to head injuries or surgical procedures in the brain or spine leading to structural defects, in the dura mater (4).

These defects, in the membrane surrounding the brain are quite concerning and can potentially cause cerebrospinal fluid to leak, which can have severe and even fatal consequences. While using stitches to close the layer of this membrane is the best way to prevent cerebrospinal fluid leakage it becomes less feasible when surgeries involve removing or extensively damaging this protective layer. In cases relying on stitches becomes impractical (4,5). This highlights the importance of using a biomaterial to successfully substitute the dura mater and tackle these deficiencies.

The hypothesis of this article are duramater substitute will give benefit for neurosurgery practice. This article objectives are give a comprehensive review of the dural substitutes, starts from the development history of dural substitutes. It will be followed by the applications of this substitutes in daily neurosurgical practices nowadays.

METHOD

We conducted an unrestricted literature review in Pubmed, disregarding publication timeframes, and employed keywords ((((((Artificial Dura[Title]) OR (artificial dura mater[Title])) OR (artificial dura substitute[Title])) OR (dural substitute*[Title])) OR (surgical management[Title])) OR (watertight duraplasty[Title])) AND (((((((cerebrospinal fluid leak*[Title]) OR (complications[Title])) OR (cranial surgery[Title])) OR (neurosurgery[Title])) OR (outcome[Title])) OR (postoperative[Title])) OR (skull fracture[Title])) OR (traumatic brain injury[Title])); PubMed reported 831 findings.

Furthermore, we undertook a manual exploration and identified a total of 12 articles. Subsequently, we excluded articles authored in languages other than English, those addressing unrelated subjects or featuring inappropriate variables, as well as duplicates. Consequently, for the purpose of our analysis, we meticulously examined 25 papers that met our eligibility criteria, focusing on delineating dural substitutes in the context of neurosurgery. The visual representation of these literature findings is presented in (Fig. 1) via a flowchart.

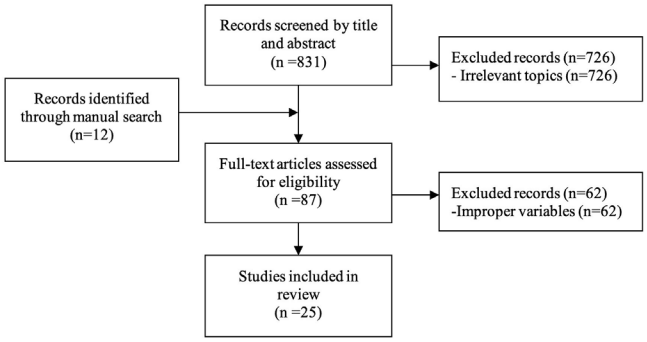

Figure 1: Flowchart illustrating the process of the literature review

DEVELOPMENT HISTORY OF CURRENTLY AVAILABLE DURAL SUBSTITUTES

The History of Dural Substitute

The observation and awareness of dura mater defects and its deadly serious complications had been already noted since centuries ago. Many techniques have been postulated to prevent this condition, but the development of dural substitute starts with the development of modern neurosurgery, on the end of 1800s (6).

In the 19th century many surgeons discovered that surgical treatments for traumatic epilepsy caused by scarring from brain injuries were ineffective if there was still a defect in the dura mater. As a result different methods were proposed to address this issue by inserting materials into the damaged dura mater. This marked the beginning of using substitutes for dura mater as seen with Beach usage of gold foil in 1893 (Beach, 1893) and Robert Abbes' use of rubber in duraplasty procedures in 1895. (Abbe, 1985). Initially there were attempts to use sheets of inert metals like gold, silver and platinum. Others also experimented with metallic grafts such as gutta-percha or celluloid sheets. These initial efforts didn't make results because the body rejected these foreign materials through various mechanisms, including connective tissue infiltration causing sheet deterioration and the formation of strong adhesions, between the brain and surrounding tissues (7,8).

Furthermore choices were made in categories such, as autografts, allografts, xenografts and synthetic materials. This pursuit of enhanced sophistication remained a consistent theme following surgical interventions (5). Ideally, grafted autograft tissues including periosteum, temporal fascia, fascia lata, or galea can be substituted for dura mater lesions (9). This previous similar research are conducted by Berjano (1999) about review of autografts, allografts, xenografts and nonabsorbable in neurosurgery practice. But this research, we review the newest literature about this topics (9).

