SENN. (N.)

Ligature —

There was only one person with Colonel Dwight during the few moments prior to his death, but one or two others were almost immediately called in.

An autopsy was held, and the theory of suicide was claimed to be sustained by a red crease in the skin of the neck, as if caused by a rope. It was stated by the defence that this was caused by the position of the head subsequent to death. The coroner's jury rendered a verdict of death by natural causes.

A second autopsy was held some weeks later, when fifteen physicians were present; the marks on the neck were then visible.

This is a brief outline of a case which has attracted unusual attention, and has been strongly contested in the courts. The Equitable Life Insurance Company paid without question its policy of $50,000, but other companies refused to do so. In a test case a decision was rendered against the company; but now, after years of litigation, this has been set aside and a new trial ordered. This is a victory for the insurance companies, and it is doubtful if the case will ever be brought to trial again.

The medical testimony in favor of suicide by strangulation was not very conclusive, but all other circumstances were strongly corroborative of the probability of suicide, and the very large amount involved made the case a famous one.

The presumption of death in cases where exact knowledge cannot be obtained, is an important one.

There is a general rule of law that a person is dead who has not been heard of for seven years by those likely to know of his movements. This presumption does not, however, arise if the disappearance and failure to hear from him can be explained on any theory consistent with that of the existence of life. Aside from this rule there are facts which may warrant the inference of death before the expiration of seven years, such, for instance, are passage on a ship which is known to have been lost, exposure to special perils, etc.

There is occasionally the simulation of death in order to secure the insurance money. A well-known illustration of this is the case of Udderzook, who was executed in Pennsylvania in 1873 for the murder of a man named Goss. Goss's life had been insured, and there was a conspiracy between him, his wife, and Udderzook to obtain the insurance. A dead body was placed in a building where Goss was accustomed to work, and the building set on fire. The charred remains were declared to be those of Goss, and a demand was made for the payment of the policy. While this was under consideration Goss threatened to betray the conspiracy, and Udderzook allured him from his hiding-place and murdered him. For this crime Udderzook was tried, convicted, and executed, and the facts of the conspiracy were made known.

Accident insurance is a species of life insurance where the liability only arises in case of death by accident.

There have been frequent discussions in the courts as to what kinds of death such a term describes, and in one case it was held that a person who was under medical treatment for nervousness, and who took an overdose of opium by mistake, could not recover.

In another instance the policy exempted the company from liability in case of poisoning, and the insured, thinking a mixture was a harmless beverage, drank it and found it to be a deadly poison. In this case it was held there could be no recovery. *Henry A. Riley.*

LIGATURE. Latin, *ligatura*, from *ligare*, to bind. A cord or string of silk, flax, catgut, or other suitable material, for tying blood-vessels or other parts.

History of the Ligature.—The history of the ligature[1, 2] has been variable and eventful, and has always been intimately connected with the history of surgery, ever constituting a reliable barometer indicating the fluctuations of rise and fall in this art and science. Its use as a hæmostatic agent was not the result of reasoning or logical deduction, but was prompted by instinct. It was used and described long before the circulation of the blood was discovered. The discovery of the circulation, anatomico-pathological investigations, experimental researches, and clinical observations, have all been contributing to the rescue of this invaluable agent from the dark domain of empiricism, and have secured for it a position, as a remedial agent in surgery, second to none in points of importance, reliability, and frequency of use. The first account of the application of a ligature for the purpose of preventing hæmorrhage is given by Sus'rutas, a disciple of the divine Dhavantari, in his Ayur Vedas (B.C. 1500), who tied the umbilical cord in newly born infants with a string, eight inches from the navel, previous to cutting it. A number of writers, among them Platner, Holtze, Langenbeck, and Fischer allude to Hippocrates (B.C. 460–377) as the discoverer of the ligature. They base their opinion on the following passage from his works, translated into Latin by Fassius:[3] "Sanguinem e venis profluentem sistunt animi deliquium, figura aliorsum tendens, venæ interceptio, linamentum contortum, appositio, deligatio."

Archigenes (B.C. 100) made free use of the ligature after amputations. Celsus (B.C. 30–25, A.D. 45–50), in his works, refers to the ligature as a well-known remedy, and credits an obscure physician of the Alexandrian school with its discovery. Celsus used the ordinary linen thread, and gave the particular indications for its use, and described the manner of its application. In speaking of the operation for hydrocele he says:[4] "Nervus, ex quo testiculus dependet, præcidendus; post id venæ et arteriæ ad inguen *lino deligandæ* et infra vinculum abscindendæ sunt."

Galen (A.D. 131–211), although no practical surgeon himself, yet familiar with the literature of that day, frequently mentions the ligature, and gives particular directions to apply it to the proximal end of the bleeding vessel. For ligature material he advises silk and fine catgut. The definite closure of the vessel he attributed to the action of the tissues surrounding it, as is evident from the following quotation:[5] "Quæ namque caso in abscisis vasorum partibus coalescit, ea pro opercula est ac osculum eorum claudit." The name of Antyllus (A.D. 350) occupies such a prominent position in vessel surgery, and his method of procedure in case of aneurism is so familiar to every student in surgery, that more than a simple allusion to his name would appear superfluous.

Paulus Ægineta (A.D. 625–690) treats extensively of the ligature, quoting freely from the writings of Celsus and Galen. In practising ligation of vessels as a therapeutical measure in diverse affections, he passed two ligatures beneath the vessel, with the aid of a needle, cut the vessel between them, and, after permitting the requisite amount of blood to escape, closed each end of the vessel separately. Rhazes (A.D. 850–922) mentions, as a last resort to arrest hæmorrhage from large vessels, the ligature which he made of strong linen thread. The prolific writer, Avicenna (A.D. 980–1037), disposes of the subject of ligation of vessels briefly thus:[6] "Quod si (sc. vena) fuerit pulsatilis, tum melius est ut veles eam cum filo lini, et similiter si fuerit non pulsatilis, verum tamen multoties elevatur sanguis ejus." Aneurisms he treated in accordance with the teachings of Antyllus. He limits ligation to arteries, believing that bleeding from veins is arrested spontaneously or yields to the use of the customary styptics. Avenzoar (A.D. 1113–1162 or 1196) and Averroes (1198) were familiar with the ligature. The latter, in his commentaries on the writings of Avicenna, directs that in performing arteriotomy the vessel should be surrounded by two ligatures before it is divided. Roland (1252), a pupil of Roger, of Parma (1214), again mentions the use of the needle in applying the ligature, a practice followed by most of the prominent Italian surgeons at that time. Bruno, of Castel Longobrugo (1252), pointed out the difference between arterial and venous hæmorrhage, and gave the advice, in cases where the bleeding could not be arrested by any other means, to seize the artery or vein with a small hook and carry a thread with a needle around the vessel and tie it firmly. Guy de Chauliac (A.D. 1300–1363) prefers the ligature when the artery is deeply seated, in which case it is brought well into view, and that end is firmly tied which is the nearer to the heart or liver. Lenardo Bertapaglia (died 1460) modified the intermediate ligation by passing the

needle armed with a double thread, not *under*, but *through*, the artery, tying both ligatures firmly over each other. Giovanni Vigo (1460–1520), the founder of the school of surgery in Rome, was acquainted with the direct or immediate ligature, but gave preference to the intermediate method of ligation. Alfonso Ferri described the ligature needle used at that time in applying the intermediate ligature—it was about three inches in length and curved only at the point, with the eye at the opposite end; the point presented four sides with obtuse angles, so as to prevent injury to the vessel or its adjacent parts. This needle was armed with a double ligature, and was introduced about two to three fingers' breadth from the margin of the wound, passed underneath the vessel, and made to emerge on the opposite side of the wound, and the ligature was then firmly tied in several knots. Angelo Bolognini (1508), founder of the school at Bologna, also practised percutaneous ligation of vessels, using silk as a ligature material. Jacques Houllier (1493–1562), in wounds of the arteries, relied on digital compression, and when this failed and the vessel was deeply located he advised that it be gently drawn forward, slightly twisted, and, after ligating both ends, divided completely at the point of injury. In Germany we find the first mention of the ligature by Hans von Pfolsprundt. Hieronymus Brunschwig (1450–1533) practised and described Bertapaglia's method of ligation.

