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AN EXPERIMENTAL INQUIRY CONCERNING ELASTIC CONSTRICTION AS A HÆMOSTATIC MEASURE.

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BY

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AN EXPERIMENTAL INQUIRY CONCERNING ELASTIC CONSTRICTION AS A HÆMOSTATIC MEASURE.

Elastic constriction in the treatment and prevention of hemorrhage is a procedure which has been known for a long time, but it required the genius and influence of the distinguished von Esmarch to give it a permanent place in the practice of surgery. During the last decade, circular elastic constriction has almost completely displaced all other methods of securing temporary hæmostasis. This method of preventing or arresting hemorrhage in the treatment of wounds and the operative removal of surgical affections of the extremities is so simple, and the means required are so accessible, that it is now almost in universal use, and the different forms of tourniquets heretofore in use are for substantial reasons regarded by the modern surgeon as objects of antiquity. When first introduced as an aid to the surgeon, its inventor aimed at rendering the tissues on the distal side of the constrictor perfectly bloodless by applying, from the periphery of the limb to the point of constriction, an elastic bandage. This part of the technique of "bloodless" operating is not only unnecessary but harmful.

Dangers attending Elastic Compression of a Limb.—Compression of a limb by an elastic bandage, as a preliminary step to elastic constriction, secures for the tissues the seat of injury or the field of operation perfect ischæmia, but is attended by two sources of danger: 1. When resorted to in the treatment of a recent injury or an infective inflammation, it might force pathogenic microbes from the wound or the seat of inflammation into the general circulation, thus adding a general to a local infection, with all the additional risks incident to such a condition. 2. In operations for malignant disease, carcinoma or sarcoma, it might force tumor-cells into the surrounding tissues, or through the lymphatic or blood-vessels into the general circulation, causing thus regional or general dissemination of the disease. These two sources of danger are not imaginary but real, and every surgeon with considerable experience can recall instances where elastic compression could be made answerable for the diffusion of an inflammatory process or the dissemination of a malignant tumor. Fortunately, Lister's experiments on the horse have demonstrated that for all practical purposes bloodless operations can be made without the use of the elastic bandage by simply placing the limb in a vertical position for a few minutes prior to the application of the constrictor.

Diminution of Blood-Supply to the Limb by Gravitation.—The influence of the force of gravitation on the supply of a limb becomes apparent by placing the arm in different positions. If one of the upper extremities is allowed to hang by the side of the body, and the muscles are fully relaxed,

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the veins become turgid, the capillaries distended, and the volume and force of the radial pulse markedly increased, and a sense of fulness and weight is experienced. If the arm is now elevated and held in the vertical position, within a few minutes the cyanosed appearance of the skin disappears and gives way to pallor, the overdistended veins collapse and are emptied of their contents, the radial pulse loses much of its volume and force, and the sense of weight and fulness is promptly relieved. If the limb is maintained in this position for five minutes, it is emptied of blood sufficiently to render operations, for all practical purposes, bloodless at any point below the elastic constriction. If an anæsthetic is used, elevation of the limb and the application of the elastic constrictor should not be done before the patient is thoroughly under the influence of the anæsthetic, as muscular relaxation is a material aid in securing a comparatively bloodless condition of the limb.

Form and Application of Constrictor.—Many surgeons have been in the habit of using a small solid rubber cord or a rubber tube of small size as an elastic tourniquet. Both of these forms of elastic constrictor are objectionable, as in either instance linear constriction is made, which, particularly if the force employed be excessive, as is so often the case, is so liable to cause temporary or permanent damage of some of the important tissues interposed between the skin and the underlying unyielding bone. The compression should include a ring at least two inches wide, in order to distribute the pressure over a larger area, in which event important structures are more likely to escape injury.