Prior investigations involving the application of biological elements for xenograft transplants have been previously undertaken. Freeman (1908) and Saar (1911) conducted studies on dogs and rabbits where they investigated the use of an egg membrane to correct a deficiency in the dura mater. Their research revealed the formation of a tissue capsule that resembled dura mater tissue histologically. This capsule showed potential in preventing adhesion formation long as the underlying membranes and cortex remained structurally intact. However when there was damage to the tissue layers adhesion occurrence became more likely. It's important to mention that this foreign material was prone, to rejection, which sometimes led to infectious complications (10,11).

Zaidi et al. (2011), in their scholarly investigation, delved into the research conducted by Harvey Cushing in 1912 (12). Cushing used a technique called grafting to treat a gap, in the protective covering of the brain in an 18-year-old female patient. This patient had been suffering from recurring seizures for 12 years following a brain injury. Despite the questionable functionality of that procedure, Cushing pioneered this procedure and to date, fat grafting have then become the staple of CSF leakage, mainly in post-transphenoidal procedures (12). It is, however, not routinely utilized for transcranial procedures of dura defect repair, as it was originally devised by Cushing.

Research conducted in the 1970s showed that when fascia is grafted it leads to a strong fusion between the brain tissue and the surrounding tissues in animal experiments. This fusion has the potential to increase vulnerability to epilepsy. Additionally further experiments revealed limitations of using unrestricted autograft procedures. For example, obtaining transplant material for autografts takes extra time thus prolonging surgery. Moreover, these transplants are often absorbed by tissues and trigger a response from them resulting in the formation of adhesions and scar tissue that connects the brain tissue with the structures above (13).

Advancements in fixing dura defects were influenced by new discoveries in chemistry and physics which coincided with the rapid growth of the chemical industry from the 1960s to the 1980s. Improvements in biological tissues preservation opened up opportunities to obtain larger quantities of materials suitable for potential plastic surgery with longer storage periods. Several

methods, such as formalin treatment, lyophilization and freezing were suggested to achieve this goal. Among these options lyophilization became the approach, for conserving cadaveric dura mater tissues (11,14).

This preservation method was discovered to not retain the physical structure of grafts but also safeguard the integrity of their DNA and RNA. These are elements for cell division and the successful integration of grafts. The use of freeze dried tissue showed toxicity and gradual breakdown after transplantation eventually leading to its replacement, with recipient connective tissue that closely resembled dura mater tissue (15). However even though these promising qualities exist there are challenges when it comes to actually implementing such implants. These challenges include immune responses from the recipients legal complications related to obtaining dura mater from deceased donors the risk of transmitting diseases like HIV, hepatitis, syphilis and prion infections as well, as the technical difficulties posed by the unique shape and small size of defects that need to be closed during transplantation (16).

Due to the constraints of the methods mentioned earlier researchers started exploring materials, which eventually resulted in the creation of xenografts (17). These grafts are made from animal collagen of type I, which has been treated to reduce the chances of reactions in recipients. The main sources, for transplants include cow pericardium cow Achilles tendon, fetal cow skin, pig small intestine tissue and horse collagen. This approach has emerged as a solution to overcome the limitations of methods by providing materials that can be better integrated into the recipients body while minimizing immune related issues (18,19).

Among the trials that were examined two studies focused on using variations while seven studies chose to use xenografts and five studies utilized allografts in dural substitution procedures within the human brain. It is worth noting that xenografts, those based on collagen-based materials were prominently utilized in these investigations. These xenografts demonstrated advantages, including the absence of short term systemic and local complications, their ability to act as a scaffold for the formation of endogenous neo dura mater (the brains protective covering), easy application and effectiveness, as a mechanical barrier to prevent the leakage of cerebrospinal fluid (CSF) from outside (5). Despite this variability, the limitation of some materials usage including autograft were commonly low supply and comorbidities of the harvest site. Other previously materials were used is xenograft. These materials are not commonly used due to the unwanted adverse effects such as allergic reactions of the foreign body and graft degradation. These factors contribute to restriction of the usage of these materials (20). The timeline of dural substitute developmental history is described in (Fig. 2), whereas the resume of dural substitute materials and their characteristics described in table I.