Hans von Gersdorf (1517), a military surgeon of great experience, frequently applied the intermediate ligature in cases of vessel wounds, but preferred styptics and the actual cautery in amputations. Walther Ryff tied the proximal end of the vessel by isolating and seizing it with a small hook and then applying firmly a silk ligature. It will be seen, up to this time, that the ligature had for the most part been used only as a *dernier ressort* in cases of wounds of vessels, while styptics and the actual cautery were still relied upon as the safest and easiest methods of arresting hæmorrhage. To Ambroise Paré (1517–90) surgery owes a great debt of gratitude, not as the discoverer, but as the first and most devoted champion of the ligature. Through his influence and untiring zeal the ligature gradually found its way into popular favor, and displaced the barbarous treatment by styptics and cautery. He practised both the immediate and intermediate ligation, according to the location of the vessel and circumstances of the case. His first operations were performed about the year 1552. In a German translation of his work on Surgery,[7] published in the year 1601, I find the following directions: "Wo auch dieses nicht helffen wolte, so muss man die Haeffte, wofern deren eins oder mehr vorgangen, widerumb auffthun, und under der verletzten Ader, gegen ihrem Anfang oder Wurtzel zu, mit einer Nadel und Faden durchhin fuhren, die Ader sampt einer solchen Portion oder Stücklein Fleisches desselbigen Orts, wie viel nemlich die Gelegenheit geben und erleiden mag, fassen und zubinden. Denn also hab ich oftmal sehr grosse und gewaltige Verblutungen, auch in denen Wunden, durch welche ganze Arm oder Schenkel abgehawen worden, gestillt, wie an seinem ort sol gemeldet werden. Dieses aber zu verrichten, werden wir vielmal genötiget, die ganze Haut, so über der Ader ligt, auffzuschneiden und zu entblössen. Denn wenn eine auss den Blut oder Lufftadern des Halses (Jugularium) durchschnitten were, und sich die beyde Ende, beydes hinauff und hinabwertz von einander gezogen, und also verborgen hetten, muss man die gantze Haut unter welche sie sich verschlossen, eröffnen, die Ader entdecken, mit einer Nadel und Faden darunter hinfahren und also zusammenbinden, wie ich dan selbst viehlmahl sehr glücklichen und wohl verrichtet. Du solt aber dieses Bandt oder Faden nicht eher auflösen, biss dass du sihest, das die Ader mit Fleisch überwachsen, und der Ader Mundlöchlein verstopfet sey, damit das Blut nicht widerumb und von neuwen zu rinnen anfange."

For fear of secondary hæmorrhage, Paré favored the ribbon ligature, made of a number of threads; at the same time he aimed to include portions of tissue surrounding the vessel, and removed the ligature as soon as healthy granulations covered the exposed portion of the vessel. He used the ligature with a view simply to approximate the inner walls of the vessel for a sufficient length of time for union to take place, when its further presence was considered useless and even detrimental. The contemporaries of Paré were slow to acknowledge the superiority of the ligature over the rude, but time-honored, cautery. On the one hand, ignorance and prejudice combined in checking progress, while, on the other, it must be acknowledged that Paré's ligature was an exceedingly imperfect thing, which, when used according to his directions, could not fail to frequently disappoint the most ardent admirer. It required centuries to establish it in the confidence of the profession.

Jacques Guillemeau (A.D. 1550–1613), Paré's pupil, friend, and successor, labored faithfully and earnestly in the interest of the cause of his illustrious master. He was one of the first who resumed the operation of ligation of arteries in their continuity for the cure of aneurism. He applied the ligature on the cardiac side, opened the sac, and allowed it to heal by granulation. Pierre Dionis (died 1718) states that at his time the cautery was used almost exclusively at the Hôtel Dieu after amputations, although he resorted to the ligature frequently, and in some instances even practised immediate ligation. In 1733, Petit (1654–1750) writes of the ligature:[8] "La ligature cause des grandes douleurs, des tressaillements convulsifs, et quelquefois la convulsion du moignon, qui souvent est mortelle, ou par elle-même ou parcequ'elle occasionne l'hémorrhagie par les mouvements extraordinaires que le malade ne peut s'empêcher de faire." Fabricius von Hilden (1560–1634) and Scultetus (1595–1645) introduced Paré's practice into Germany. The former made use of the hemp ligature, but restricted its application to young healthy persons. Cornelius Von Solingen (died 1692) practised immediate ligation after the example of Dionis. Anton Nuck (died 1692) only made use of the ligature in operating for aneurism, after the method of Antyllus. In England the ligature was introduced by Wiseman (1566–1625), and was eagerly adopted after the discovery of the circulation by Harvey, in 1619. Fabricius ab Aquapendente (died 1620) applied two ligatures to arteries, and divided the vessel between them, so as to allow both ends to retract. Marcus Aurelianus Severinus (1580–1656) was the first to tie the femoral artery near Poupart's ligament. Cesare Magati (1597–1647) followed the advice of Galen and Avicenna, and tied the vessel only on the cardiac side. Kirkland (1721–98) attributes the definitive closure of vessels after ligation to the inherent contractility of the vessel-wall. White and Aikin expressed a similar view, as becomes apparent from the following passage: "That the arteries, by their natural contraction, coalesce as far as their first ramification."[9] John Bell (1760–1820) concurred in this view, but added another important element, adhesive inflammation in the vessel-wall, induced by the ligature.[10] Larrey (1766–1842) observed that in many cases after ligation no coagulum formed, and, in consequence, asserted that definitive obliteration of the vessel can take place independently of it, and is then due to contraction of the vessel-wall.

Richerand (1779–1840) believed that the ligature brings the inner walls of the vessel in contact, and that direct adhesion takes place, the result of adhesive inflammation. Garengeot (1688–1759) feared the cutting through of the ligature, and, for the purpose of preventing this accident, advised the use of a broad, ribbon-like ligature. Claude Ponteau (1725–75) abandoned the use of the broad ligature, but, to guard against the same evil, included within the ligature a sufficient amount of paravascular tissue. Lorenz Heister (1683–1758) used a stout ligature, and tied over a small cylinder of lint to prevent premature cutting through. J. Z. Platner (1694–1747) made use of a similar contrivance, but always applied a double ligature, with a third (reserve ligature) on the cardiac side, to be tied in the event of secondary hæmorrhage. Alexander Monroe (1697–1767) protested against the intermediate ligature, and emphasized the importance of direct ligation. He used broad ligatures, and tied only with sufficient firmness to approximate the inner

