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CASE REPORT

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Postmortem Analysis of Anastomotic Suture Line Disruption Following Carotid Endarterectomy

ABSTRACT: The tensile strength of a surgical suture is essential in maintaining the integrity of vascular anastomoses. While faulty operative technique and the loading strength of individual sutures have been implicated in spontaneous suture line disruptions, there has, to date, never been a published postmortem analysis of a suture that has known to have failed. We present the case of suture line disruption leading to fatal exsanguination in a 77-year-old man following carotid endarterectomy with a facial vein patch. Using both dissecting and scanning electron microscopy, we determined that surgical technique (an untied knot) was the cause of the suture line disruption. The removal of a broken or untied suture at surgery or at autopsy should not preclude proper analysis of the failed suture, because the results can have both medico-legal and public health implications.

KEYWORDS: forensic science, forensic pathology, suture, polypropylene, carotid endarterectomy, anastomosis, postmortem, autopsy

Surgical sutures are relied upon for the re-approximation of incised tissues. Suture tensile strength is essential in maintaining the integrity of vascular anastomoses, which are subject to pulsatile pressures from within the vessel. Failure of such an anastomosis can lead to disastrous consequences. Suture line disruption can result in acute hemorrhage or delayed pseudoaneurysm formation (1,2). While faulty operative technique, including improper handling of suture material or the choice of suture used, has been implicated in suture line disruption after arterial repair, other physical factors, such as flexion, extension and rotational forces on the surgical site, have also been theorized to be contributory (3,4).

Failure of a suture to maintain an anastomosis may result from untying of a knot or from breakage of the suture itself. Regardless of the number of throws, it is widely recognized that a squared surgical knot is far superior to a granny knot or sliding half-hitch, and that the latter are more likely to slip and untie (Fig. 1) (5). Several studies have examined various surgical knotting methods using laboratory models to approximate the in-vivo forces on an anastomotic suture line (6,7). Though case reports have suggested that polypropylene sutures may spontaneously fracture after arterial repair, the in-vivo studies have clearly demonstrated that the 6-0 polypropylene suture material has an inherent tensile strength which is orders of magnitude greater than is necessary to withstand arterial forces (6,8–12). The overarching conclusion of these studies is that spontaneous suture line disruption is most likely related to suture injury during handling, lowering its tensile strength (13).

We present the case of a suture line disruption leading to fatal exsanguination in a 77-year-old man following carotid endarterectomy with a facial vein patch. As part of the public health role performed by the medical examiner's office and in compliance with the requests of family, hospital and the suture manufacturer, we performed a detailed analysis to address the question of whether the suture or the surgical technique was at fault. Based on the results of a complete autopsy followed by dissecting and scanning electron microscopy, we determined that an untied knot was the cause of this suture line disruption. To date, there are no reports published in the literature that describe the utility of such an analysis after the death of a patient.

Case Report

A 77-year-old white man with a history of hypertension, coronary artery disease, remote myocardial infarction status post coronary angioplasty, peripheral vascular disease and chronic renal insufficiency underwent a carotid endarterectomy for high-grade stenosis of the right carotid artery. Under general anesthesia, the endarterectomy was performed and a right facial vein patch was placed using a double armed, #6-0 Prolene suture. A Jackson-Pratt drain was laid adjacent to the surgical site and the overlying skin was closed. The procedure was performed in 2 h 35 min and total anesthesia time was 3 h 25 min. There was minimal blood loss and the patient awoke without signs of neurologic deficit.

In the immediate post-operative period, the patient was normotensive. Approximately 18 h after surgery, however, he awoke from sleep agitated and demanded to get out of bed. While nursing staff and physicians tried to calm the patient, blood was noted to "gush" from the operative site, rapidly soaking his bandages. The patient was intubated, pressure was applied to his neck and he was rushed back to the operating room, where he expired. An autopsy, requested by the patient's family, was performed at the Office of Chief Medical Examiner in New York.

At autopsy, there was a 1 cm defect at the antero-medial aspect of the sutured anastomotic line. One suture end was coiled and the other was straight, while the vein graft borders were smooth (Fig. 2).