The best instrument for elastic constriction is a strong band of rubber at least an inch in width, of which at least two turns are applied side by side. In the absence of such a constrictor a soft rubber tube half an inch or more in diameter, an ordinary rubber bandage, or an elastic suspender should be used. As soon as the limb has been drained of its blood to the requisite extent by position, the constrictor is applied with sufficient firmness to interrupt at once both the arterial and the venous circulation. Simple as this advice may sound, it is nevertheless a fact that frequent mistakes are made in applying the constrictor properly. It is of the utmost importance that the pressure should first be made on the side of the limb occupied by the principal blood-vessels. If pressure is made first on the opposite side of the limb, the superficial veins are constricted first, and before the arterial circulation is interrupted, the limb presents a cyanotic appearance, caused by an intense passive venous stasis. If, on the other hand, the elastic pressure is applied in such a manner as to arrest the principal arterial blood-supply first, venous return in the superficial veins is not interfered with until the circular constriction is completed, and the limb below the constriction is then in a comparatively bloodless condition, and remains so after the application of the constrictor. Some tact and experience are necessary in regulating the force required to interrupt quickly and completely the arterial and venous circulation. Less force is required, of course, when the main blood-vessels are near the surface and close to a bone than when a thick

layer of muscles is interposed between skin and blood-vessels or between blood-vessels and the underlying bone. Pressure beyond the required degree, especially if continued for an hour or more, is liable to result in injury of muscles and nerves, and should be carefully avoided. Instead of using the chain, or tying the constrictor in a knot, it is better after encircling the limb at least twice to cross the constrictor and fasten it between the blades of a heavy hæmostatic forceps. A well-recognized disadvantage of elastic constriction as a hæmostatic measure is *increased parenchymatous hemorrhage.*

The profuse capillary oozing which so often follows the removal of the elastic constrictor is undoubtedly, at least in part, due to a temporary vasomotor paresis caused by the constriction. This result is obviated most successfully by keeping the limb in an elevated position at the time the constrictor is removed, and by maintaining this position for at least six hours. The intravascular tension is reduced to a minimum by elevation of the limb, and this condition is most conducive to the formation of a minute thrombus in each of the small vessels—capillaries, arteries, and veins—divided during the operation. Another exceedingly useful resource in diminishing unnecessary loss of blood, after all visible vessels have been ligated and the constrictor has been removed, consists in making firm pressure against the wounded surface. This is most effectually done by using a moist compress of gauze large enough to cover the whole surface, which is firmly held against the wound with one or both hands. After an amputation, for instance, all the principal vessels should be sought for and tied before the constrictor is removed, and the limb held in a vertical position. A compress of moist gauze is then placed against the wound surface, the flaps brought over it, and firm compression made over the end of the stump with both hands for at least five minutes. If the capillary oozing does not yield to this treatment the wound should be irrigated with sterilized water at a temperature of 110° F., which makes a delicate white film on the surface, and has a very prompt effect in definitely arresting the bleeding. In obstinate cases the addition to these expedients of an application of peroxide of hydrogen serves an excellent hæmostatic purpose, and does not interfere with primary union of the wound.

Other complications arising directly from elastic constriction are—

Temporary Loss of Muscular Power and Nerve Paralysis.—These consequences undoubtedly are often the direct outcome of a faulty use of the constrictor. The experiments related below show conclusively that firm constriction, continued for several hours, almost invariably results in loss of function of the limb, which continues for several days or weeks. In these instances the disability was undoubtedly due to injury of the constricted muscles. If in the use of the constrictor more force is used than is necessary to interrupt the circulation, and particularly if linear pressure is made, injury of the muscles exposed to this undue pressure is very likely to be produced. The same can be said of injury to the nerves from the same cause. Two cases of nerve paralysis resulting from elastic constriction have occurred in my own practice.

The first case was a young man who was the subject of necrosis of the radius. Elastic constriction was made just above the elbow-joint at a point where the musculo-spiral nerve is almost subcutaneous. The operation lasted about an hour. The next day it was discovered that the patient was unable to extend the hand. The operation was performed under strict antiseptic precautions, and the wound healed without suppuration. The function of the nerve was destroyed as completely as though it had been divided. Massage and electricity were used at the end of the second week, but no signs of improvement were noticed before the expiration of two months, and function was not fully restored at the end of three months. During this time muscular atrophy was noticeable. With the restoration of nerve-function muscular nutrition set in, and eventually the use of the hand and forearm was restored to perfection.

The second case was a student suffering from extensive necrosis of the tibia. Elastic constriction was applied just above the knee-joint. The disease involved nearly the entire shaft of the tibia. The skin flaps were turned inward into the deep gutter and fastened with aseptic bone-nails. Necrosis of the margins of the wound set in, and the extensive cutaneous defect was replaced by a slow process of granulation, cicatrization, and epidermization, which required several months to complete the healing process. Soon after the operation it became evident that the function of the peroneal nerve had been destroyed by the elastic constriction. Electricity and massage proved of no avail in restoring nerve-function. Two years after the operation the paralysis remained and has persisted to the present time.

