SUTURE AND LIGATURE MATERIAL.[1]

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In attempting to discuss this subject we at once encounter an obstacle in the paucity of our nomenclature. Both suturing and ligation should be included under a common general term, since both involve the primary conception of an artificial retentive device, thread-like in form, and destined to remain in place for a considerable period, until the vital process of cellular activity has secured at least the beginning of permanent union.

Suturing implies the retention of tissues in appreciable sheets or masses, with the object of securing union by adhesion, or at least of diminishing, so far as practicable, the space to be bridged in by granulation tissue. In suturing there is also anticipation of the necrosis of very minute masses of tissue. Ligation, on the other hand, implies the occlusion of a single tubular structure, such as a vessel or duct, or of a mass of similar minute structures included in a pedicle. Excepting comparatively rare instances in which a vessel or duct, especially the spermatic duct, is occluded without severance, ligation differs from suturing in implying the presence of an appreciable mass of tissue destined to undergo necrosis, preferably without sepsis, but with absorption of the tissues distal to the ligature. Generally speaking, ligation is also performed in deeply-seated structures, whereas suturing implies the presence of a free surface, either upon the exterior of the body or internally, as in the case of the alimentary canal, a duct, vessel, and similar structures.

The process of union, assisted by either ligation or suturing, is essentially a function of mesoblastic, leucocytic cellular activity, epithelium and endothelium probably never being restored to an ideal state of integrity, although the gap bridged in by connective tissue may be minute, and there may even be a superficial covering of the connective tissue bridge by epithelium. A visible scar of exterior surfaces is inevitable, but in the case of the alimentary canal and of tubes lined with endothelium no visible defect may remain.

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The typic operation of suturing involves a succession of penetrating stitches, while the typic ligature surrounds a column of tissue with a single loop secured by a knot. Yet a small wound requiring only a single suture conforms closely to the concept of ligation, while, on the other hand, the Tate ligature, or *a fortiori*, the atypic ligature of a broad pedicle, by a series of retentive loops, trespasses on the definition of suture. Thus, it is impossible to distinguish sharply between suturing and ligation, and no attempt will be made to do so in the further discussion of this subject.

Broadly speaking, any thread-like substance may be used for either suturing or ligation. It would require too much space to discuss in detail the limitations and preferences which exclude the vast majority of fibers from use for either purpose, or the well-known, though not always unanimously accepted, reasons for choosing certain materials for use in one operation, and certain others when circumstances are different. Especially as the choice depends largely upon individual physical characteristics of various fibers, it would be a waste of time to attempt to lay down general laws for selection, in the present unsettled state of surgical opinion. We may, however, be influenced by the fact that usually, though by no means invariably, the suture is under observation and destined to voluntary removal when its purpose has been fulfilled, while the ideal ligature is one that may be left deep in the body and its subsequent fate intrusted to vital processes.

Undoubtedly, the first use of a thread-like device to secure occlusion was that of a hair, sinew, or vegetable fiber to ligate the umbilical cord.

Such practice has been observed more or less generally in various primitive people, and must long antedate the dawn of history. The earliest authenticated use of the umbilical ligature is by Susrutus, B. C. 1500. Owing to the natural safeguards against hemorrhage and infection, there has been comparatively little incentive to improvement in this regard, until the introduction of aseptic measures into obstetrics, within our own recollection. Indeed, it is altogether probable that beyond the availability of different forms of string, the majority of modern ligations of the umbilical cord are not a step in advance of the practice of many prehistoric savages.

Barring the tourniquet, which is merely a temporary ligature of an entire limb, which may even have antedated the ligature of the umbilical cord, the next step, historically speaking, is the application of the ligature to severed vessels, dating at least from the

time of Hippocrates, B. C. 460, and also mentioned by Celsus, B. C. 25. It is somewhat doubtful whether either of these writers, who were essentially physicians and not surgeons, actually practiced ligation, but if not, their references to it are even more significant, as indicating that it was an accepted item of contemporary practice. Owing to ignorance of the principles of antisepsis, as well as to purely mechanical imperfections, the danger of secondary hemorrhage has militated against the popularity of the ligature, and throughout the dark and the middle ages it was almost entirely supplanted by hemostasis by external pressure and styptics, of which favorite means were the cautery and immersion in boiling oil.

