Henry Ford Hospital Medical Journal

Volume 3 | Number 2 Article 8

6-1955

The Artery Bank

D. Emerick Szilagyi

Claibourne P. Shonnard

Gerald A. LoGrippo

THE ARTERY BANK

D. Emerick Szilagyi, M.D., Claibourne P. Shonnard, M.D.,
and Gerald A. LoGrippo, M.D.

One of the most noteworthy achievements of surgery in recent years has been the treatment by resection and grafting of vascular lesions of grave import formerly regarded as unsuited for such direct approach. First chronologically, if perhaps not in practical importance, was the successful accomplishment of the cure of coarctation of the aorta by resection and grafting. Through lessons learned from angiography it has been established that peripheral arteriosclerotic occlusive disease is often segmental in its distribution and that lesions of this type are amenable to excisional and grafting procedures. Aneurysmal disease of the aorta and of the large vessels have likewise been found to be manageable by resectional treatment. Graft replacement, on the stimulus of its successes in the handling of chronic degenerative lesions, has come into wider use also in the care of acute vascular injuries and their complications (such as arteriovenous fistulas).

With the rapid and wide expansion of the scope of vascular surgery the demand for vascular replacements — grafts and prostheses — has grown apace. The pioneering work of Carrel on vascular transplantation[1], done at the turn of the century and its results long dormant, has been revived and extended by many workers. As a result of these efforts — the detailed review of which is not our present purpose — some important problems related to the replacement of vascular segments have been solved. While many unanswered questions still remain, the recent advances in our knowledge of vascular grafting have made it possible to turn into reality the idea of a *vascular bank*, the agency that assures a constant supply of arterial grafts. In what follows we shall attempt briefly to describe — for the most part on the basis of our own experiences at the Henry Ford Hospital — the organization of such a unit. We shall begin with a short review of the types of arterial substitutes that are at present at the disposal of the surgeon.

TYPES OF VASCULAR REPLACEMENT.

The type of vascular graft first used on a wide clinical scale, and still the most popular, is the *homologous arterial graft*.[2-13] Except for autogenous arterial graft—the use of which is, of course, a practical impossibility—this type of replacement most closely approaches the ideal substitute. It can be used in any situation: in the replacement of large or small, short or large segments.

Autogenous vein grafts serve well in some situations, but are subject to serious limitations of usefulness. They are unsuited for aortic replacement and they often fail in replacing long, narrow segments. They can be used with a good degree of success however to substitute for short and narrow arterial segments, in other words, in situations often created by traumatic injuries. *Homologous vein grafts* have the same advantages and shortcomings as autogenous vein grafts, but perhaps to a more pronounced degree.

Homologous arterial grafts have received a very extensive clinical trial (the number of cases in which they have been used must be well over a thousand) and have so far shown no serious inherent undesirable qualities; the rate of success with their use has been generally high, and the failures have been for the most part attributable to causes extrinsic to the grafts. Nevertheless the search for other types of arterial replacement

From the Departments of Surgery and Pathology.

is intensive, and for good reasons. First, the obtaining of arterial homografts is still a complicated task. It requires the cooperation of many people and the good will of the lay public. Until recently these grafts had to be gotten with aseptic precautions,—a truly formidable job. Secondly, certain misgivings are entertained by many concerning the fate of homografts after longer periods of observation then hitherto obtained. While it is now generally accepted that a homograft merely serves as a framework for the ingrowth of host tissue by which it is completely replaced,[14-20] there remains some serious concern that the fibrous tube that results may become calcified or undergo aneurysmal dilatation. It should be added, however, that observations of short aortic segments for over seven years, of long aortic segments (including bifurcations) for over three years, and of long, narrow segments for over two years have failed to reveal degenerative changes of importance.

To overcome the difficulties of procurement, *heterografts* have been tried both experimentally and, on a very small scale, clinically. In general grafts of this type fail in such a large number of instances as to make their clinical use impractical.