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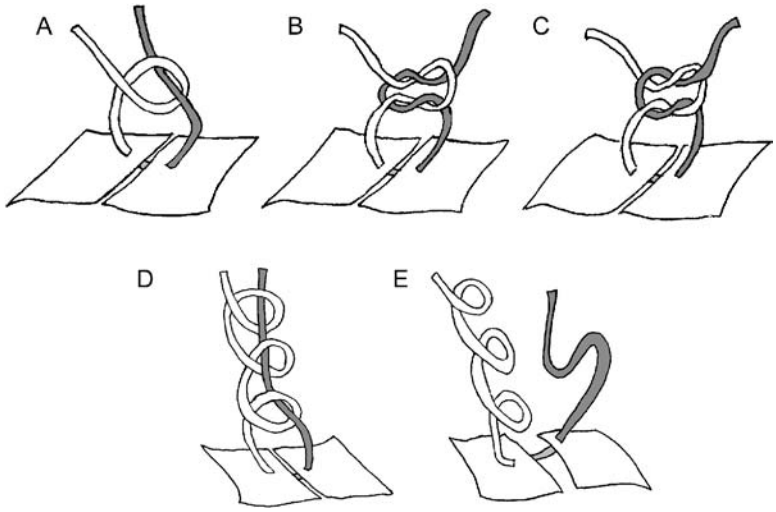

FIG. 1—*Surgical knots. A. Half hitch. B. Square knot. The half hitch is laid flat and an opposite half hitch is set above it. This knot is secure. C. Granny knot. The half hitch is laid flat but an identical half hitch is set above it. This knot is not secure and with tension on one end it can easily slip and become a series of stacked half hitches (D). D. Stacked half hitches. E. Stacked half hitches unraveling.*

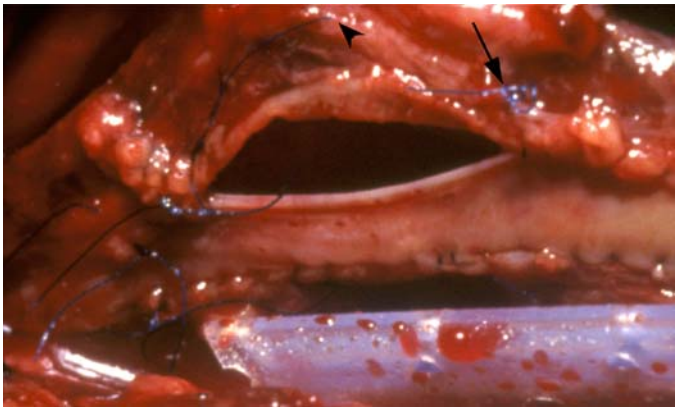

FIG. 2—*Autopsy photograph of disrupted anastomotic line. Note that the cranial suture end (arrowhead) is straight and the caudal end (arrow) is coiled. The edges of the vein graft and carotid artery are smooth.*

There was soft tissue hemorrhage surrounding the carotid sheath, extending down to the aortic arch and into the posterior pharyngeal space. The patient had marked hypertensive and atherosclerotic cardiovascular disease. Focal scarring of the left ventricular myocardium was consistent with a remote, inferior wall myocardial infarct. The cause of death was certified as hemorrhagic complications of carotid endarterectomy for treatment of atherosclerotic cardiovascular disease. The manner was classified as a therapeutic complication.

The larynx and trachea, including the adjacent soft tissues, right carotid artery and surgical site were removed en-bloc and placed in 10% formalin. Further evaluation of the surgical site and suture tips were performed at Mount Sinai Hospital, New York, using dissecting and scanning electron microscopy.

Methods

Both dissecting microscopy and scanning electron microscopy were utilized to evaluate the surgical specimen. A Nikon SMZ-10 binocular dissecting microscope attached to a Morrell MI-10 fiber optic illuminator was used to evaluate and photograph the disrupted suture as well as other sutures adjacent to the anastomotic line.

For scanning electron microscopy, suture tips from the disrupted anastomotic line and from elsewhere on the specimen were carefully removed and oriented. For comparison, several #6-0 Prolene control sutures were removed directly from the manufacturing package and were alternately cut with a scalpel blade, surgical scissors or were manually broken. An additional control suture was prepared by "popping off" the suture needle from the end of the suture. Each suture tip was mounted to an aluminum stub with silver paint. The stub was placed in a sputter coater and a very fine layer of gold-palladium was put on the suture. The suture was then viewed with an S530 Hitachi scanning electron microscope at 15 kV.