The reintroduction of the vascular ligature is due to Ambroise Paré (1517-1590), who was its untiring champion. Yet opposition both to the ligature and to the suture has persisted to the present day, as is attested not only in medical literature directly devoted to polemic discussion, but by numerous records of invention of clamps, angiotribes, cauteries, lacing devices, serre fines, and various other substitutes for thread-like retentive devices.

To one of modern anatomic and physiologic training, it is almost incomprehensible that Paré and his predecessors, men of ample intelligence and wide experience, could have used the vascular ligature to prevent hemorrhage without having discovered that arteries were not, as the name implies, air tubes, and without having conceived of the circulation of the blood. It is almost beyond belief that they did not connect in some vague way the beating of the heart and the jetting of arterial blood, and distinguish between arterial and venous hemorrhage. Yet the actual discovery of the circulation of the blood dates only from the researches of Harvey in 1628.

The next step in the extension of the ligature, beyond the function of direct hemostasis, was its application to the treatment of aneurysms, in which we see illustrated both the therapeutic effort directed toward the aneurysm and remote prophylaxis of hemorrhage. Here, too, we find the first example of ligation without severance. The history of the ligature treatment of aneurysm is scarcely germane to our present subject, as the choice of material and its preparation conforms to the general principles for ligation for other purposes.

The use of the suture, excepting for clean external wounds of short length, or of longer ones in very vascular and rapidly heal-

ing parts, such as the scalp, was prevented by the almost inevitable occurrence of local sepsis, whose occasional occurrence to-day is a recognized indication for the removal of sutures, except as they may be retained merely to abridge the chasm between granulating surfaces. Thus, until recently, suturing has had mainly a cosmetic function, its application on a large scale to deep and penetrating wounds being subsequent to aseptic surgical development.

So, too, until this development has been achieved, the internal suture of the alimentary canal, of vessels, ducts and the like, accidentally wounded or torn, and not situated comparatively superficially, as in amputation stumps, was impossible. Ephraim McDowell, as early as 1809, successfully removed an ovarian cyst and treated the pedicle with a ligature, said in the first instance to have been cut from his buckskin mitten. By some fortuitous combination of circumstances, he anticipated the logical results of asepsis. But, while all credit should be given to this pioneer American abdominal surgeon, the fact should not be overlooked that the routine and successful use of the deep ligature, as well as of the deep suture, and especially the extension of the ligature beyond the function of tying good-sized vessels individually or in associated groups of arteries and veins, required the discovery of anesthesia and antisepsis as prerequisites.

At present, the primary application of the ligature to the umbilical cord is regarded as a matter of very minor, almost of domestic surgery, while its next important application to vessels of good size is considered rather as an incidental feature of most operations. Matters of greater consequence and subject to freer surgical discussion, with marked differences of individual opinion, are the ligation of pedicles, as of the spleen, kidney, ovary, or tumor; of stumps left after the resection of the vermiform appendix or diverticula; of broad expanses of tissue, as of solid organs from which portions have been excised, or of the omentum; while the internal suture is required in the most varied ways, often involving the principles of the ligature, in the most intricate operations of the modern gynecologist and abdominal surgeon.

The problem is no longer the comparatively simple one of direct hemostasis, but involves painstaking detail to prevent immediate damage from leakage of contents or secretions, to prevent the establishment of fistulæ and development of retention cysts; and when hemostasis is the prime object, it is seldom a problem of extreme difficulty, except when one has to deal with a solid mass of tissue, such as the liver, which is freely supplied with vessels too

minute for individual ligation. In practically all cases the abdominal surgeon has to anticipate the necrosis of an appreciable portion of tissue distal to the ligature, infection of which will not only prevent its ready absorption in accordance with physiologic principles, but will result disastrously, either in comparatively speedy death from sepsis or in a delayed and impeded recovery, often with a complete nullification of the primary object of operation.

The ideal treatment of an intraabdominal stump or pedicle demands that it shall be left in its original position and permanently and immediately closed inside the abdominal cavity, trusting absolutely to the efficiency and future harmlessness of the ligature. In certain cases this ideal treatment is obviously impossible and the stump must either be inclosed in the abdominal wound or allowed to extrude from it, or at least the abdominal wound must be left open provisionally, for the inspection and further care of the stump and ligature. Yet, in general, the internal ligature and, only to a less degree, the internal suture, present problems as far as possible removed from the orginal and simple requisites of the umbilical ligature, and far more difficult of solution than those involved in the purely hemostatic ligature of vessels in an amputated limb or exposed wound and in the ordinary external suture, in which case the foreign material is subject to inspection and may be readily removed.