walls of the vessel. William Bromfield (1712–92) isolated the artery, drawing it out on the surface of the wound with a hook of his own construction, and which still bears his name, and applied a flat ligature. In France, Deschamps (1740–1824) advocated the superiority of immediate ligation by means of a broad ligature, on the ground that when the intermediate ligature is used the interposed tissues disappear very rapidly, leaving the ligature loose around the artery, thus favoring the occurrence of secondary hæmorrhage. Abernethy (1763–1831) applied a double ligature in tying an artery in its continuity, and divided the vessel between them, claiming that in doing so he was able to relieve the tension in the peripheral portion of the vessel, and, at the same time, to enable both ends of the artery to retract into the tissues. He also condemned the reserve ligature, as it would necessitate more extensive isolation of the vessel, thus cutting off nutrition and provoking a higher degree of inflammation and suppuration. August Gottlieb Richter (1742–1812) introduced the immediate ligature into Germany. On December 12, 1785, John Hunter (1728–93) for the first time tied the femoral artery *in loco prædilectionis* for popliteal aneurism. He applied four ligatures at short distances apart, of which number only the most distal one was tied firmly; the remaining ligatures were tied in such a manner that the lumen of the proximal end of the artery represented a cone, with the base toward the cardiac side of the vessel. Hunter anticipated that this method of operation would favor the formation of a thrombus, and thus afford additional security against secondary hæmorrhage. His expectations, however, were not realized, as secondary hæmorrhage occurred on three different occasions, and the patient did not recover until seven months had elapsed. He did not repeat this operation, and subsequently used only one ligature. Desault accidentally made the observation that, in the ordinary method of ligation with the round ligature, the two inner tunics of an artery are ruptured. This fact was verified by Jones, who, in 1806, made a series of careful experiments to determine this point. The classical work of Jones exerted a potent influence in establishing the claims of the ligature, not only in England, but wherever surgery was practised. He claimed that obliteration of an artery, after ligature, can take place independently of the formation of a thrombus, by the traumatic inflammation and plastic exudation induced by the ligature. In his experiments on animals he applied several ligatures in close proximity. He called particular attention to the deleterious effects of suppuration on the process of cicatrization in the blood-vessels, and, for the purpose of guarding against this event, advised the removal of the ligatures immediately after they had ruptured the internal coats, or before suppuration was established. He believed that provisional closure of the vessel was accomplished by the lacerated tissues within the lumen of the vessel, and that the healing process within the vessel was the same as in any other wound, and produced the definite obliteration. In tying large arteries he advised the double ligature and division of the vessel between. B. Travers adopted the views promulgated by Jones, but substituted the temporary for the momentary ligature. He recommended the removal of the ligature as soon as plastic inflammation was fully established, and before suppuration had had time to take place. The period of time in which the ligature would accomplish this object he placed at forty-eight to ninety hours, according to the size of the vessel which had been ligated. Jones and Travers deserve to be called the discoverers of the temporary ligature upon a scientific basis. On February 14, 1817, Travers for the first time put his theory into actual practice. He ligated the brachial artery for aneurism, and removed the ligature after fifty hours. The case proved successful. The next case, the artery being the same, did not terminate so favorably; secondary hæmorrhage set in and proved fatal. J. Hutchinson's case, operated upon in a similar manner, also terminated in death by recurring hæmorrhages. Sir Astley Cooper applied the temporary ligature in two instances. The results not meeting his expectations, he abandoned it. Among the most formidable opponents of the temporary ligature may be mentioned Hodgson, Vacca Berlinghieri, and C. J. M. Langenbeck, who claimed that it was impossible to determine the exact length of time after which it would be safe to remove the ligature, and that the necessary manipulations for the removal of the ligature would interfere with the prompt healing of the wound. In Italy, Antonio Scarpa (1747–1832) strongly advocated the employment of the temporary ligature. He used the broad ligature and tied over a cylinder of lint for the purpose of bringing and keeping in apposition a large surface of the inner walls of the vessel. His experiments have demonstrated that obliteration of a vessel by adhesive inflammation can, and does, take place without division of the coats. He compared the inner surface of blood-vessels with serous membranes, and credited it with the property of undergoing the same pathological changes when subjected to traumatism. He ascertained that adhesive inflammation follows about four days after the application of the ligature, while the time required for suppuration to arise requires from one to two days longer; consequently he determined the time for removal of the ligature in accordance with the general condition of the patient. In young, robust persons he removed the ligature on the fourth day, and in old or decrepit persons he allowed it to remain for six days. P. von Walther asserted that definitive closure of vessels after ligation takes place within forty hours, and urged that the ligature should be removed after the lapse of this time. In Germany, Victor von Bruns was the next and last to bring the temporary ligature before the notice of the profession. He removed the ligature after two or three days, according to the size of the vessel, and supported his claim for the superiority of this method of ligation by the results of a large clinical experience. Pécot compared the methods of Jones and Scarpa by way of experiment, and came to the conclusion that the round ligature, if applied with sufficient firmness to sever the inner coats of the artery, excites adhesive inflammation earlier than if the broad tape ligature is used. Ponteau attributed great importance to the connective tissue around blood-vessels in the process of obliteration, hence he advised that an abundance of this tissue should be included within the ligature. Delpech (1777–1832), in France, and C. J. M. Langenbeck, in Germany, arose against Scarpa. Langenbeck regarded the adhesion of the inner vessel-walls of prime importance in effecting permanent closure, while to the thrombus and lymph-coagulum he assigned a less important rôle. The older German surgeons were in the habit of using hemp or linen ligatures. The silk ligature was first proposed in that country by Ph. Fr. von Walther. For the purpose of preventing the ill effects of the customary ligature, a variety of ligature materials were proposed, such as chamois-skin by Physick (1814), catgut by Sir Astley Cooper, silkwormgut by Wardrop, elastic rubber strings by Levert, tendons by Paul Eve, human hair by Porta. Metallic ligatures were brought forward as being less irritating than the ordinary ligature; gilt iron wire was proposed by Ollier, fine iron wire by B. v. Langenbeck, and silver wire by Wagner and Sims. Levert experimented with all kinds of metallic ligatures—lead, gold, silver, and platina—and always obtained primary union of the wound. Metallic ligatures were always cut short and remained permanently in the wound. Until the end of the eighteenth century the ends of the ligature were brought out through the wound. The first attempts to cut short the ligature and leave it permanently in the wound were made by Lawrence, who, in 1814, published the results of his experience. For ligatures he used fine dentist's silk. According to Samuel Cooper, however, the priority of this procedure should belong to a certain Haire, of Essex, who is said to have practised it in 1786. Hennen adopted the practice in 1813, and within four months followed it in thirty-four cases without observing any unfavorable results. Delpech and Guthrie also indorsed the practice. The introduction of antiseptic surgery has, however, wrought the greatest improvement in the ligature, and the founder of antiseptic surgery, Sir Joseph Lister, has also furnished

us with the ideal ligature—the aseptic ligature. What has been sought for centuries has at last been found—a ligature which will arrest the circulation with safety and certainty, which will produce a minimum amount of traumatism until the process of cicatrization is completed, and which, when its work is accomplished, will gradually disappear by absorption and substitution. Since the introduction of the antiseptic treatment of wounds and the aseptic ligature surgery has received a new impulse; results have been obtained which were never realized before; operations have been performed successfully which were previously beyond the grasp of even the most ambitious; and, more than all, those horrible spectres, hospital gangrene, erysipelas, pyæmia, septicæmia, and secondary hæmorrhage, which haunted the surgeons of only fifteen years ago by night and by day, have almost completely disappeared from hospital as well as private practice. For all this we are indebted to Lister. A variety of other animal tissues have been made into ligatures and rendered aseptic, and have been recommended at different times as substitutes for the catgut ligatures. Among them we may enumerate silk, silkworm-gut, whale and deer tendon, peritoneum, coats of blood-vessels, and nerve-tissue. With the exception of the first two, all of these ligature materials, if rendered perfectly aseptic, will, after a certain time, undergo absorption, but it is questionable if any of them possesses any advantage over well-prepared catgut. Czerny is entitled to a great deal of credit for the improved silk ligature. He has demonstrated that when silk is made perfectly aseptic, by boiling and immersion in carbolized water, it can be safely left in the tissues, where it becomes encysted.

In regard to the relative position of the ligature to the subjacent blood-vessel, two distinct classifications are made: I. Intermediate ligature, ligature *en masse*. II. Immediate or direct ligature. In the former instance a varying amount of paravascular tissue is interposed between the ligature and the blood-vessel, while in the latter case the vessel is isolated and the ligature applied directly.

I. Intermediate Ligature, Ligature en Masse.—All of the older surgeons were in fear of a too early separation of the ligature, and aimed to prevent secondary hæmorrhage, as the result of such an occurrence, by including adjacent tissues, thus protecting the vessel against undue pressure. The object of this practice was simply to apply the ligature as a provisional mechanical agent to arrest the flow of blood in a vessel, without any theory as to the permanent closure of the vessel. The ligature was passed underneath, with points of entrance and exit some distance from the vessel, and firmly tied. This method was practised by Paré, and through his influence and example it was adopted by all of the prominent surgeons until nearly the end of the eighteenth century. Guillemeau, Thévenin, Garengeot, Le Dran, Louis, Dionis, and Petit were faithful followers of Paré, and, with few unimportant modifications, followed his directions to the letter. Since the definitive closure of vessels has been made an object of study and experiment this method of ligation has been abandoned, and is only resorted to in exceptional cases where isolation of the vessel or vessels is impossible from the nature or location of the wound. At the present time it is resorted to more particularly in cases of obstinate parenchymatous hæmorrhage which cannot be controlled by compression; also in cases where isolation of the bleeding vessel is impossible on account of inflammatory or neoplastic deposits around it; and lastly, in cases of advanced degeneration of the tissues of the vessel-wall, where obliteration of the vessel cannot be secured without imminent risk of causing a solution of continuity of all of its coats. In such cases a curved needle is armed with a stout catgut ligature and is passed through the tissues some distance from the vessel, including thus a circular portion of paravascular tissue; the ligature is then drawn sufficiently tight to arrest bleeding, when it is tied in a surgical knot and its ends cut off short.

