EXPERIMENTAL SURGERY ON REUNION OF AMPUTATED EXTREMITIES

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It has long been a dream of surgeons to accomplish surgical reunion of amputated extremities. In 1903, Hoephner successfully reunited an amputated leg on a dog, but the animal died 10 days post-operatively. In 1905, Carrel and Guthrie made extensive researches on the autograft of kidney, leg, thyroid and ovary on dogs and obtained two successful reunions of amputated legs. Unfortunately the dogs died 50 hours and 10 days postoperatively. Since then, many surgeons have tried the same sort of experiments in vain, and their enthusiasm for the experiment seemed to die down. In 1940, Zhenkin made a report of two successful reunions. In one case the animal lived 41 days and in the other, 122 days postoperatively. During the period between 1950 and 1960, Russian workers reported successful cases apart from this, but we had no way of obtaining a detailed report from them.

In 1958, a 12 year old girl was brought into our hospital immediately after her right thigh was run over by an electric train. Although we had no experience in this kind of surgery, we tried to unite all the tissues as nearly as possible into their original states. The leg was kept under mild hypothermia. It stayed alive for three weeks and patency of the femoral artery and vein was confirmed by angiography during this period. In 1959, we had another patient whose thigh was severed at the upper end. All tissues including the femur, muscles and sciatic nerve were cut. But, in this case, fortunately the femoral artery and vein were not severed. We sutured all the cut tissues so successfully that she is walking without a crutch at present. She has a small area of hypoesthesia left on the lateral side of the right leg. We learned from the above experiences that the amputated leg could be reunited only if we successfully anastomosed the main vessels after proper cleansing of the wound. An accidentally amputed leg is usually left in dirt for hours. Therefore, before we try to sew it back, we must resuscitate the leg by giving oxygen and wash out all dirt and coagula from both the outside and the inside of the amputated leg. We thought this could be done by using a pump oxygenator which was in use in the field of intracardiac surgery. We had started working on this subject in the same year by using the hand-made pump oxygenator.

Dogs were anaesthetized by intravenous pentobarbital sodium and the airway was maintained by endotracheal intubation. Artificial ventilation was used only when the respiration was inadequate. In many cases blood transfusion or dextran infusion was necessary. A Sterile technique was employed. The skin incision was made in the middle of the thigh all the way around the leg. The femoral artery and vein were isolated from the surrounding structures and a tape was placed around the vessels. All muscles, the sciatic nerve, the femoral nerve and the femur were cut in this order at the same level as the circular skin incision. The femur was shortened by about 2 to 3 cm. so as to decrease the tension at the suture site. The tape around the femoral vessels was now tightened and the vessels were cut at the level of the skin incision. At this stage, the leg was connected to a pump oxygenator and the artificial circulation was maintained for as long as we wished. The pump oxygenator was constituted from a Lillehei type bubble oxygenator and a Sigma motor pump as used in open heart surgery. The whole system was constructed of polyvinyl and the inside was silicone coated. The priming blood volume was 200 to 300 cc. and the flow rate was 60 to 80 cc. per min. per kg. At the end of the planned period of the artificial circulation, surgical reunion of the amputated leg was started. An intramedullary nail was applied for the fixation of the femur. The muscles were sutured by silk. Since the femur had been already shortened by 2 to 3 cm., end-to-end sutures of the muscles were not difficult. The sciatic nerve and femoral nerve were sutured end-to-end through the nerve sheath using an atraumatic needle with