Tersely stated, the requirements for ligature and suture material in the more difficult and more deeply seated fields of modern abdominal surgery, are:

1. Absolute sterility, not only at the time of use, but during the vicissitudes to which it is subsequently subject.

2. Adaptability to torsion and flexion, and to the formation of a secure knot.

3. Strength, not only at the time of its use, but subsequently.

4. Resistance to absorption during the process of union by cellular activity.

5. Ultimate complete absorbability, with the possible exception to be noted later.

Excepting the general principles of asepsis, which are included in the present problem, there is no other topic in surgery about which there is so unanimous agreement as to principle, and so wide a discrepancy of individual opinion with regard to details, than this one of suture and ligature material. This paradox is due to the fact that no readily available thread fulfils the requisites

mentioned, and that in any particular case, or in the experience of any particular surgeon, greater or less importance is laid upon the relative perfection and imperfection of any one material.

We may discuss first the comparatively rare cases in which a permanent ligature or suture is required. In the past, an exaggerated idea has been held of the length of time required for the healing of wounds by the formation of cicatricial tissue. Generally speaking, the requisite degree of restoration of integrity is reached within ten days or two weeks at the longest. In bone surgery, metallic sutures or pins of some dense material may be required for several weeks, but Sir William Macewen, in the address on surgery before the British Medical Association, 1904, incidentally alludes to the fact that such foreign bodies do not remain firmly fixed, even in bone, for a longer time than a few weeks. After this time the bone softens about them and their usefulness as retentives has passed, while nature is obviously making an effort at the extrusion of a foreign body. Gynecologists and abdominal surgeons are interested in this use of permanent sutures only in complicated cases, and in the treatment of the symphysis after symphysiotomy.

Granted that a permanent ligature or suture is indicated for operations upon the soft parts, it must be smooth, unirritating, aseptic, and susceptible to encapsulation. These requirements are met, as well as by any other material, by silver wire, though gold or any other ductile and non-corrodable metal may be employed. The writer questions, however, whether any metallic suture actually fulfils the theoretic indication of supplying a permanent support, or, rather, whether a permanent foreign support of this nature is ever really indicated. Almost the only instance in which the need and desirability of such support is now claimed is in the treatment of hernial rings. Sir William Macewen (*loc. cit.*) expresses himself strongly in this regard, and cites five cases in which gold wire had been used in the treatment of hernia. All of these cases apparently demonstrated the futility of the effort to erect a permanent metallic barrier. In one the physiologic tendency to extrude a foreign body was manifest, and in two others not only was the loop of wire loose in the aponeurosis, but the bowel had actually become entangled in it, and in one of these had already become perforated by impinging against the wire. Practically, the only indication for the use of silver or other metallic wire suture in abdominal surgery of the soft parts, is to afford strong union of the abdominal wall after section in insane

patients or those otherwise not amenable to ordinary restraints of motion and straining. No indication is afforded in abdominal surgery for the use of silver wire as a ligature in the strict sense.

Generally speaking, any animal or vegetable material imbedded in the living tissues will be ultimately absorbed by a species of cellular digestion, of whose exact nature we are in ignorance, unless (1) it is completely impregnated with some mineral matter; or unless (2) it is so large and unirritating as to become encapsulated permanently; or unless (3) it is or becomes infected with microorganisms, when (A) it will either be extruded by the well-known process of suppuration and sinus or fistula formation, or (B) the resulting sepsis will become general and will result fatally.

Silk has always been a favorite suture material and has had many advocates, even as a material for buried ligatures. On account of its flexibility, strength, smoothness, and unirritating qualities it fulfils admirably the second, third and fourth requisites of an ideal material. While not an absolute exception to the principle just enunciated, it is practically non-absorbable, and numerous instances are recorded of its recognition at necropsies or subsequent operation long after is implantation, as well as of its discharge through fistulæ and sinuses. While its sterility is readily secured by boiling five minutes, its strength is impaired even by a second boiling, and, owing to its free absorption of water, it becomes a favorable medium for bacterial cultures, so that stitch-hole abscesses are comparatively common after its use. For intestinal suture there is no material so reliable as silk, used in the form of small sterile filaments, not in the coarse twists or braids often sold for this purpose and for surgical use generally. A silk which will stand repeated boiling without marked impairment of strength has almost certainly been adulterated with vegetable fiber.