II. Immediate or Direct Ligature.—The experiments of Jones led the way to the immediate or direct ligature. Jones and his followers placed great stress on the laceration of the inner tissues of an artery by the circular constriction of the ligature in effecting provisional and definitive closure of the lumen of the vessel. The simple round ligature was gradually adopted by all surgeons who aimed at division of the internal coats by the ligature. The size of the ligature has also undergone considerable modification. Bell used fine, oiled ligatures, which he supposed would apply themselves accurately to the artery. Some united from two to as many as eight (Arndt) ligatures into one string. Lisfranc used moderately broad ligatures, but he claimed that in tying the knot they were changed into round cords and would as effectually divide the inner coats as the round ligature. Lawrence spoke highly of the use of very fine silk, dentist's silk, in tying arteries of any size. Velpeau used ligatures proportionate in size to the vessel to be ligated. Hodgson used the fine round ligature. A. Cooper was also in favor of the round single ligature. The circular constriction of Jones, with a single round thread, by degrees won the favor of surgeons, and firmly maintained its position as the best method of ligation until the advent of the aseptic ligature. The advantages presented by this method during the pre-antiseptic period were: 1. Effective and safe provisional closure of vessel. 2. Promotion of the process of definitive closure of vessel. 3. It favored the spontaneous elimination of the ligature by diminishing the amount of tissue included in its loop. The circular constriction of a blood-vessel by a round thread brings in apposition a sufficient surface of the intima, and, in the event of primary union, the resulting cicatrix affords sufficient resistance to the blood-current and effectually guards against secondary hæmorrhage. As the aseptic ligature, in aseptic tissues, never produces suppuration or other destructive changes which would interfere with the prompt formation of the intravascular cicatrix or weaken the vessel-wall, it should include a minimum amount of vascular tissue and should never be made to destroy the continuity of any of the tunics of the artery.

Forms and Number of Ligatures.—1. *Scarpa's Aplatissement.*—Scarpa's ligature was intended by its author to fulfil the two essential indications in obliterating the lumen of a vessel: (1) To arrest the circulation temporarily by mechanical pressure without lacerating the tissues of the vessel. (2) To approximate and keep in constant and accurate contact a comparatively large surface of the inner vessel-walls for union to take place by adhesion. His leading idea was that the intima resembles serous surfaces, and for rapid union to take place only a moderate amount of irritation is necessary, and that the injury inflicted by the circular ligature is too severe to obtain the most desirable result. He used ligatures two lines in width and tied over a small cylinder of linen. The ligature was usually expelled spontaneously about the fifteenth day; but if this did not occur, and the ligature lay loose upon the vessel, it was taught that it should be removed at this time. Scarpa's theories found many admirers, who introduced modifications in the operation to suit their individual ideas. Förster substituted for the cylinder of linen, charpie and cork; Deschamps, agaricus; Desault, small plates of wood; Cline, cork; and Roux, small rolls of diachylon plaster. In England this practice was advocated by Crampton, and in France it was represented more particularly by Boyer and Roux. Some exponents of the theory of aplatissement, while believing in the doctrine, objected to the introduction of foreign bodies into the wound, which they regarded not only as useless but as injurious to the healing process. Jameson used ligatures made of strips of raw chamois skin, which he claimed would, by their pliability and elasticity, hold in approximation the inner vessel-wall without inflicting injury on its tissues. Without means to prevent suppuration, it can be readily understood that the expectations held by the originator of this method of ligation and his followers were not realized, and it was by degrees displaced by the round ligature.

2. *Double Ligature.*—The double ligature is mentioned by Celsus and Ætius. Rolandus of Parma speaks of the double ligature as applied to the vena organica (jugu-

laris). John Bell and Maunoir not infrequently applied two ligatures in close proximity. In ligating arteries in their continuity Abernethy always applied the double ligature after isolating the vessel freely, claiming that, even if the intermediary isolated portion sloughed, the ligatures would successfully guard against secondary hæmorrhage. As an important advantage of this method he mentions that the vessel could be divided between the ligatures, thus relieving tension and allowing both ends of the artery to retract into the tissues, occupying then the same favorable position as vessels divided during an amputation. The double ligature has been frequently employed in experiments for the purpose of studying the process of cicatrization in blood-vessels after ligature, and will be again referred to in the section treating of that subject.

In regard to time, ligatures may be classified into: 1, Momentary; 2, temporary; 3, permanent. The first two varieties aim at obliteration of the lumen without loss of continuity of the vessel, while until recently the permanent ligature was always expected to divide the artery before it could be eliminated as a foreign body from the wound.

(1) *Momentary Ligature.*—A series of experiments on animals made by Jones satisfied him that frequently definitive closure of an artery could be obtained by drawing the ligature tightly and removing it at once. The rupture of the internal coats in many instances produced satisfactory closure by mechanically interfering with the circulation and causing the formation of a thrombus, the definitive obliteration following as the natural consequence of the traumatism. To insure these results more constantly, he made several of these circular constrictions in close proximity, so as to inflict a greater amount of traumatism and secure a larger surface for cicatrization. Jones called attention to the superior advantages offered by this method of ligation over all other methods, as it would secure obliteration of vessels without incurring the necessity of leaving a foreign substance in the wound. Unfortunately, however, the results obtained were so uncertain that he did not dare to recommend its adoption in practice. In many instances, as late as the third or fourth day, the artery was found permeable, a sufficient proof that the operation, with all its other advantages, lacked reliability. Porta made fifty experiments with the momentary ligature on dogs, sheep, and goats, with the result that partial or complete obliteration of the vessel by thrombus or lymph-coagulum followed in only ten instances, while in all of the remaining cases only division of the inner coats could be demonstrated. Maunoir attempted to accomplish the same object by different means. He crushed the internal coats of arteries with a forceps of his own construction, and expected the same series of changes to occur in their interior as the result of the laceration of tissues; but his results must have been equally unsatisfactory, as the procedure does not appear to have been adopted to any extent in practice.

(2) *Temporary Ligature.*—The temporary ligature was introduced for the purpose of obviating the deleterious effects of the presence of a foreign body upon the healing of a wound and the process of cicatrization in the blood-vessel. While the ordinary ligature remained for a period of time varying from three to twenty days, it was argued that the average time necessary for the ligature to remain was much less, hence various contrivances were invented which were intended as substitutes for the ligature and which could be removed with greater facility after the necessary time had elapsed; such were the pressure-forceps designed by Deschamps, Desault, Percy, Assalini, Koehler, Porter, Billroth, L'Estrange, Richardson, Crampton, Nunnelly, Wolfe, Jeoffresson, and Speir. A similar function and sphere were assigned to the percutaneous acu-pressure of Middeldorpf, the *ansa fili metallici* of B. v. Langenbeck, the filo-pressure of Dix, the *ansa hæmostatica a tergo* of Schmitz, and more recently the amovable ligature of V. v. Bruns. The laborious researches of Jones prepared the way for the temporary ligature. Travers believed with Jones that vessels are obliterated by inflammatory adhesive exudation and union between the inner coats, but affirmed that the inflammatory process requires a longer period of time to secure the requisite firmness in the adhesions. His first experiments were directed toward ascertaining the length of time required for a sufficiently firm adhesion to take place. The experiments were made on the carotids of horses and asses. The ligature was applied either in the form of a loop or tied over a tape placed parallel with the artery for the purpose of facilitating its removal. The ligature was removed after one, two, and six hours, and the animal killed from twenty to thirty hours after the operation. In fifty per cent. of the cases where the ligature remained for one hour the vessel was not obliterated. In all cases in which it was allowed to remain from two to six hours the experiments proved successful. From these experiments he concluded that six hours is the longest time required for the ligature to remain, and that by this time definitive occlusion will have always been accomplished. With a view to determine whether the closure of the vessel is perfect at this time, or whether obliteration is effected after the removal of the ligature, he made another series of experiments, dividing the artery on the peripheral side after removing the ligature.