Late 1800s	• Surgeons notice scars from dura defect in TBI lead to epilepsy • Attempts to repair defects using inert metals (gold, silver, platinum) and noon-metallic grafts (gutta-percha, celluloid plates)
Use of biological materials for dural substitute; egg film	1900s
1910s	• Harvey Cushing utilized fat graft for dura defect in a patient with post-TBI (7) recurrent seizure • Wide fascia of the thigh for autograft dural replacement
Dandy pioneered the use of autologous fascia lata (9)	1920s
1950s	The use of freeze-dried human-cadaveric allogenic dura mater (10)
New discoveries in chemistry and physics lead to subsequent development of plastic repair of dura mater defects	1960s
1970s	• Studies highlighting the occurrence of cicatricial fusions between the brain and overlying tissues in fascia grafting
• Neuro-Patch membrane by B. Braun, Germany, made from microporous non-woven highly purified polyester urethane for rapid infiltration of connective tissues • Reperen; a synthetic material used for medical practice in USSR	1990s
2000s	FDA approval of poly (lactic-co-glycolic acid) (PLGA) for dural substitute with its proper degradability and watertightness (11)

Figure 2: Timeline of dural substitute developmental history

The Ideal Dural Substitute and Recent Developments

Recent developments gave several appropriate options for dural substitute for neurosurgical patients. The ideal dural substitute should be able prevent CSF leakage, prevent troublesome adhesions, anchor, be resorbed and replace host tissue, be vascularized for longevity, and have lower risk of infection and inciting foreign body reactions (21). Alternatives to human dura include silicon-coated Dacron, reconstituted collagen foil, expanded polytetrafluoroethylene porous material, bioabsorbable polymers, and nonabsorbable Neuro-Patch. On the other hand, there have been promising results observed in animal studies with newly developed biomaterials. Some examples of these materials include constructs made of glycolide-co-lactide)/type I collagen/ chitosan knitted fabric made of cellulose and dural substitutes derived from pericardium obtained from horses or cows (22). Each material variant presents its distinct set of advantages and drawbacks. Autograft materials offer advantages, including compatibility with the body, easy availability and cost effectiveness. However, obtaining these materials often requires larger incisions, which can bring about surgical risks as well as

Table I: Varieties of materials used as replacements for the dura mater and their distinct attributes (9)

Material	Description	Advantages	Disadvantages
Autologous	Utilizing the patient's own resources, materials like the periosteum of the skull, fascia lata, cap aponeurosis, or fascia from the temporal muscle can be gathered before or during the procedure to mend the dural defect.	Efficiently circumvent the potential for immune rejection, transmission of pathogenic microorganisms, and also help in curtailing medical expenses.	Due to its constrained dimensions and configuration, it is not appropriate for addressing extensive dura defects.
Allogenic	Lyophilized dura mater from human cadavers	(progressively becoming less favored due to its drawbacks)	Elevated likelihood of complications including progressive cognitive decline, seizures, and distinct clinical manifestations, notably a particular variant of Creutzfeldt–Jakob disease known as dura mater graft-associated CJD (dCJD).
Xenogenic	Porcine, bovine, equine, and other animal tissues are employed to create dural substitutes, with the most frequently utilized type of dural substitute being derived from these sources.	Preserves the integrity of fibrous scaffolds within the extracellular matrix of animal tissues, offering a conducive microenvironment for the regeneration of the dura mater. This favorable environment is facilitated by the intricate network of crisscrossing collagen fibers.	Certain researchers hold the viewpoint that the utilization of animal-derived substances like bovine or porcine tissue could potentially elevate the risk of transmitting diseases.
Synthetic	Expanded polytetrafluoroethylene and polyurethane are examples of nonabsorbable dural substitutes. On the other hand, absorbable options include polyglycolic acid (PGA), copolymers of L-lactic acid and epsilon-caprolactone, as well as copolymers of lactide and polydioxanone.	Modifying the proportion of lactic acid to glycolic acid (PLGA) allows for the modulation of degradation speed and water impermeability.	Considered absorbable; however, their degradation process can be challenging and may trigger foreign body reactions. In contrast to collagen-based dural substitutes, they do not possess the biological capabilities to stimulate cell migration or facilitate the secretion of associated cytokines.

postoperative pain and discomfort. Moreover, the range of options is extensive. The process of harvesting can be inconvenient for the patient.