Vegetable fibers are occasionally employed for ligatures and sutures mainly in emergent practice, in the absence of more suitable material. As they present no marked advantages over animal material and have many disadvantages of their own, they will not be discussed in detail.

Silkworm gut is made by drawing out into a thread the fluid silk in the body of the worm about to spin its cocoon. This material is obtained in bundles of a hundred threads, each twelve to fifteen inches long. These are smooth, strong and springy, yet capable of being tied securely. Occasionally they break, especially if too much tension is placed on the knot while being tied. Like

silk, silkworm gut may be sterilized by boiling, and it is practically non-absorbable. On account of its polished surface it is unirritating, unless the sharp ends are buried, and the threads are readily withdrawn. It is an excellent material for tension sutures.

Kangaroo tendon has been exploited as a material for deep sutures and ligatures, especially in cases of hernia, in which a degree of permanence is desired. Numerous reports, however, show that it is often absorbed within a few days. It may be sterilized by boiling, but repeated boiling lessens its strength. Dorsett, at the meeting in 1902 of the American Association of Obstetricians and Gynecologists reported two cases in which tetanus was traced to infection of this material. Tetanus, though a rare complication of supposedly clean wounds, demands our serious attention, not only on account of the high mortality, but of the direct responsibility which attaches to the surgeon when it develops without accidental traumatism, but in a wound inflicted as a therapeutic measure. The United States Public Health and Marine Hospital Service published a bulletin in 1902 in which six cases of tetanus due to gelatin were studied. It was shown that brief boiling does not insure against infection with tetanus, but that it must be continued for at least half an hour or must be repeated.

The writer would emphasize the fact that thorough asepsis can be obtained in practice only by extemporaneous disinfection of all materials used. It is needless to state that surgeons are practically unanimous in the view that the most satisfactory method of obtaining sterility is by boiling prior to the employment of instruments and other accessories. While, theoretically, suture and ligature material may be sterilized long before use and maintained in a sterile state by immersion in antiseptics or by hermetic sealing, there are numerous practical obstacles to the perfection of an antiseptic technique dependent upon such materials. When prepared on a commercial scale, by comparatively unskilled and uninterested employees, errors in technique are inevitable. Even when prepared under the immediate supervision of the responsible surgeon, the opening of packages, the drawing of a thread through an opening in a receptacle, the almost inevitable contamination of such receptacles from exposure to the air of the clinic, or the waste of material and delay if the attempt is made to prepare material in just the quantity liable to be needed, all favor the plan of extemporaneous sterilization by boiling. Even elaborate processes of sterilization of catgut by immersion in sub-

limated ether, juniper oil, silver salts, dry heat of high temperature in paper packages, etc., have, in the writer's experience, not proved entirely satisfactory, as infection has occasionally developed. These methods undoubtedly produce complete primary sterility, but reinfection is likely to occur through some unforeseen error of technique, perhaps on the part of an assistant, in a small minority of cases it is true, yet in too large a number to satisfy surgical ideals. In experiments in which the writer participated at the University of Berlin, 1894-1895, it was found that reliable sterilization of previously infected suture and ligature material by sublimate required twenty days, whereas, even tetanus spores were killed by exposure in the steam sterilizer for three minutes in the majority of instances, and were positively killed by three similar treatments on alternate days.

For some unknown reason, possibly a predilection to tetanus on the part of the kangaroo, possibly by adulteration with sinew from the horse, which is notoriously liable to tetanus, kangaroo tendon has proved a notable, though still rare source of tetanus, while, so far as the writer can learn, such infection has never been traced to catgut, although it has been used a thousand-fold more often. Commercial catgut is prepared from the intestine of sheep, which are very little subject to specific infections, such as tetanus, tuberculosis, and the like. Catgut has long been a favorite suture and ligature material; it is cheap, easily obtainable and easily handled, and is not liable to contamination, except with the saprophytes and pyogenic bacteria. In considering it in the light of the five requisites for an ideal suture and ligature material, we find that it fulfils the second, third and fifth. It is, however, notoriously deficient in its resistance to absorption, so that even heavy catgut cannot be relied upon for deep sutures and ligatures without special preparation by impregnation methods; in its original state it cannot be boiled in water without being destroyed; even as ordinarily prepared to resist absorption, it cannot be subjected to extemporaneous disinfection by boiling without loss of strength and inhibition of water, so that it is with difficulty threaded into needles and handled. Chromicized and cumol catgut resist absorption, but cannot be boiled sufficiently for thorough sterilization without loss of consistency.