These experiments satisfied him that definitive closure takes place *after* the removal of the ligature, and is effected by an exudation of plastic lymph. If the ligature remained for twelve hours, and the artery was cut on the peripheral side, no hæmorrhage followed its removal. He reduced his theory to practice by ligating the brachial artery in a man suffering from aneurism and removed the ligature fifty hours after the operation. No hæmorrhage followed, and the patient recovered. He next tied the femoral for popliteal aneurism, and removed the ligature twenty-seven hours later. Pulsation soon returned below the seat of operation. The disappointment due to the failure in this case deterred him from giving the temporary ligature further trial, and he returned to the ordinary ligature. This method was tested by a few English surgeons, but, not producing more encouraging results, was soon completely abandoned. Scarpa, in Italy, was the next advocate of the temporary ligature. His pathological views regarding the use of the ligature and the process of obliteration of vessels, as well as his method of ligation, are given elsewhere. Delpech claimed that a few days after ligation the ligature is found loose on the vessel, and consequently could exert no influence for good, and therefore should be removed, like any other foreign body, so as not to interfere with the normal healing of the wound. Velpeau also regarded the temporary ligature with favor. P. von Walther studied the effects of the temporary ligature on animals. With a ligature instrument of his own device he aimed to divide the inner coats of the vessel, and removed the ligature after from forty-eight to seventy-two hours, when definitive closure was always found. R. N. Smith constricted the vessels with an iron wire passed through a silver tube, and found arteries of the fourth and fifth size obliterated after six hours. The femoral artery was found permanently closed after two days. Victor von Bruns originated his method of filo-pressure in 1868.[11] The silk ligature which he used was passed around the artery and brought out of the wound through a silver cannula with a crossbar, to which it was fastened. Arteries of the size of the radial he found closed after eighteen hours, while larger arteries required from one to three days. For six years this method was used exclusively in all cases requiring ligation, in Bruns' clinic, with entire satisfaction. Only in two cases did secondary hæmorrhage occur; in one instance the common carotid was ligated during an operation for the removal of a cancerous tumor of the thyroid gland, and the ligature was removed on the fifth day; in the second case the femoral artery was ligated, and the ligature was removed on the third day. The great objections against the temporary ligature have always been that the wound could not be completely closed, or had to be reopened at the time of removal of the ligature, thus increasing the risks of suppuration and preventing primary union of the wound,

circumstances which the ligature was intended to obviate. Absence of suppuration and primary union of the wound are the most reliable safeguards against secondary hæmorrhage after any method of ligation, and a method which cannot secure these results with some degree of certainty must be considered as faulty in principle and practice, and this can be said without hesitation against the temporary ligature as described above. The aseptic animal ligature must be considered as a temporary ligature in every sense of the word, only that the material of which it is composed is removed by healthy active granulations instead of by the hand of the surgeon, an advantage which it would be difficult to overestimate, and which neutralizes all valid objections against the temporary ligature. The ligature of the future, then, will be the aseptic animal ligature.

(3) *Permanent Ligature.*—The permanent ligature is composed of a material which will remain for the most part unchanged in the tissues of the body, and is either permanently retained (encysted) or spontaneously expelled. Before the aseptic ligature came into use, the ligature usually cut its way through the remaining tissues of the artery in from three to twenty days, by a process of molecular death, and was spontaneously expelled, thus destroying the continuity of the vessel in every instance. Hodgson held that the ligature, as usually applied, divides the two inner coats of the vessel, and destroys the vitality of the circularly constricted portion of the adventitia, which separates like any other slough and comes away in the loop of the ligature. The same explanation is given by Guthrie, Brodie, and Gross. Bruns, however, maintains that the constricted portion, under the pressure of the ligature, undergoes molecular necrosis, a process necessarily attended by suppuration. He also claims that in animals, if the ligature is cut short, it cuts through the tissues and is encysted in the cicatrix. Porta studied the fate of ligatures in the wound experimentally. He made 300 experiments, using catgut, silk, hemp, linen, and horse-hair ligatures, cutting them short. The animals were killed in from a few days to three years after the operation. Of the 300 ligatures, 64 were completely absorbed (of 80 catgut, 33; of 120 silk, 19; of 50 linen, 10; of 40 horse-hair, 2). Of the 236 ligatures which remained in the wound, only 26 were found lodged in an abscess cavity. He claimed that the ligature destroys the continuity of the vessel by interstitial absorption. P. von Walther in his numerous experiments with the temporary ligature found the adventitia divided only in one case. He removed the ligatures at variable periods of time (from one to one hundred and ten hours) after operation. P. Bruns[11] made fifteen experiments to determine the effect of the ligature on the coats of vessels, and confirmed the observations of Walther. If the constricted portion of an artery is examined some time after the application of the ligature, it is not always easy to determine whether complete division has taken place or not. A few days after ligation the artery in close proximity to the ligature is thickened, the swelling on each side effacing the depression made by the ligature and shutting the ligature out of sight. The traumatic periarteritis produces a connective-tissue proliferation which covers the ligature and both ends of the artery in a similar manner as the provisional callus after fracture surrounds the broken ends of the bone. If the inflammation does not proceed beyond the process of tissue-formation, the granulation tissue is converted into cicatricial tissue, which forms an additional connecting medium between the ends of the artery, and by forming at the same time a capsule around the ligature the latter becomes permanently encysted. If the end of an artery is tied, the vitality of the ligated stump will depend on the manner in which the wound heals; if suppuration takes place, it will in all probability separate as a slough, and will escape with the ligature in the wound secretions; if, on the other hand, the wound heals by primary union, it will either remain in organic connection with the vessel and form new vascular communications with the adjacent tissue, or, in the event of a cutting through of the ligature, it may still retain its vitality and remain in the tissues, or finally it may be removed by gradual absorption. John Bell and Otto Weber were convinced that the end of the ligated vessel invariably separates and dies. There is, however, good reason to believe that the ligated artery stump, in the absence of suppuration, will retain its vitality and will again unite with the surrounding tissues from which it receives its nutrition. P. Bruns made a few experiments in this direction.

Experiment No. 1: Double ligation of carotid artery of the dog; division of artery between ligatures. The animal was killed, and parts were examined fourteen days after operation. The ends of the artery were separated 2 ctm., the interspace was bridged over by a band of connective tissue, in which were embedded both ligated stumps a short distance from the closed ends of the artery.

Experiment No. 2: Vessels and operation the same. The separated ends of the artery embedded in the intermediate connective-tissue string.

Experiment No. 3: Femoral artery; operation the same; local conditions the same, only that the bridge of new connective tissue was larger and firmer. The separated ends of the artery somewhat reduced in size.

Experiment No. 4: Femoral artery; operation the same. Separated pieces much smaller, and incorporated in the newly formed connective tissues.

In all of these experiments it appears that the ligature cut its way through the tissues of the artery, thus completely separating the ligated stumps, and still they retained their vitality through the influence of the surrounding living tissue. The ligatures were undoubtedly drawn very tight, and as the operations were done without antiseptic precautions, the reaction was in excess of that which is necessary to obtain obliteration of the vessels, and these circumstances will go far toward furnishing an explanation of the uniformity with which the constricted portion of the vessel gave way under the ligature. The use of the aseptic ligature and antiseptic wound treatment tend to preserve the continuity of the ligated vessel, as has been abundantly proved by clinical experience and experimental research. In many of my specimens it can be seen that weeks and months after the operation the ligatures remained in their original location and occupied the same relative position to the vessel as immediately after the operation, the ligature, in every instance where suppuration was prevented, being surrounded or encapsuled by a dense capsule of connective tissue.

If under antiseptic precautions the end of an artery is ligated, the stump of the artery retains its vitality in a similar way, and is nourished in the same manner as the pedicle after ovariotomy, with the only difference that in the former instance the local conditions are perhaps more favorable for the preservation of the vitality of the ligated parts.

Aseptic Ligatures.—In his first communication to the profession on this subject Lister alludes to the advantages of the aseptic ligature as follows: "If the antiseptic ligature be employed, it merely inflicts a wound or injury upon the vessel without introducing any permanent cause of irritation. The injured part, therefore, becomes repaired after the manner of a subcutaneous wound, without passing through the process of granulation and suppuration, which is induced by the employment of the ordinary septic ligature."[12] It may now be truly said that some form of aseptic ligature is used at present by almost every surgeon, and that while the merits of the antiseptic treatment of wounds are still denied by many, few or none would dare to use the ordinary ligature, or, in so doing, would realize that their duty toward their patients had not been conscientiously discharged. Perhaps no other surgical procedure has ever enjoyed the confidence of the whole profession throughout the civilized world to the same extent as the aseptic ligature. This universal faith in the reliability and safety of the aseptic ligature is only a natural outgrowth of the superior results following its use. Protracted suppuration in wounds—the result of retained ligatures—secondary hæmorrhage, and suppurative inflammation of vessels have been gradually diminishing in frequency, and bid fair, under the in-

fluence of the aseptic ligatures, to be almost completely expunged from the future category of wound complications. Nussbaum very appropriately remarks: "Catgut is, without doubt, Lister's greatest discovery."[13] And again: "How pleasant it is to cut the ligatures short and leave them, unconcerned, to their fate in the wound! In ovariotomies, etc., their value cannot be overestimated. The manner in which catgut adheres to an artery, forming connections with it and the surrounding tissues, assisting at the same time in forming a firm ring around the coats of the artery, are exceedingly welcome occurrences, guarding against secondary arterial hæmorrhage in ligating in the continuity of a vessel, and rendering even the application of a ligature in close proximity to a large collateral branch devoid of danger. All this, silk cannot do." Before the introduction of antiseptic surgery, suppuration at the seat of ligature was almost a necessity. As suppuration interfered seriously with the hyperplastic processes in the tissues of the arterial tunics, secondary hæmorrhage was of frequent occurrence, because the adhesion between the surfaces of the interior of the vessel-walls were not sufficiently firm to resist the intra-arterial pressure at the time of the separation of the ligature. It was on this account deemed necessary by the older surgeons, in deligating an artery in its continuity, to apply the ligature at least an inch distant from the next collateral branch, so as to favor the formation of a thrombus. The aseptic ligature marks a new era in the surgery of blood-vessels. Ligating a vessel under antiseptic precautions presents the following advantages:

1. The ligature remains undisturbed in the wound, becoming either absorbed or encysted after having fulfilled the purpose of a provisional hæmostatic.

2. Prompt obliteration of the vessel takes place by proliferation of new-tissue elements from pre-existing cells, independently of the formation of a thrombus; in fact, thrombosis is often wanting. The constricted portion of the vessel does not necrose; it is infiltrated, like the catgut, with living tissue.[14] Bardeleben makes a similar assertion.[15] In all operations with the aseptic ligature small size of the clot, and its frequent entire absence, is in remarkable contrast with the results observed after the ordinary septic ligature. The importance of the thrombus as an active agent in the definitive closure of vessels has vanished before the brilliant results obtained with the aseptic ligature. John A. Lidell, in speaking of vein ligature, says: "If a ligature of animal origin, such as carbolized catgut, has been applied, the approximated walls grow directly together, and the ligature itself disappears by absorption or is replaced by new connective tissue."[16] A discrepancy of opinion still exists regarding the time in which the catgut ligature is absorbed. The results of experiments in this direction have not been uniform. Lister ligated the carotid artery of a calf with carbolized catgut, and on examining the parts, thirty days after operation, he found only small portions of the ligature remaining, the rest having been absorbed, its place being occupied by new tissue. Czerny operated on rabbits, and examined the parts from one to thirty days after operation. After a number of days the ligature was always found loose on the vessel, softened and infiltrated with cells. Fillenbaum applied a double ligature to the carotid artery of a dog, and killing the animal fourteen days subsequently, found only microscopical remnants of the ligatures. Schuchardt experimented with guinea-pigs, and if the ligature was allowed to remain for five weeks, only traces of it remained. P. Bruns[17] operated on dogs four times, tying the femoral and axillary arteries, no antiseptic precautions being used, and the specimens were examined after ten days. In two cases the catgut ligatures had undergone but little change; in the third case the ligature could not be detected with the naked eye, but the microscope showed traces of it; in the fourth case two ligatures had been applied to the femoral artery, 4 ctm. apart, and in this instance the proximal ligature showed no change, while of the distal ligature only the knot remained. He also ligated the carotid artery three times, and examined specimens after twenty days had elapsed, and found only in one instance traces of the ligature on making longitudinal section of the vessel. In two cases he examined the ligatures after thirty days, the carotid and axillary arteries being the vessels tied, and found only microscopical traces. In four more operations he tied the axillary and femoral arteries, and examined after forty days, and on careful search found remains of the ligature in but one case, while in the other three the microscope revealed only traces. From these experiments he concluded that the catgut ligature, from the first to the tenth day, is either not changed at all, or that the changes are not constant; absorption is constant from the twentieth to the thirtieth day, and after the fortieth day only microscopical remnants can be found. M. Arnaud, in a series of careful experiments, gives these results in regard to the absorption of carbolized catgut ligatures:[18]

Catgut disappeared once in	4 days.
Catgut disappeared twice in	7 days.
Catgut disappeared once in	9 days.
Catgut distinctly visible once in	4 days.
Catgut distinctly visible once in	9 days.
Catgut distinctly visible once in	11 days.
Catgut visible, but softened and infiltrated, once in	16 days.

A most valuable contribution to our knowledge of the behavior of catgut in the different tissues of the living body we owe to Von Lesser, of Leipzig.[19] The time required for absorption, although variable in the same animals and in the same locality, will depend on: 1, The quality of the ligature; 2, the size of the ligature; 3, the nature of the tissue with which it is kept in contact; 4, the presence or absence of suppuration. P. Bruns claims that catgut is dissolved by pus, hence it will disappear in a shorter time in wounds that suppurate. In my experience I have observed the contrary. In suppurating wounds I have seen the catgut remain unchanged for an exceedingly long time, and after weeks have seen the ligature come away in the secretions, having undergone but little change. The absorption of the catgut ligature is accomplished by a process of softening and infiltration of cellular elements, and is consequently accomplished in the shortest space of time in wounds in which the process of granulation is not impaired by suppuration. The immediate and remote effects of the catgut ligature on the vessel also deserve consideration. The impression prevailed at one time that the catgut ligature does not destroy the continuity of the artery. This assertion has, however, met with opposition. P. Bruns,[11] in his experimental work, has made special search in this direction in thirteen ligations of arteries in their continuity. In the three specimens obtained ten days after operation, he found the artery completely severed in one instance, while in the other two cases a fine thread of adventitial tissue was found in the loops of the ligatures. In the remaining ten cases, in which only traces of microscopical remnants of the ligatures could be found, three different conditions of things presented themselves. In three cases the vessel was completely divided in the same manner as occurs after the ordinary ligature is used, only the intermediate space between the vessel-ends was less than after the silk ligature had been employed; the space measured only from one and a half to three millimetres, and was filled in with connective tissue. In six cases a solution of continuity had apparently not taken place, and its occurrence was ascertained only by close examination. The place of ligature presented a somewhat prominent circular ring; on making a longitudinal section the intima and media were found severed, and their margins directed toward the interior of the vessel, shutting off its lumen on both sides by a concave or funnel-shaped end. The interspaces between the two blunt ends was occupied by a solid intermediary substance about the thickness of the ligature and continuous with the adventitia. The intermediary substance was composed of young connective tissue, interspersed with particles of the catgut ligature. In one case the continuity of the vessel was perfect, all of its coats being entire. Evidently the ligature was not tied with the same degree of firmness as in the other cases. The lumen was only narrowed by the ligature and rendered impermeable by a

thrombus. Bruns is willing to admit that in case the catgut ligature is drawn only sufficiently tight to interrupt the circulation, all of the coats of the artery remain intact during the healing process, and the continuity of the vessel is preserved in the strictest sense of the word. He also asserts that in the cases in which division of the vessel has taken place, and a bridge of connective tissue corresponding to the diameter of the ligature has been formed, this process may *practically* be regarded as similar to the process of healing, without loss of continuity of the vessel-tunics. Stimson[20] agrees with Bryant, that the catgut ligature not only primarily divides the two inner coats of an artery like the ordinary silk ligature, but that subsequently the adventitia also gives way under the pressure of the ligature, thus completely interrupting the continuity of the vessel. They affirm that the bridge of intermediary connective tissue may impart an appearance as though no division had occurred. The results of my experience have demonstrated to my satisfaction that it is not necessary to tie with sufficient firmness to divide any of the arterial coats, and yet prompt obliteration of the artery will ensue, and that in such instances the coats of the vessel are transformed into a solid string of connective tissue, the best possible result which can be obtained after ligature. Even in case the ligature is tied with sufficient force to rupture the inner coats, the constricted adventitia may retain its vitality and form part and parcel of the intermediary connective tissue, uniting the two ends of the vessel; and still further, if the vitality of the adventitial coat is suspended, and it is removed by a slow process of molecular disintegration and absorption, it is replaced by elements which are converted into a similar tissue, thus practically preserving the continuity of the vessel. In the event of suppuration, the advantages of the aseptic catgut ligature are lost, and the ligature escapes with the discharges, either entire and unchanged, or in fragments after it has undergone softening and disintegration. Ligatures made of any other animal tissue rendered properly aseptic are disposed of in the wound in a similar manner as catgut, and it has not been proved that any of them possesses any advantages over the well-prepared catgut ligature. Mr. Barwell,[21] in tying large arteries, uses a broad ligature made of the strong middle coat of the aorta of the ox. His idea is to approximate the intima without rupturing it. In sixteen cases of ligation of large vessels this method proved successful. In one case of ligation of the femoral artery hæmorrhage occurred at the time of operation from a small opening near the ligature; at the request of Mr. Barwell two more ligatures were applied within an inch of the first ligature, and the case terminated favorably. Mr. Barwell still maintains the novel belief that his ligature material is not absorbed, but is organized and becomes a part of the living tissue around it. Aseptic ligatures made of materials which are not capable of being absorbed remain in the wound and are encysted. All of these ligatures are more prone to destroy the continuity of the vessels than animal ligatures, but they do not do so invariably. Czerny's silk, for example, which is used next in frequency to catgut, is infiltrated with cellular elements, and, after a long time, is partly absorbed and completely encysted.