Bolly et al. (2020) identified five aspects to consider when choosing the best material for a dural substitute (5). These aspects include: 1.) physical characteristics, 2.) safety in terms of response 3.) support for the natural healing process of the dura 4.) economic. 5.) clear indications in the product regarding prevention of complications (Table II). Based on these factors an ideal dural substitute should have no impact on the immune system maintain sterility to prevent infections from spreading be readily available when needed, not cause any adhesions, with brain tissue or cranial bones be cost effective and encourage the natural regeneration of the original dura.

Previous studies reported the efficacy of these so-called xenografts. Synthetic dural substitute such as Cerafix and biomaterials such as bovine-derived pericardium have proven to be successful in preventing complications of craniectomy such as CSF leakage (22,23), despite the discrepancies in the scale of these corresponding studies. The best, or 'most ideal' dural substitute is still yet to be elucidated, and future larger scale of studies to help determine the answer to this is needed. It may also be necessary to determine choices like this in an individualized manner, suited to every patient and conditions.

APPLICATIONS OF DURAL SUBSTITUTES IN NEUROSURGERY

Defects with dura mater may cause leakage of

Table II: Aspects of the ideal duraplasty material (5)

Aspect	Ideal attribute	Aspect	Ideal attribute
Physical Characteristics	• Ability to match suitability and size requirements • Secure • Doesn't require suturing • Doesn't bind to brain tissue or bone • Resistant to tearing during suturing • Easy handling • Watertight • Strong • Maleable	**Economic Aspect**	• Cost effective or cheap • Ready stock/availability
Immunological Safety	• Immunological inert • Non-toxic • Sterile: incapable of spreading infectious agents • Non-carcinogenic	**Prevent Post Duraplasty Complications**	• Prevent leakage of cerebrospinal fluid (CSF) • Prevent additional complications (seizures, fibrosis, hemorrhage) • Prevent the formation of CSF fistulas
Contribution in Native Dural Healing Process	• Biodegradable • United with native dura • Stimulate native dural development		

cerebrospinal fluid (CSF) that can be life threatening. The effective approach to prevent CSF leakage is typically suturing the dura mater; however this may not always be possible if the surgery involves complete removal or significant damage, to this protective layer (24). After taking these factors into account it becomes evident that a significant quantity of material is necessary to replace the mater and successfully seal the defect. (25). In order to close the defect in the dura mater, such neurosurgical procedures involve a duraplasty. The destruction of the initial dura mater in cases of trauma or cancers, enlargement of the dura mater compartment in cases of Arnold-Chiari malformation, reconstruction operations for dura mater fistula, and surgery involving dura mater graft such as Myelomeningocele are some of the cases that involve duraplasty (26).

In order to cover the dura mater defect, the duraplasty treatment requires a subtitute or graft. Many forms of graft biomaterials, including autograft, allograft, and xenograft, are used as a replacement for dura defects from biological sources (26). In situations after undergoing a decompressive craniectomy it may not be necessary to repair the damaged dura. This can often result in decompression outcomes, shorter hospital stays and increased cost effectiveness, for patients. In fact, in some underdeveloped countries, this technique is still commonly used. Ever more research help the sealing of the faulty dura with various biomaterials (22).

Dural Substitutes in Traumatic Brain Injury

Traumatic brain injury (TBI) is a condition that can result in symptoms and disorders. Unfortunately it can lead to fatalities, in our population among individuals aged 1 to 45 (22). Patients often experience types of brain injuries such as concussions, subdural hematomas and subarachnoid hemorrhages (27). When assessed using the Glasgow Coma Scale (GCS) individuals who have suffered brain injuries often require intervention. Decompressive craniectomy has emerged as a procedure aimed at reducing pressure inside the brain (ICP) and enabling medical treatments within the cranial region (28). It is a used method for treating brain injuries (TBI). In some cases patients may encounter challenges with the layer of tissue called the mater due to surgery or the injury itself. In situations the affected area can be left uncovered or repaired using alternative materials as substitutes, for the dura mater (29). The exposed compromised area can be addressed by utilizing substitute materials (22).