Results

Inspection of the specimen under the dissecting microscope confirmed the appearance at autopsy. At the antero-medial aspect of the anastomosis, between carotid artery and vein patch, there was a 1 cm open defect, associated with extensive hemorrhage into the soft tissue. The running suture line on the postero-lateral aspect of the vein patch anastomosis was intact. At the defect, two suture tips were identified: one at the cranial end of the defect and one at the caudal end. The cranial suture end was straight and the caudal suture end was tightly coiled. There was no knot on either side, nor were any loose suture fragments identified. The appearance of the two loose suture ends and the complete absence of a knot or additional pieces of suture, suggesting a break, were consistent with a knot that had untied or slipped. The smooth edges of the vein graft and carotid artery confirmed that the tissue itself didn't fray or tear.

Further examination of the specimen under a dissecting microscope demonstrated that other suture knots from the specimen, some involving vascular ligatures and others involving a distant line of interrupted sutures, were tied in stacked granny or half-hitch configurations. There were, on average, 3–5 throws to the stacked knots and they all had the appearance of one suture wound or coiled around the other (Fig. 3*A*). Several of these interrupted sutures were in various stages of untying, with one that had completely untied but had not yet pulled through the tissues (Fig. 3*B*). High power appearance of the suture ends at the anastomotic line under the dissecting scope demonstrated the coiled caudal and straight cranial tips (Figs. 3*C* and 3*D*).

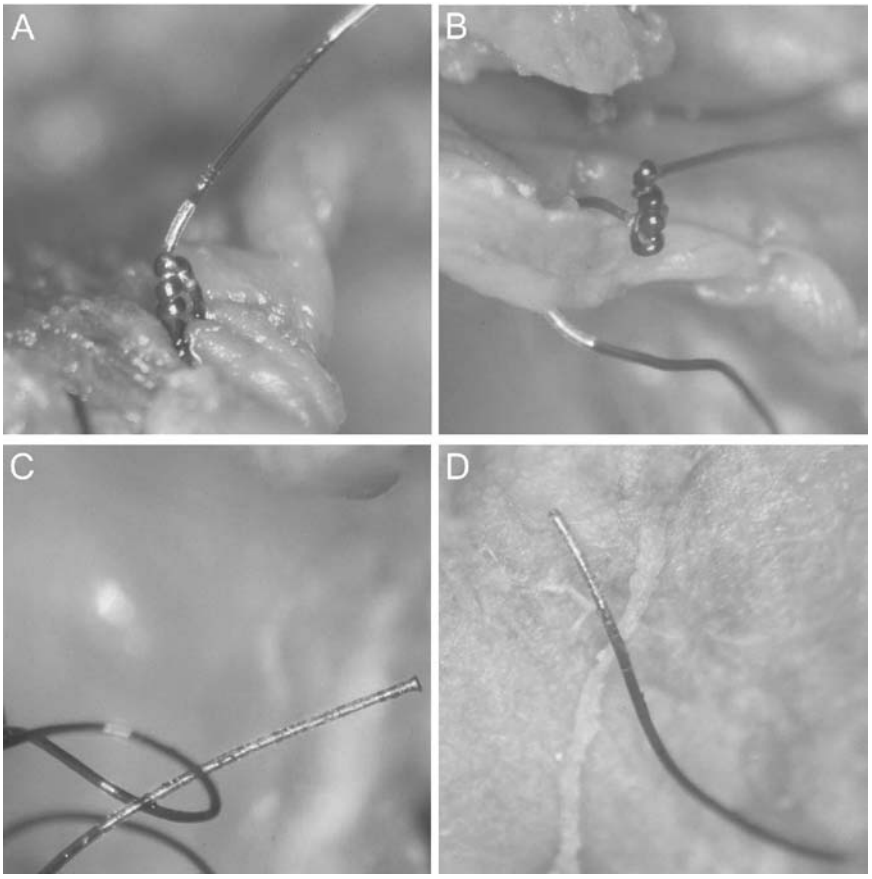

FIG. 3—*Dissecting microscope analysis at 20×. A. Stacked unsquared knots from the interrupted suture line. B. Untied knot from the interrupted suture line; suture has not yet slipped through the tissue. C. Suture tip from caudal end of failed anastomosis. D. Suture tip from cranial end of failed anastomosis.*