For the purpose of preventing injurious pressure on nerves from elastic constriction it is necessary to tie only with sufficient firmness to interrupt the arterial and venous circulation, and the pressure should not be linear, but distributed over a wide area, a ring at least one inch or two in width. The last requirement is best attained by using a wide band, or if an elastic tube or cord is used the limb should be encircled several times, each turn drawn with uniform force and arranged in such a manner as to compress with equal firmness a wide circle, thus exerting the same effect on the tissues underneath as pressure made by a wide band. If for any reason the constriction cannot be made at a point where the principal nerves are well protected by a thick layer of muscular tissue, a thick compress of gauze should be placed between the constrictor and the limb, in order to protect the nerves against injurious pressure.

Necrobiosis and Gangrene following Elastic Constriction.—Experimental research has shown that an ischæmic condition and elastic constriction for two hours or more are liable to produce an unfavorable influence on the karyokinetic processes in the tissues deprived of blood for this length of time. This is a sufficient proof that prolonged constriction retards the healing process. Necrobiosis, slow healing, and necrosis of margins of the wound are some of the remote consequences which follow prolonged constriction of a limb. At the last meeting of the National Association of Military Surgeons in St. Louis, Major Hoff gave some highly interesting and instruc-

tive demonstrations of litter drill. I had the pleasure, at his request, to catechise one of the members of his corps in reference to elastic constriction as applied on the battle-field. I asked the young soldier how he would distinguish between arterial and venous hemorrhage. He pointed out very clearly the signs upon which he would depend in distinguishing between these two forms of hemorrhage. I further asked, "How long would you deem it safe to continue elastic constriction as a hæmostatic measure?" He replied that he never would allow it to remain longer than two and a half hours. This matter may become—perhaps it has already—the subject of serious medico-legal thought, and no one is in a better position, where he has such abundant opportunity in testing the reliability and safety of elastic constriction as a means of controlling hemorrhage, than the railroad surgeon. In the use of Esmarch's constrictor in arresting hemorrhage that threatens life, it is practically not necessary to distinguish between venous and arterial hemorrhage. It was the consensus of opinion of the members of the military section of the last International Medical Congress in Berlin that it is no longer wise nor practical to differentiate between arterial and venous hemorrhage in rendering the first aid to the wounded on the battle-field or in a case of accidental hemorrhage; that the one point that must be taught the soldier, the brakeman, and the conductor is that, if hemorrhage is so profuse as to threaten life before medical aid can be summoned, it should be at once arrested by elastic constriction,—by a suspender if nothing else is at hand,—applied invariably on the proximal side of the seat of injury. The constriction must be made with sufficient firmness to arrest completely both the arterial and venous circulation, as has been repeatedly insisted upon above. By applying the constrictor only with sufficient firmness to diminish the arterial circulation the venous hemorrhage is increased. It is by overloading the tissues with venous blood by imperfect constriction that gangrene is invited and venous hemorrhage increased.

The following experiments were made for the purpose of studying the effect of prolonged elastic constriction on the nutrition of the parts excluded temporarily from the circulation. The constriction was made with rubber tubing a quarter of an inch in diameter, with which the limb was encircled at least twice, and tied with sufficient firmness to interrupt both the arterial and venous circulation completely. As the constriction appeared to produce considerable pain, the animals were kept fully under the influence of morphine, which was administered subcutaneously, usually in divided doses. I am greatly indebted to Dr. C. W. Oviatt, of Oshkosh, Wisconsin, for valuable assistance in conducting these experiments.

CONSTRICTION EXPERIMENTS.[1]

First Series.

1. Large female dog. Constriction above knee-joint by three turns of strong elastic tubing. Time of constriction six hours. Cut the posterior tibial artery and vein before removal of constrictor. About a tablespoonful of dark blood escaped,

[1] Experiments performed February 14, 1892.

soon followed by bright arterial blood. Circulation restored. Dog killed to secure bone-plate specimen from operation six weeks previous.