By the method which the writer has employed for a number of years, catgut is modified so that it may be boiled like silk, and is, therefore, rendered thoroughly dependable for deep sutures and ligatures without destroying its ultimate absorbability or inter-

fering with its natural adaptability for handling and tying. We may even gauge quite accurately the length of time for its absorption. This method was originally brought out by Hofmeister, and was introduced to the American profession by Nicholas Senn in 1896. It is so simple and reliable that anyone may prepare his own material, and so accurate that it may be adapted for an artificial support for a few days or a number of weeks, as required by the nature of the case, thus rivaling the claims that have been made for kangaroo tendon, and which, unfortunately, have not been altogether substantiated in the general experience of reporters.

The method of preparing catgut, as modified by the writer as the result of experimentation since 1896, is as follows: take dry catgut, which comes in strands ten feet long, carefully test for imperfections by passing through the hands and noting its strength and inspecting for weak points and irregularities, fasten one end to the end of a glass cylinder, for instance, an ordinary drainage tube which has a hole drilled near each end, wind snugly in a single layer, and fasten the other end similarly. Completely submerge in a 3-per-cent. formalin solution. The writer finds that only the sizes from No. 1 to No. 4 are necessary.

No. 4 is allowed to remain in the solution for 4 hours.

No. 3 is allowed to remain in the solution for 3 hours, 5 minutes.

No. 2 is allowed to remain in the solution for 2 hours, 15 minutes.

No. 1 is allowed to remain in the solution for 1 hour, 35 minutes.

The catgut is removed and immediately placed in running water for the same length of time that it has been in the formalin solution. It is then dried in the open air at ordinary temperature. labeled and put away for future use.

This process may be termed mercerizing, since the catgut thus prepared may be handled precisely like silk; it does not deteriorate by repeated boiling more than silk, it is pliable and easily and securely tied, and it differs from silk only in its ultimate absorbability. The reliability of boiling this material to secure sterility has been repeatedly tested by the writer clinically, by the absence of local septic complications, and has also been verified by bacteriologic tests by Dr. William G. Bissell, of the Buffalo Department of Health.

The approximate time for which material thus prepared may be depended upon to furnish support to the tissues is as follows:

No. 4, 7 days. No. 3, 5 days. No. 2, 3 days. No. 1, 36 hours.

While it has been the general object to secure a material which shall be absorbed as rapidly as possible, with regard to the nature of the case, there are conditions, such as hernia, in which it seems desirable to support and maintain the tissues in apposition for a long time. To secure this end, a 5 per cent. solution of formalin is employed instead of a 3 per cent. solution, and the gut is left in the solution for as long a time as is compatible with the preservation of a fair degree of flexibility. This time has been found to be approximately double that stated for the respective sizes of gut when treated by the 3 per cent. solution. If allowed to remain too long in formalin, the gut becomes brittle. In any case, the washing in running water is carried on for the same length of time used in the immersion in formalin solution. Number 4 gut, treated according to the latter specifications, will remain in the tissues for 4 to 6 weeks, but is subsequently completely absorbed. In large hernias of long standing, in which there is likely to be considerable traction on the fascia, No. 4 catgut will meet all expectations, not disappointing so frequently, as has commercial kangaroo tendon, by too rapid absorption or infection. If there is not too great separation of the fascia, No. 2 or No. 3 gut prepared by the second process, or No. 4 prepared by the first process, will be found amply resistant.

No. 1 gut prepared by the second process meets many indications. It may be used in surgery of the biliary or urinary bladder or their tracts with perfect safety, when a non-absorbable substance would probably become the seat of calcareous deposits.

In obstetric practice, in the performance of immediate repair of the perineum No. 3 or No. 4 gut, by the first process, is to be selected. In cases of long standing, where the muscles and fascia are widely retracted, the vagina is separated from the rectum, the levator muscles are exposed with their fascia and are united directly with No. 4 gut prepared by the second process.

A further advantage of the method here described is that it can be taught, not only theoretically, but by actual participation on the part of the student, and, owing to its extreme simplicity and the lack of complicated apparatus, it can be carried into practice by occasional operators at a distance from clinics, who may thus be made entirely independent of commercial sources except for a supply of raw material.

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