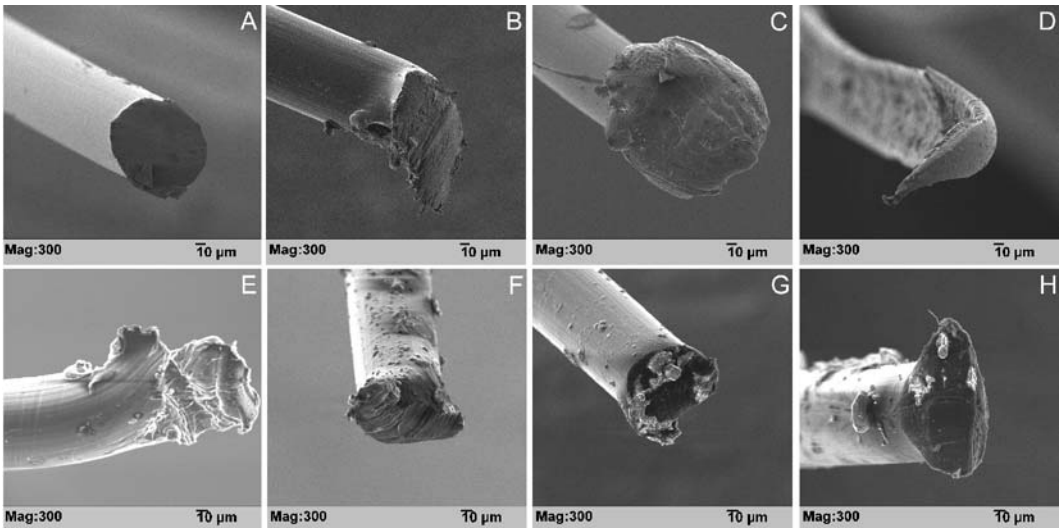

FIG. 4—*Scanning electron microscopy at 300×. A. Suture tip cut by scalpel. B. Suture tip cut by scissors. C. Torn and frayed suture tip. D. Stretched and torn suture tip. E. Suture tip after needle is "popped off." F. Internal control: Suture tip from interrupted suture line showing scissors cut. G. Suture tip from cranial end of failed anastomosis. H. Suture tip from caudal end of failed anastomosis.*

Scanning electron microscopy was performed on unused suture tips that had been cut with a scalpel, cut with scissors, stretched and torn, or "popped off" the needle (Figs. 4*A–E*). The scanning electron microscopic appearance of the ends of the disrupted sutures from the anastomotic line (Figs. 4*G* and 4*H*) were also compared with interrupted sutures from the specimen, which served as our suture controls for the surgical scissors used in this operation (Fig. 4*F*). Suture tips cut by a scalpel (Fig. 4*A*) have a squared-off, straight edge while ones that have been cut by scissors are flattened (Fig. 4*B*) or wedge-shaped (Fig. 4*F*). Scissors also produce horizontal linear shear marks along the wedged or flattened cut surface. Tissue debris in the used and formalin-fixed suture adheres

to the surface of the polypropylene, but, overall, the shape and conformation of the tip is clearly visible. In stretched and torn sutures, the tips are bulbous and ballooned out with irregular frays (Fig. 4*C*) or the polypropylene stretches and narrows to a point (Fig. 4*D*). The ballooning or mushrooming of the tip is a result of the imposed tensile recoil forces, while the narrowing is related to Poisson effects and yielding of the polypropylene. When "popped off" the surgical needle, the suture tips are also frayed with irregular contours (Fig. 4*E*). The cranial suture tip from the disrupted anastomosis (Fig. 4*G*) has a squared end, consistent with having been cut with a scalpel. The caudal suture tip (Fig. 4*H*) is wedge-shaped with horizontal linear shear marks, identical to the shape created by surgical scissors (as in Fig. 4*F*, our internal control). In neither case does the presence of tissue debris effectively hinder the examination of the tips, and neither tip has the stretched or torn appearance of a broken or "popped off" suture. Our past experience indicates that tissue can effectively removed, if necessary, by sonication.