2. Medium-sized male dog. Constriction above ankle-joint. Time of constriction eight hours. Plantar artery cut before removal of constriction. About a teaspoonful of dark blood escaped. Arterial hemorrhage appeared a few minutes after removal of constrictor. Dog killed.

3. Large female dog. Constriction by three turns of tubing above elbow-joint. Time of constriction three hours. Limb perfectly cold below constriction. Pulsations distinct a few moments after removal of constrictor, with prompt increase of temperature. Puncture yields arterial blood. Limb useless. Recovered the full use of limb in fifteen days.

4. Large male dog. Constriction by three turns above wrist-joint. Time of constriction seven hours. Pulsations distinct soon after removal of rubber tubing. A deep groove in muscles at point of constriction. Was unable to use the limb at all for five days. Recovery complete in nine days.

5. Male puppy. Constriction by two turns above knee-joint. Time of constriction three hours and thirty-five minutes. Return of pulsations prompt after removal of constrictor. Puncture in sole of foot followed by free hemorrhage. Recovered the use of limb in four days.

6. Male poodle. Constriction above knee-joint. Time of constriction two hours and twenty-five minutes. Return of circulation prompt after removal of constrictor. Recovered in three days.

7. Large female dog. Constriction above elbow-joint. Time of constriction four hours. Deep gutter in muscle at point of constriction after removal of tubing. Pulsations felt distinctly almost immediately after removal of constrictor. Limb entirely useless for four days. Did not fully recover until twelve days.

8. Female pug. Constriction by three turns above the knee. Time of constriction five hours. A deep groove at point of constriction. Pulsations distinctly felt soon after removal of constrictor. Fully recovered on the ninth day.

9. Small male dog. Constriction above knee-joint. Time of constriction four hours and thirty minutes. Prompt return of circulation after removal of constrictor. Limb entirely useless for two days. Entire recovery in six days.

10. Small male dog. Constriction above the elbow-joint by three turns of tubing. Time of constriction five hours and thirty minutes. Deep groove at point of constriction. Pulsations appeared almost immediately after removal of constrictor. Limb entirely useless for five days. Complete recovery in ten days.

Second Series.[1]

1. Large male dog. Constricted at 8.30 A.M. Constriction by means of stout rubber tubing, two turns, just above the wrist. Removed at 9.30 P.M. Time of constriction thirteen hours. One and one-third grains of morphia sulphate were administered hypodermically in divided doses during this time. Puncture of palm before removal of constrictor yields dark venous blood. Deep gutter in tissues at point of constriction. Blood became arterial. Pulse perceptible.

May 10, limb still badly swollen and useless.

May 12, begins to step on foot.

May 14, recovery complete.

2. Medium-sized female dog. Constricted at 8.35 A.M. Constrictor applied by two turns above the wrist. Removed at 11.35 P.M. Time of constriction fifteen hours. Limb greatly swollen. Deep cut in palm before removal of constrictor yields only slight venous oozing. After removal, bleeding soon became arterial. Pulse perceptible almost immediately after removal of constrictor. Soft tissues at point of

[1] Performed May 9, 1892.

constriction seemed almost divided subcutaneously. One and one-third grains of morphia sulphate injected in divided doses.

May 10, limb greatly swollen and useless.

May 12, about the same condition.

May 14, swelling somewhat decreased.

May 16, much better, uses the foot.

3. Medium-sized female dog. Constricted 8.40 A.M. Constriction above elbow by three turns of tubing tightly drawn and tied. Removed at 1.10 A.M. May 10. Time of constriction seventeen hours. Palm incised before removal of constrictor yields a little dark venous blood. In ten minutes blood becomes somewhat lighter in color but does not flow freely. In twenty minutes pulse could be detected, but was very indistinct. Leg greatly swollen. Soft parts appeared nearly divided subcutaneously at point of constriction. One and one-third grains of morphia sulphate injected in divided doses.

May 11, limb swollen as much as ever.

May 14, limb still swollen ; entirely useless ; begins to show discoloration.

May 15, gangrene complete.

4. Medium-sized male dog. Constricted at 8.45 A.M. Constrictor applied by two turns above the wrist. Removed at 3.45 A.M. May 10. Time of constriction nineteen hours. Limb much swollen, hard and cold. Deep cut in palm before removal of constrictor yields a few drops of venous blood. Deep gutter at point of constriction. Blood becomes lighter in color in five minutes, and in ten minutes pulse was perceptible. Circulation fully restored in twenty minutes. Three-fourths of a grain of morphia sulphate injected in three doses.