Practical Suggestions.—The results of my own experiments,[22] as well as the literature on the subject, tend to prove that all kinds of ligatures, provided they have been made aseptic, always become encysted in aseptic wounds. All ligatures, however, which permanently resist absorption destroy the continuity of the vessel, and on this account, instead of adding strength to the paravascular cicatrix, weaken the vessel-walls at the seat of ligation. I have never observed a single case, in hospital or private practice, where the catgut ligature failed to fulfil in the most satisfactory manner the purposes of a provisional hæmostatic agent until the definitive cicatrix had become sufficiently firm to resist the intra-arterial pressure. In place of severing the tunics of the ligated vessel, the catgut ligature is gradually displaced by organized tissue, which increases the resisting capacity of the vessel, providing an additional safeguard against secondary hæmorrhage, if from any cause definitive obliteration is retarded. In enumerating the superior advantages of the catgut ligature, Nussbaum says: "The most careful microscopical examinations have shown that catgut increases to a considerable extent the resisting capacity of an artery in forming firm connective-tissue connections with the vessel."

The aseptic animal ligature possesses two distinct and important advantages over all permanent ligatures. 1. It does not necessarily destroy the continuity of the vessel. 2. It gives additional strength to the extra-vascular cicatrix. These advantages recommend the animal ligature more particularly for the purpose of tying an artery in its continuity. I am firmly convinced that in many of my experiments the internal tunics of the arteries remained intact after ligation, and yet cicatrization progressed in a satisfactory manner; hence it is no longer necessary to tie the ligature so firmly as to crush the tunics of the vessel. All that is necessary is to tie with sufficient force to approximate the inner surfaces of the intima, with a view to insure effective provisional obliteration of the vessel, when cicatrization will follow as a necessary result, provided the vessel-tunics are in a healthy condition. If cicatrization in a vessel takes place from the fixed cells of its tunics, without the formation of a thrombus, it will be seen that in many instances a vessel can be ligated with safety in its continuity, close to a collateral branch, when existing circumstances dictate such a course. Objections have been made by different surgeons against the safety of the catgut ligature, as it has been claimed that the slipping of the knot has frequently given rise to secondary hæmorrhage. To guard effectually against this accident it is only necessary to make a surgeon's knot, which will securely hold the ligature in place until definitive closure of the tunics of the vessel has taken place. One of the constant rules usually given by all authors in vessel surgery was to make a small opening in the sheath of the vessel, of only sufficient size to permit the passing the ligature needle around it. It was feared that a more free opening in the sheath, and a more extensive isolation of the vessel would lead to necrosis of its tunics on account of the cutting off of the vascular supply. That this idea still prevails is evident from one of the most recent text-books on surgery. Lidell calls special attention to this point in the following language: "The risk of sloughing, however, arises mainly from isolating the artery too much, or from separating it too extensively from its sheath, while dissecting to expose it, or while preparing to pass a thread around it whereby the minute vessels which nourish its coats are too extensively destroyed; hence the danger of passing a spatula or the handle of a scalpel under the artery, and of dragging it out of its bed when tying it."[23] All of these fears are unfounded when the operation is performed under antiseptic precautions. In all of my experiments I did all that is here cautioned against. I isolated the arteries and veins from their sheaths for an inch or more, and dragged the vessel near to the surface of the wound in applying the second ligature, and yet I never observed any sloughing except in the cases in which the operation was followed by suppuration. I am strongly in favor of opening the sheath freely, so that the operator can not only feel, but *see* what he is doing, and I am convinced that by pursuing this course there is less harm done than by operating in the dark.

My experiments on the veins have taught me another important and practical lesson, viz., their tolerance to traumatic insults. In not one of the cases was death produced by the operation, although in a few of the animals both the jugular and femoral veins were tied at different times. I never observed progressive phlebitis, embolism, or pyæmia. Veins like those of the peritoneum may be contused, torn, lacerated, cut, punctured, burned, and ligated with immunity, if infection is avoided. Veins are exceedingly prone to infection, but if infection can be prevented, their injuries are repaired with wonderful rapidity. As regards the time required for definitive obliteration to take place, the results of the experiments would indicate that, in the case of arteries of the size of

the carotid or femoral, from four to seven days are necessary, while in the jugular vein the same object is accomplished in three to four days. The double catgut ligature may be resorted to with advantage in the human subject in ligating large vessels in their continuity, more especially if the operation is done near a collateral branch, as it approximates the inner surfaces over a larger area and thus furnishes a more extensive surface for cicatrization. The practicability and utility of the double ligature are, however, rendered most apparent in the treatment of varicose veins. For many years I have successfully used the subcutaneous double catgut ligature in the treatment of varicocele. In operating on varicose veins of the lower extremity the intervening portion can readily be rendered bloodless by applying an Esmarch bandage before tying the ligatures. The entrance of blood into the vessel between the ligatures, through small collateral branches, can be prevented, and the process of cicatrization materially assisted by applying an antiseptic compress over the seat of the operation before removing the elastic bandage. *N. Senn.*

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LIGHTNING, THE EFFECTS OF. The frequency with which persons are struck by lightning varies much in different countries, but is greatest in the temperate zones, where thunder-storms are the most frequent. In the higher degrees of latitude they occur less often, and are nearly absent in certain parts of the tropics. In the United States and in most countries of Europe deaths from lightning-stroke occur with moderate frequency, and injuries from lightning, which do not prove fatal, are still more common. The total number of deaths from lightning in France, in fifty years, from 1835 to 1885, was 4,609. According to the English Registration Reports, the number of deaths from lightning in England and Wales for a period of twenty years, from 1865 to 1884 inclusive, was 416. Hofmann reports that in 1870, 202 persons were killed by lightning in the United States. The number of deaths from this cause in Massachusetts during fifty years, from 1855 to 1884 inclusive, was 101. Out of 82 persons thus killed 25 were females, 57 males.

The effects of lightning upon the object struck are manifold and various, and we see very different results produced, according to the varying circumstances. These results depend both upon the form of the lightning, that is, upon its *quantity* and *intensity*, and upon the receptivity or conductivity of the object struck.

Three forms of lightning are commonly described: The sheet lightning, the zigzag lightning, and the ball lightning. Sheet lightning appears in the form of a broad flash, is usually paler than the other forms of lightning, and extends over a considerable surface, with rapidly changing, feebly marked outlines. It may be either simple or compound, in the first case there being only the simple flaming flash, while in the second, a tense, thin, burning flash is combined with it. Zigzag lightning, on the other hand, is more vivid and dazzling, more intense, and consists in appearance of a sharply defined line of fire passing from one point to another, forking and forming well-marked zigzags in its course. Ball lightning is so rare and so terrible that we have few trustworthy accounts of it. It is said to consist of a fiery globe of a reddish tint, rotating on its axis, which slowly traverses the ground, sometimes at an elevation of a few feet, and which, in some cases, explodes with a loud noise and emits vivid flashes of lightning in all directions.

The various forms of lightning have been more or less closely imitated artificially by various observers, and certain other forms of powerful electrical action have been produced. From experiments made with very powerful currents of electricity on animals, certain deductions have been drawn in regard to the action of the different forms of lightning.