Another class of arterial substitutes promises to overcome both the scarcity and the doubtful future fate of homografts. These are the *prostheses made of plastic textiles*[24-27]. One can readily see the great potential value of the ease of storage and ready availability of such artificial vascular substitutes. It has been demonstrated by many that cloths woven of certain types of plastic filament (nylon, orlon, dacron, and others), when implanted, are accepted by the body with minimal tissue reaction. When such a cloth is shaped into a tube and the tube is inserted to replace arterial segments, it will not only be accepted by the surrounding tissues but a new arterial wall will be built on its framework. This new artery has a connective tissue wall and a psuedo-intimal lining that appear to be quite similar to those that, in time, replace a homograft. The organization of the new artery, however, laid down around the plastic prosthesis is generally more orderly, since there is much less foreign body reaction in the recipient tissues. This surprisingly effective arterial regeneration around the prosthesis has raised speculative hopes that the newly formed vascular channel will be less likely to undergo degenerative changes than a homograft would be. In clinical practice, in certain circumstances, during periods of observation up to two years, plastic cloth prostheses have been found entirely satisfactory. Good results have been noted in the replacement of a simple aortic bifurcation, or of a short and broad arterial segment that does not cross a joint. But even in replacing the aortic bifurcation, one must reckon with the disadvantage of having to tailor and sew the prosthesis, for, whereas seamless straight tubes of plastic textile are available, so far the technique of weaving a bifurcation has not been mastered. Aside from this shortcoming, plastic cloth prostheses have the defects of easy wrinkling when bent, and of complete lack of elasticity; mainly owing to the last-named property such protheses have been unsuited for the replacement of long and narrow arterial segments.

Plastic textile prostheses undoubedly have a brilliant future, for their present undesirable qualities will most likely be eliminated. At the present, however, homografts remain the most desirable arterial substitutes.

THE PREREQUISITES OF A SOLVENT ARTERY BANK

From the foregoing it is evident that the currency of the artery bank of the present day is the arterial homograft. To extend the metaphor, in order to keep the bank

solvent the following requirements must be met:

(1) There must be a supply of homografts sufficient to satisfy the demand.

(2) A method of storage must be available to allow the preservation of grafts for a relatively long period of time; without this prerequisite the loss through deterioration of such a perishable material as vascular grafts would make the maintenance of an adequate supply impossible.

Factors influencing the source of homografts. The adequacy of the source of homografts in a given hospital is determined by many factors such as the size of the institution, the criteria of acceptability of the grafts (in particular as regards the age and cause of death of the donor), the degree of cooperation of the hospital staff and, perhaps most importantly, the ease of procurement of the graft at the time of autopsy. With respect to the last-named factor, until recently the greatest single obstacle in the way of obtaining grafts was the aseptic technique of removing the arterial segments, requiring several hours and leading to delay and loss of time that inevitably alienated the pathologist; as will be seen presently this great impediment has now been done away with. These factors will now be considered singly.

As regards *the smallest general-hospital population* that can provide enough autopsy material to assure a satisfactory graft supply, extrapolating from the experiences at the Henry Ford Hospital, one can postulate that an artery bank is not practicable unless the hospital has 250 beds or more and the autopsy percentage is fifty percent or higher. The following factors enter into this calculation. In a typical general hospital there will be approximately one death per bed per year; in a hypothetical case of a hospital with 250 beds, this figure will, of course, be about 250 deaths. If the success of the hospital in obtaining autopsy permits is fifty percent there will be about 125 autopsies in course of the year. Of this number (on the basis of criteria to be discussed presently) about twenty percent or twenty-five cases will be potential donors of grafts. With a very well indoctrinated house staff, the necessary permits will be obtained for about twenty of these twenty-five potential donors. It would seem that twenty donors will supply sufficient graft material to justify the investment for a modest artery bank (which ranges from $1000 to $3000, depending on the type and scope of equipment) and to satisfy all the possible demand for graft material.

In our experience the criteria for the *qualities of acceptance of a usable graft* have changed greatly during the past two years. It has been found, for instance, that with the sterilization technique employed the cause of death has lost most of its importance as a contraindication to the use of a given graft. Satisfactory grafts have been obtained and inserted with complete success from patients who died of the following diseases: malignant hypertension, various forms of carcinoma, brain tumor, postoperative peritonitis, retroperitoneal sarcoma, Hodgkins' disease, purulent encephalitis and heart disease. It has been found, moreover, that usable grafts can often be obtained from patients over fifty years of age. In a survey of the experience of the Henry Ford Hospital artery bank during the past eighteen monthes among the thirty-seven donors from whom sixty grafts were obtained, the age varied from seventeen to sixty-one years with a mean age of 37.4 years. As a result, our instructions to the house staff state that permit for tissue removal should be obtained in all cases between the ages of twelve and sixty years. A member of the artery bank staff is present at every autopsy for which tissue permit has been signed, and inspects the arteries. The decisive factor in judging whether an artery is usable or not is the state of the physical qualities of the artery. When the

cadaver is properly refrigerated it is possible to obtain grafts without postmortem changes as late as twenty-two hours after death. The time that elapsed between death and autopsy in the cases that supplied grafts for the Henry Ford Hospital artery bank varied from one to twenty-two hours with a mean of 8.2 hours.