Decompressive craniectomy (DC) has shown efficacy in addressing intracranial hypertension. It is an employed technique in the field of neurosurgery and holds a significant place, as a frequently utilized method (30). The inadequate procedure in cranioplasty will lead to many problems as too dense flap will inevitably lead to dura rupture, and too thin flap can certainly lead to inadequate blood circulation in it and even rupture during shedding, and flap stripping may produce broad indirect pressure to the brain tissue, leading to cerebral contusion, subsequent intracranial hemorrhage, epilepsy, and so on (31).

In a study involving 195 patients who had suffered a brain injury (TBI) underwent a medical procedure called decompressive craniectomy. During this process an artificial material known as dura material (ADM) made from freeze dried bovine pericardial membrane was used for restoration purposes. Throughout the study close monitoring was done on the patients symptoms, which included hematomas, seizures, brain infections, leaks and reactions of fluid (CSF) to certain substances. The findings revealed that patients who received ADM experienced difficulties compared to the control group who did not undergo dural repair, after decompressive craniectomy (22)

On the other hand, a study conducted by Vieira et al. (2018) compared the results of using water-tight duraplasty versus standard duraplasty in a randomized controlled trial, included 58 participants had no significant differences between the two groups. This suggests that both techniques produced outcomes. When it comes to decompressive craniotomy achieving watertight dural closure alone is not possible in its design. If watertight dural closure is attempted during a decompressive craniotomy some form of graft or artificial material (like pericranium or fascia lata) would still be needed. These grafts are used to prevent fluid leaks and contamination, at least from a technical standpoint (30). Another study involving the dural substitutes in traumatic brain injury was elucidated by Wang et al. (2014) which used the suturing-free dural substitute in 23 patients. This research investigated the consequences of using a substitute, which resulted in saving time during the first step of decompressive craniectomy by eliminating the need for sutures that require tension. Additionally in the following phase the lack of adhesion within the duraplasty made it easier to remove the preserved temporal muscle resulting in fewer noticeable complications, post-surgery (31).

Dural Substitute in Brain Tumor Surgery

Duraplasty often involves the use of materials like expanded polytetrafluoroethylene (ePTFE) polyglycolic acid (PGA) or collagen matrix. However there can be complications associated with using artificial dura substitutes, such, as an increased risk of postoperative bleeding compared to a complete craniotomy after removing a brain tumor (29).

Previous study by Centonze et al. (2016) showed different result following duraplasty in meningioma. This study included 8 patients affected by intracranial meningioma who has undergone tumor excision prior to dural reconstruction with equine-derived heart membrane. The specific alternative, to the material was

known for its excellent ease of use as it could be stitched effortlessly using common materials (32). Similar findings were founded in Biroli et al. (2008) which observed the duraplasty in 114 patients who were undergone variety of neurosurgical procedures especially in tumor cases. The novel collagen-derived dural materials were used. Postoperative scans with magnetic resonance imaging showed only one patient who did not demonstrate signs of severe inflammatory response. There was no clinical symptoms or neurological disorder that have been postoperatively. According to the findings of this research the dural substitute seemed to encourage significant regrowth of the dura leading to minimal or no adhesions, between patients and surrounding tissues. Moreover the study also discovered the presence of the brain cortex (33).

Dural Substitute in Vascular Surgery

Over the years microvascular decompression (MVD) has become a recognized surgical method for treating trigeminal neuralgia (TN) hemifacial spasm (HFS) and other cranial nerve related conditions. The goals of this procedure have evolved with advancements, in technology and medical knowledge resulting in improved safety and dependability. The study was conducted by Li et al. (2005) investigated the clinical application or dural substitute following microvascular decompression surgery. There were 103 patients underwent dural substitute using finely fibrillar, microporous, non-woven material manufactured from a special high purity polyester urethane which is aimed to prevent postoperative leak. The outcome was satisfying with no CSF leak found in dural substitute group whereas the leakage was found in group not receiving dural substitute. According to this study using a substitute during microvascular decompression seems to be a reliable and effective approach, for preventing the leakage of cerebrospinal fluid (CSF) (34).