fine silk. The canulae were removed from the peripheral ends of the femoral vessels and end-to-end anastomosis of the femoral artery and vein was done by hand sewing or Inoguchi blood vessel sewing apparatus. The vascular anastomosis is one of the important factors in salvaging an amputated leg. After trying all kinds of technique of vessel anastomosis, we came to the conclusion that the vessel sewing apparatus by Prof. Inoguchi was by far the best method of anastomosis. By using the apparatus, the time necessary for an anastomosis of the femoral vessel was shortened to a few minutes. The inside of the vessels sewed by the apparatus is smooth and no suture material is exposed on the inside. After a waiting period of about 3 to 5 min. to make certain that the sutured site was not leaking and the good flow was maintained, the skin was closed. The replanted leg was usually warmer than the other leg. An elastic bandage or a plaster of Paris was not used. The close observation of the operated dog was continued for 12 hours postoperatively. Antibiotics were given for one week following surgery. The wound healed primarily. Edema developed in the replanted leg from 24 hours postoperatively onward and it became maximum on the third to fifth postoperative day, and gradually subsided later and finally disappeared about 2 weeks postoperatively. Then, muscular atrophy at the replanted leg developed. The animals started walking around with the operated leg hanging down. In a few weeks, the dogs started to touch the ground with the replanted leg and 2 to 3 months postoperatively they came to use the replanted leg for weight bearing. About 6 months postoperatively, muscular atrophy recovered and they walked freely with a slight limp. (Fig. 1).

Fig. 1. Photograph of a dog whose left hind limb was operated on six months ago.

During the past 4 years, 62 dogs were operated on for the experimental amputation and reunion, and in twelve dogs the successful reunion of the amputated leg was obtained. In the remaining 50 dogs, the causes of failure were thrombosis and ruptures at the suture site in 26, infection in 6, renal failure in 4, operative death in 5 and other unknown postoperative deaths in 9. The postoperative thrombosis and death took place within 10 postoperative days.

Many factors are influencing the successful reunion of amputated legs. As mentioned previously, vascular anastomosis is an important factor in salvaging an amputated leg. The length of amputated period is another important factor. In our experiments, the time from the amputation to the reestablishment of circulation to a replanted leg varied from $\frac{1}{2}$ hour to 5 hours. During the period, the amputated legs were intentionally left alone in room temperature without circulation and then the legs were perfused artificially by a pump oxygenator for 5 to 15 minutes prior to reunion. The possibility of successful reunion was high when the amputated period was less than 2 hours, and the possibility became rare when the amputated period exceeded 3 hours.

According to the histologic examinations of amputated legs, phosphorylase reaction at the cut end of the muscle fiber was markedly diminished.

There is a well demarcated zone of lowered phosphorylase activity, and the width of the zone increases as the amputated period is prolonged. This would suggest that the surface of the cut end should be removed before any attempts of reunion, especially when the amputated period exceeds 2 hours.

For the purpose of studying the metabolic changes in an amputated leg, such a leg was perfused by a pump oxygenator, and metabolism was studied by determining chemical changes in the perfusion blood. The amputated legs were left alone in room temperature without perfusion for 2, 4 and 6 hours. At the end of the above periods, the leg was connected to a pump oxygenator, and artificial perfusion was started. Oxygen consumption of an amputated leg decreases as a result of decreasing amount of glucose in the perfusing

blood. By the addition of glucose, oxygen consumption increases as a response to the increased amount of blood glucose. This means that an enzyme system for glucose breakdown is still active. If an amputated leg was left in room temperature for 2 hours, the response was active. After 4 hours, this response is still seen. But if an amputated leg was left in room temperature for 6 hours, the response disappeared. However, when an amputated leg was placed in a refrigerator at 2° to 4° C., the response of oxygen consumption to added glucose was kept active for 6 hours.

These histologic and biochemical examinations showed that irreversible changes developed in muscle fibres 4 hours after the amputation when the amputated extremity was kept in room temperature. Although the incidence of reunions was low in the group of animals whose legs were left amputated over 2 hours in room temperature, the possibility of reunion is still present. However, recovery of function after surgery is questionable, because of possible Volkmann's ischemic changes in muscle when the amputated period exceeds 2 hours.

The advantage of a reunited extremity over a prosthesis lies in the regained functions. If sensations and muscle functions do not recover, the only advantage of a reunited extremity over a prosthesis is psychological, and a prosthesis would be much better and more useful in function. Detailed study on the recovery of functions after this kind of surgery remains to be investigated.