Dr. B. W. Richardson, in his experiments with the immense induction coil of the Royal Polytechnic Institution, the primary wire of which is 3,770 yards, and the secondary wire 150 miles long, succeeded in producing four forms of electrical spark, each of which produced different effects on the living organism. The third and fourth forms, however, varied more in degree than in kind. These four kinds are as follows:

1. The simple discharge, in which the secondary wire is simply charged from the primary wire. The spark thus produced, which in this case was twenty-seven inches long, consists of two flames—of a line of thin, blue, tense flame, surrounded by a thick, burning flame, which can be blown aside with a bellows. This form has been likened to the sheet lightning. A single shock of this character on the external surface of the animal body is harmless. There is sometimes a slight singing of the hair or fur, and general muscular contraction ensues, but the animal remains uninjured. If the shock be many times repeated a peculiar anæsthesia is produced which will last for a considerable time. Even when passed directly through the tissues, as by needles run into the flesh, this form of electricity does not injure.

2. The second form is the interrupted current. It differs from the first merely in the fact that the latter is a constant current, and continues steadily and equally while in action; but in this form we have a continual series of changes, rapid alternations of current and no current. It is produced by means of a vibrating or mechanical break. The spark is blue, intense, forked, almost continuous. This form has been likened to the zigzag lightning. When applied to the external surface of the animal body this, like the preceding form, is found to be harmless, but the muscular contraction thereby produced is persistent or nearly so. If conducted through the body, the muscular contraction becomes more pronounced, and, as the current is continued, the muscles of respiration are affected (contract) and death may occur from asphyxia.

3. The third form of electrical discharge is that obtained from a Leyden jar directly charged from the induction coil. This form is not yet recognizable in lightning. When received on the exterior of the body this form does not kill, but if it once succeeds in piercing the surface one or two shocks usually cause death. This shock, when not fatal, may cause a state of insensibility, in which the body lies prostrate and is analgesic, but may still be capable of recovery. There are frequent convulsive movements, and contusions are often found.

Richardson supposes that when death occurs the shock has affected the centres which govern the involuntary acts: (1) The respiratory, and (2) the circulatory. When

death does not occur, it affects nervous centres governing voluntary acts and common sensibility.

4. The fourth form, which may be known as the intensity discharge, is produced by charging a number of jars in cascade, that is, Leyden jars connected together *in series*, heterologously. The spark is not flaming and not burning; as it falls on the animal body it does not pass harmlessly over the surface, but penetrates, and always kills. It leaves no mark on the body, which retains the position which it was in before being struck. This action seems to be due to its intensity, and we find many cases of lightning reported in which similar results are said to have occurred.

M. Planté, with his enormous secondary battery and condenser arrangement, has succeeded in producing a form of electricity closely resembling ball lightning. "The effect appears to consist of a kind of brush discharge through films of moisture or vapor, which form an apparent globe of fire rotating on its axis" (Sprague).

The second factor which acts to determine the effect of lightning upon the person struck is the condition of the person at the time of the accident.

Position.—Persons are naturally more liable to be injured by lightning, if, during a thunder-storm, they find themselves in the vicinity of objects which are good conductors of electricity and are not so placed as to convey the electricity away from them, either to the earth or elsewhere. Lightning conductors do not act as protective agents because they attract or convey a discharge from the clouds, but because they supersede or prevent the condition of polarization or tension in the space to be protected. People may, however, be struck by lightning almost anywhere. Most frequently this occurs out of doors, and in that case usually under trees; but it may occur to persons who have sought shelter under hayricks, behind piles of sheaves, or in sheds. Not rarely a person has been struck in the open field, or plain, where there was no object of height in the vicinity, or on the road, or even in the street, or on the quay. Sailors or persons on board ship are peculiarly liable to be struck, unless the vessel be properly protected. When inside buildings, the persons struck are usually near an open door or window, where there is a draught, and through which the lightning enters, and the danger is increased if there be some metal object in the vicinity.

Out of 30 cases of lightning-stroke, taken at random, I find that 20 occurred out of doors; in 8 cases the people struck were under trees, in 2 behind ricks, in 3 cases the persons were in an open field or on the prairie, in 3 on the streets or road, in 2 in the garden, in 1 case the persons struck were sitting on a rock in an open field near a metal bell, and the last case was that of a soldier on guard. Three cases were on board ship, and 7 in buildings; 1, however, where the persons stood at an open barn-door, 1 where they were only under a shed. In 3 cases the people injured were at church; in 3 cases only, in a house. People carrying with them, or on their persons, metallic objects during a thunder-storm, thereby render themselves more liable to be struck, and if struck to be more seriously injured. As the liability to be struck by lightning varies according to the place and surroundings of the person, so the amount of injury likely to be received is affected by the character and condition of his clothing and the objects which he may have about his person or in contact with him. Thus, if the clothing be of such character as to be a good conductor, the lightning may pass along it, leaving the body only slightly injured, or possibly untouched. When wet, clothing conducts better than when dry. If the person struck has about him metallic objects, the lightning will probably pass through these objects rather than along the adjacent skin; but where the metallic conduction ceases, and the lightning passes from the good-conducting metal to the badly conducting body, that is, where the lightning meets with resistance in its course, there it is likely to produce more serious effects. In other words, the greater the resistance, other conditions being equal, the deeper and more severe is the burn. Thus we find that the lightning, in its course from the head to the feet, not infrequently meets with a chain, a metal band, or a a truss, and almost invariably follows this, at least in part, and causes a deep burn where it again transfers itself to the skin. The same thing occurs in the case of a watch, of keys, coins, metallic buttons, shoe-buckles, and the like.

Action of the Lightning on the Clothing.—Clothing may be treated by the lightning in the most various ways, and this often without reference to the injuries of the body underneath. It may be uninjured, while the person himself is killed or injured (Nick, Alexander), or, on the other hand, the clothing may be torn to pieces, or even carried away entirely, while the portion of the body to which it belongs is unhurt. In rare cases the sufferer is stripped entirely naked, as in that of Wilks, where absolutely nothing was left on except part of the left arm of a flannel vest. In this case the patient was much burnt and otherwise injured. As a rule, however, when a person is badly burnt by lightning the clothing also is more or less injured. It may be burnt or pierced or torn into large or small pieces, or even into the finest shreds; any solid portions may be broken, bent, or crushed. When, as most frequently occurs, the patient is first struck by lightning in the head, we usually find an irregular hole in the hat or cap corresponding to the injury. The head covering, however, may be totally destroyed (Griffin), or we may find several holes in it (Heusner). In Van Horn's case the hat was riddled with minute holes.

The clothing about the body—coat, vest, shirt—may be burnt, torn to pieces, or carried entirely away. The pieces may be large or small, or the article injured may be reduced to fine shreds or fibres (Claes, Van Horn).

The trousers may be the conductors of the lightning from the waist downward, or it may pass along the limb, or the current may be divided and go in both ways. The wetter the trousers the better conductors, and hence the more likely is the current to pass along them. Thus they may be entirely destroyed, or partially burnt and torn, or wholly spared.

Of all portions of the clothing injured, however, the coverings of the feet are the most commonly and the most seriously so, because here the lightning usually makes its exit from the body, and the resistance is greater here than elsewhere. The injury may be of various kinds. The boot or shoe—and of course the stocking—may be simply pierced as by a bullet (Davies). More often a large hole is torn in it, or it may be torn to pieces, or even reduced almost to lint, as in the case of Decerez, where the foot was entirely uninjured. If a wooden shoe be worn it may be broken to pieces (Gabart). In Dressler's case the shoe was torn into little pieces, shrivelled, and burnt, yet the foot was unhurt. The whole shoe may be carried off, or the sole alone taken, which latter may be cleanly divided from the upper leathers.

The shoe-buckles may or may not be injured.

Metallic objects which are in the pockets or about the person may be bent, broken, or otherwise injured. More rarely they are fused. Iron objects are often magnetized.

Symptomatology.—The effects of lightning on the human body are so various, and the combinations of symptoms so manifold, that to attempt to give more than a general sketch of them would be impossible. We will therefore first describe in a general way the results of lightning-stroke, and afterward take up the more important symptoms in detail. For our present purpose we will divide the cases of lightning-stroke empirically into three divisions—the mild, the severe, and the fatal. Of course in nature these three divisions run into each other, and many cases stand on the border-line.

1. *Mild Cases.*—In the mild cases the patient when struck is dazed, and may or may not lose consciousness for a short time. He may or may not have the impression of a blow or of a dazzling light, and he may or may not be knocked down. On recovery of his faculties he usually experiences temporary anæsthesia, paræsthesia, or paralyses of one or more extremities, which rarely last more than twenty-four hours. The anæsthesia and paralysis