Another value of dura patches was presented by Aurel et al (2016). The case revolves around a patient who's 32 years old and had multiple injuries in a car accident approximately 10 months ago before they arrived at Bucharest Sanador Hospital. The patient has been experiencing an issue of slight watery discharge from their left nasal cavity. Around a month after the accident the patient went through an episode of meningitis, which was treated using antibiotics and several lumbar punctures over a period of two weeks. Both CT scan and 3D CT evaluations revealed that there is a deviation in the nasal septum caused by trauma and also a fracture, in the cribriform plate. In addition MRI imaging showed that there is a herniation of the surrounding brain tissue (35).

To address the issue the patient underwent a procedure using an approach from inside the skull (intradural left fronto basal approach). This method was chosen because previous attempts through the nose using an endoscope did not yield results according to ENT specialists assessment. During the surgery a fracture was found in the ethmoid bone and repaired using fibrin glue and dural substitutes. The surgery went smoothly without any complications and a CT scan conducted 24 hours later showed that the fluid (CSF) leakage was successfully closed, with no indication of fluid buildup, in the ethmoidal cells (35).

Dural Substitute in Pediatrics

Dural substitute in pediatric case was reported by Hayashi et al. (1997) The case pertained to a man who is 21 years old and has a past medical history of a head injury he suffered when he fell from the second floor at the age of 1 year and 8 months. One notable outcome of this childhood head injury is the development of a skull fracture that has been progressively growing. When it comes to treating growing skull fractures, procedures like duraplasty and cranioplasty are crucial components, in their management. However, the selection of appropriate materials for cranioplasty remains a subject of debate. The scalp in the region of the fractured shown a swelling and the imaging presented the fracture had widened 3 months following the accident. Cranioplasty were performed with dural substitute which methyl-methacrylate (MMA) material was used. This study conducted to present the 19 years follow up following the cranioplasty. CT-Scan and 3-D CT has shown the growth of the skull was great and MMA had adapted smoothly. This could be indicated that MMA had not prevented this patient's own skull form growing naturally (36).

Esmaeili et al. (2012) documented complications linked to the use of a dural substitute in a young patient. The case centered around a 7 year girl who underwent surgery to treat a specific type of brain tumor called posterior fossa midline pilocytic astrocytoma. After regular follow up MRI scans indicated no recurrence of the tumor the patient began experiencing headaches and vomiting two years later. Brain CT scans revealed bleeding in the area where the previous surgery took place near the lining of the mater and close to an enlarged ventricle. Despite subsequent MRI scans with contrast dye not detecting any tumors or abnormal blood vessels the patient had three instances of bleeding within four weeks. These episodes were accompanied by symptoms of hydrocephalus (buildup of fluid in the brain) and an expanded blood clot (hematoma). To address this external ventricular drainage was performed initially followed by ventriculo peritoneal shunting to alleviate hydrocephalus. Further imaging techniques such as brain MR angiography and digital subtraction angiography did not reveal any abnormalities in blood vessels. During exploration the previous surgical opening in the skull was reopened, exposing a patch on the side that adhered to the cerebellum, with small abnormal vessels that were cauterized during the procedure. The synthetic graft previously utilized was also addressed.

The defect in the covering (dura) surrounding the brain was repaired by using tissue from the cervical fascia. When examining the ventricle different stages of hematoma were found no abnormal blood vessels were present. The recovery, after surgery went well without any complications. During the two year follow up period there were no instances of bleeding observed (37).

In another instance there was a case involving a 6 month baby boy who had to undergo surgery for a significant mass located in the middle of the back part of his brain, known as the posterior fossa. The doctors determined that it was pineoblastoma. Although chemotherapy was recommended the parents decided against it. Instead opted for regular MRI scans to monitor the situation. The first few follow up MRIs, conducted at 3 and 6 months after the surgery showed results. However at the 9 month mark after surgery an MRI revealed a mass with increased contrast in the area where the operation took place. It looked similar to a recurring tumor in that location beneath the membrane covering the brain (subdural). Another MRI performed 3 months confirmed that there was indeed a new mass growing near the pineal gland. To address this issue another surgical procedure was performed through the opening used previously to remove an artificial patch made of synthetic material that had become thickened over time along with surrounding tissue inflammation and scarring (fibrosis). The examination of this mass under a microscope showed no signs of cancer cells but rather evidence of inflammation and fibrosis. Moreover during this operation, they also removed another mass near the pineal gland which turned out to be pineoblastoma. Enough it seemed that there was an elevated risk of bleeding associated with a specific type of material called silastic used during previous surgeries near important areas like ventricles (fluid filled spaces) close, to where this patients fourth ventricle is located as well as around his prior surgical site. This increased risk might be connected to formed small blood vessels that were discovered during this second operation where parts of his cerebellum were found adhered or stuck together with this artificial patch made from silastic. These tiny vessels could not be detected using MRA and angiography. Their susceptibility, to bleeding was eliminated by cauterization and graft removal. (37).