Discussion

Polypropylene suture material is frequently used for peripheral arterial reconstruction and myocardial re-vascularization. It is also widely regarded as an appropriate choice for the arterial repair of a carotid endarterectomy. In the surgical literature, there have been several reports of suture line disruptions due to apparent fracture of the polypropylene suture, including failure of an atrial septal defect repair (8), a proximal anastomosis of a coronary artery bypass, an aortic closure in a patent ductus arteriosus repair, a femoral-popliteal bypass repair (9), and a carotid endartectomy (2). Calhoun and Kitten described a case of suture breakage after an episode of forceful coughing (12). These previous case reports do not present a detailed analysis of the suture tips and there is no photography to document the findings. However, longitudinal studies of multiple surgical centers' endarterectomy experiences have also implicated suture fracture as a cause of both early and late complications of therapy (1,2,14). All these published reports have prompted investigators to examine the tensile strength of different polypropylene sutures, the effects of surgical manipulation on the sutures and even the minimum number of throws necessary to tie a secure surgical knot (7,13).

Scanning electron microscopy is an excellent method of examining the external contour of sutures and has been employed to show that surgical manipulation gouges and creases the suture surface (15). Because the apparent stiffness and tensile load-carrying ability of a suture correlates with the circumference of a filament, rather than its core, it was assumed that these morphologic changes caused a significant decrease in tensile strength (16). Based on these studies and on in-vivo measurements of suture strength, several recommendations on surgical technique were proposed, among them that sutures with stray knots should be discarded and that sutures should not be handled with surgical implements (13). In subsequent research, however, Landymore et al. demonstrated that the force required to break an intact strand of 6-0 polypropylene suture was in the range of 437 g, and only decreased to 390 g after gentle stretching to remove suture memory or to 317 g after knotting. Even if exposed to the 150 g of force caused by a tissue forceps, the tensile strength of polypropylene sutures is orders of magnitude greater than the maximal force exerted on a suture during normotension, induced hypertension and through a full range of static and dynamic measurements, which were all less than 27 g (6). Nevertheless, the debate has continued over how to measure and evaluate adequately the chronic load and superimposed acute forces on an anastomotic line (17–19).

Increased experience with carotid endarterectomy over the past 30 years has reduced the mortality and major morbidity to a rate between 1 and 5%, and yet, when complications arise they can range from minor skin numbness to disabling stroke and death. Hemorrhagic complications are rare and may correlate with sustained periods of prolonged post-operative hypertension (20). In this case report, acute hemorrhage from a carotid endarterectomy anastomosis was investigated following a period of post-operative normotension in a chronically hypertensive patient. Dissecting and scanning electron microscopy were employed to evaluate the disrupted suture line, suture tips and other ligatures and sutures on the specimen, away from the anastomosis. Our analysis revealed that an untied knot was the cause of the hemorrhage and that the surgical technique appeared inadequate with regard to proper squaring to secure the surgical knots. The findings were reported to the hospital, suture manufacturer and the deceased's family.

Because all knots slip to some degree regardless of the suture material, surgeons will use more throws than are necessary, to extend the length of the cut ends and to compensate for slippage. The additional throws are time-consuming and introduce more foreign material to the surgical site, promoting localized inflammation and possibly increasing the risk of infection. Because the additional throws do not enhance the breakage strength of a secure knot, the surgeon must tie a secure knot with a minimal number of throws (7). One cannot overemphasize the importance of a surgeon's experience and proper surgical knotting technique in preventing post-operative complications (21,22). Studies have shown that even experienced surgeons may not be aware that they are tying knots incorrectly, but with proper tuition their skill can improve (23,24).

A review of records at the New York City Office of Chief Medical Examiner revealed two other similar cases in a ten-year period. In one, an untied knot led to fatal exsanguination from the proximal anastomosis of a coronary artery bypass graft. In another, the vascular ligature of a donor nephrectomy unraveled and the patient died despite surgical efforts to oversew the defect. In both cases photography at the time of autopsy was invaluable in establishing the cause of the bleeding and was available for subsequent civil litigation. In cases where an anastomotic failure is successfully repaired, a broken suture is often discarded along with any clot and blood-soaked gauze. The failure may be reported in the surgical literature or to the suture manufacturer but, without photography or an ultrastructural evaluation of the filament, it cannot be confirmed whether surgical technique or defective manufacturing was at fault.

In the forensic setting, there is a singular opportunity to examine the sutures and resolve these issues. The findings can have both medico-legal and public health implications. In this study, it was clear that tissue debris and formalin fixation did not significantly hinder such an analysis and we, therefore, recommend that in future death investigations of this nature, the medical examiner should refrain from handling the suture ends with dissecting implements, and preserve the anastomotic suture line with the surrounding tissue en-bloc so that a more detailed analysis can be performed.

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