May 12, foot still swollen, but uses it at times.

May 15, uses the foot quite well, but the limb is still swollen.

5. Large male dog. Constricted at 8.50 A.M. Constrictor firmly applied above the elbow by three turns. Removed at 5.50 A.M. May 10. Time of constriction twenty-one hours. Limb enormously swollen. Deep cut in palm before removal of constrictor yields a little venous blood. In twenty minutes blood flowed a little more freely and was somewhat lighter in color. In thirty minutes the pulse was indistinctly felt, and blood was arterial. One and one-half grains morphia sulphate were injected in divided doses.

May 11, limb still swollen ; pulse normal.

May 13, limb still greatly swollen and useless.

May 14, swelling undiminished.

May 16, swelling subsiding; sensation is normal, but the limb is completely limp and useless.

Condition of limb five weeks and two days after constriction.—Limb entirely useless. Drags foot upon the ground without the least ability to raise it. Somewhat larger than its fellow. Circulation feeble but distinct. Dog killed.

Post-mortem appearances.—Tissues pale and œdematous. The radial artery and median nerve show marked changes at point of constriction.

6. Medium-sized female dog. Constricted at 9 A.M. Constrictor applied by three turns above the wrist. Removed at 11 A.M. May 10. Time of constriction twenty-six hours. Limb greatly swollen. Deep gutter at point of constriction. Palm freely incised before removal of constrictor yields dark blood. In ten minutes blood becomes lighter in color, and in twenty minutes pulse is distinct, and bleeding arterial. One and a half grains morphia sulphate in divided doses.

May 12, foot still greatly swollen and entirely useless.

May 14, begins to use the foot.

May 16, very lame, but uses the limb.

It will be noticed by glancing over the details of the experiments that in most of the animals, where constriction was continued for more than two

hours, the limb was either useless or the animal walked lame for a number of days. This temporary disability of the limb was undoubtedly occasioned not by pain but by injury to the constricted muscles. In the cases in which loss of function was continued for several weeks, there can be but little doubt that the pressure produced at the same time a nerve lesion, retarding the recovery until a sufficient time had elapsed for regeneration of the nerve to take place. In the median nerve removed after the experiment in which the constriction was continued for twenty-one hours, the essential histological nerve elements at the point of constriction could not be identified, and the nerve-fibres on the distal side showed all the appearances of far-advanced degeneration. Gangrene of all the tissues below the point of constriction was produced only once, and in this instance the constriction was made very firm, and continued for seventeen hours. The animal which was subjected to constriction for the longest time, twenty-six hours, recovered full use of the limb after the lapse of six weeks.

My clinical experience and the results of these experiments have induced me to formulate my views on elastic constriction as a hæmostatic agent in the following conclusions, which I will submit to you for consideration and discussion :

1. The use of the elastic bandage to secure a bloodless condition of a limb should be discarded, as compression of the parts affected may produce mechanically dissemination of malignant tumors and microbic diseases.

2. A bloodless condition should be secured by elevation of the limb prior to constriction.

3. Constriction should be made with sufficient force to interrupt at once both the arterial and venous circulation.

4. Prevent venous stasis by constricting quickly, beginning pressure on the side of the limb supplied with the principal blood-vessels.

5. Linear or too firm constriction should be avoided, as they are liable to give rise to muscular injury and temporary or permanent paralysis due to harmful compression of a large nerve-trunk.

6. Elastic constriction of a limb for hæmostatic purposes should be diffused over an annular space not less than two inches in width, and can be made with least danger of injuring important structures by an elastic band made for this purpose or an ordinary elastic bandage.

7. Circular constriction of a limb should be made, if possible, at a point where the large nerve-trunks are well protected by overlying muscles, and if this cannot be done on account of the site of operation, a thick compress of gauze should be interposed between the constrictor and the limb.

8. The vitality of the tissues when excluded from the circulation is endangered by prolonging the ischæmic condition for three or four hours, and gangrene may take place if constriction is continued for a longer time.

9. The process of karyokinesis in tissues temporarily deprived of circulation by elastic constriction is unfavorably affected if constriction is continued for more than two hours.

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