In the patient mentioned there was an invasion of cells into the dural substitute patch. This resulted in the formation of a mass that looked like tumor recurrence in imaging studies. Both malignant and inflammatory cells infiltrated the patch leading to changes in the surrounding environment. Fibroblasts, which are known to produce substances that cause inflammation played a role in this process. Additionally pre-existing bleeding, infection and cortical laceration further contributed to inflammation and fibrosis. These combined factors potentially led to the development of a mass, at the site where the previous dural repair was done (37).

FUTURE DEVELOPMENT OF DURAL SUBSTITUTES

The need of dural substitutes that is biocompatible and safe to use is increasing given the collision which occurred in traumatic brain injury at any time may cause direct trauma and tearing of the dura mater. Dural tear which not treated immediately will lead to poor outcome. Various studies have been conducted to investigate the materials that are biocompatible for dural substitutes. However, to date, there are still many challenges in creating the latest dura mater, including limited materials which are biocompatible and safe for use.

One of the most used materials for dural subtitute is bacterial cellulose given its widely known role for membrane applications. Various studies have shown its eligibility as potential artificial duramater (38,39). According to Espositos research it has been shown that using a collagen biomatrix made from horse tendon as a dura mater is a safe and effective alternative for common neurosurgical procedures. The study observed this method over a period of 5 years. Found no instances of delayed complications or any negative effects, on the local or overall health of the patients (40).

Poly (L-lactic acid-co-glycolic acid-co-ε-caprolactone), a different substance has shown promise in preventing the leakage of cerebrospinal fluid. This material is designed to be absorbed by the body within a month reducing the chances of any negative effects, from implanted materials (41). Silk fibroin, a component of silk protein has been used as a surgical suture because of its compatibility with the human body and its ability to minimize inflammation. While not extensively studied as a substitute for the covering around the brain (dura mater) research on rats that underwent skull surgery suggests that silk fibroin shows great potential in this regard. Nonetheless additional evaluations are necessary to determine its practicality, in settings (42).

A detailed study conducted on the use of cow derived pericardium membrane as a material for dura mater has shown its suitability and compatibility as an alternative, to natural dura mater. The research findings indicate that this material leads to clinical results when used for replacing the dura mater (22). In a study conducted by Takeuchi et al., new and innovative models of dura mater were created using a multi layered design that combines a rubber material (which imitates the elastic component of the dura mater) with a fiber sheet (which mimics the fibrous component of the dura mater). These artificial dura mater models were specifically designed to be integrated into a brain surgery simulator for trans nasal pituitary surgery. The mechanical properties of these models were thoroughly examined to ensure they closely resemble real porcine dura mater. Parameters such as stress, viscoelastic behavior and the force required for incision using micro-scissors were carefully

assessed to determine how well these fabricated models functioned. The results, from these evaluations indicated that the developed dura mater, made up of acrylic rubber and two distinct non-woven fabrics exhibited properties that accurately replicated human dura mater characteristics within surgical simulations (43).

CONCLUSION

The use of materials to replace damaged dura in neurosurgery has become widely accepted and provides significant advantages in addressing the impact of dura defects. In this review we explore the various applications of these substitute materials in different areas of neurosurgical practice. However it is important to acknowledge that each dural substitute material available has its own limitations. There is a drive to enhance these substitutes leading to the development of newer generations of materials. It is expected that innovative solutions, for dural substitutes will emerge in the near future as efforts continue in this quest. Future clinical research in wider population are needed to evaluate the efficacy, complication in each material of dural substitute.

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