A factor that must be ranked very high in a plan for a functioning bank is the *co-operation of the house staff*. Since it is necessary to have a special permit for every arterial graft and since the permits are usually secured by the internes and residents, the truth of this statement is easy to see. The help from the house staff is readily forthcoming once the purpose and needs of the bank are understood. This requires repeated indoctrination. In reminding the house staff of their duty it is helpful to have the tissue removal permit attached in some form to the authorization for autopsy.

The crucial phase of graft procurement is the actual removal of the graft material. When this was done with aseptic technique the practical difficulties were almost insurmountable. As has already been briefly mentioned there are at present effective *methods for sterilizing arterial grafts* after their removal at routine autopsies without asepsis. High voltage irradiation (from a cyclotron or a cobalt bomb) has been used by some[28-30], and chemical sterilization with ethylene oxide[23], has received very extensive clinical trail. The results of irradiation have not been uniformly good; this method has the disadvantage, moreover, of lack of easy availability. Ethylene oxide, while apparently quite effective, is cumbersome to handle since it is volatile and explosive.

Beginning two years ago, and following the experimental work of Hartman and Lo-Grippo[31], and Trafas and his associates[32], we have developed a method of sterilization utilizing *betapropiolactone* in 1% (w/v) solution[33,34]. Before the method was put to clinical use, extensive experiments on human autopsy material proved that immersion of arterial segments in 1% betapropiolactone for two hours at 37°C did not appreciably alter the elasticity, tensile strength or histological structure. The procedure of sterilization now employed is as follows:

The arterial specimens are obtained in the autopsy room without aseptic precautions after the pathologist has removed all the thoracic and abdominal organs. The entire aorta is removed from the level of the ascending limb, down to the bifurcation and beyond, as far as technically feasible to dissect. Whenever the permit allows, through special incisions, the femoral arteries are also taken. It facilitates dissection and does not compromise the usefulness of the graft to transect the aorta at the level of the diaphragmatic hiatus. The vessels are removed by a member of the artery-bank staff because it is important to exercise caution in cutting the smaller arterial branches; these branches must be left with stumps of 2-3 mm. to make possible easy ligation just before use. It is of great importance to tie, by means of very heavy black silk left long, for identification by the undertaker the following branches: innominate, common carotid, subclavian, internal iliac, and external iliac arteries. It is most desirable to cannulate with long plastic tubes, for the embalmer, the deep femoral and popliteal arteries when the common and superfical femoral arteries are also taken.

The processing of the graft is carried out in three steps.

1. After its removal the graft is washed in sterile saline and the saline wash is cultured. The graft is now taken to the blood vessel laboratory where the periarterial fat and areolar connective tissue are carefully trimmed away. As formerly mentioned the stumps of the branches are not ligated until the time of use.

2. A familiarity with certain properties of betapropiolactone will be useful at this point. While quite stable in concentrated form, in watery solution at room temperature BPL rapidly hydrolyzes and loses its sterilizing effectiveness. Keeping low the temperature of the solutions, to be described presently, until the actual beginning of the sterilizing process reduces this hydrolysis. In hydrolysis, acid breakdown products are formed; hence the need for careful control of the pH throughout..

The clean vessel is next transferred to a container (preferably a wide-mouth glass jar 8 x 16 cm., with a screw cap) kept in ice, in which has been placed a quantity of buffered normal saline.* The volume of buffered saline used depends on the size of the artery to be sterilized. Specimens no larger than abdominal aorta with the common iliac arteries attached may be sterilized in a volume of fluid of 225 ml.; larger specimens require a volume of 450 ml. To the flask containing either 225 ml or 450 ml of buffered saline is now added 25 to 50 ml., respectively, of 10 percent BPL.** The addition of betapropiolactone solution is done slowly and under vigorous stirring, care being taken to bring the solution in contact with the entire inner surface of the jar and cap. The flask is now placed in a water bath for two hours at 37°C. From this time on the vessel must be handled aseptically.

3. At the end of two hours the graft is taken out of the flask under an ultraviolet hood, washed in a .2 molar phosphate buffer (7.4) and transferred to a storage flask. It is practical to use a Fenwal storage flask with a rubber stopper, which can be punctured with a needle to withdraw fluid for ascertaining sterility. The sterilized graft may be stored in any of a number of isotonic or nutrient solutions, or it can be lyophilized in precisely the same manner as a fresh graft.

Grafts prepared in this manner have been used in sixty grafting operations with an overall success that compares favorably with the results reported in the literature with grafts otherwise processed. These cases can be classified in the following manner (with the rate of early patency in parenthesis): Replacement of aortic bifurcation for aneurysm 17 cases (100%), replacement of aortic bifurcation for aorto-iliac occlusion 17 cases (100%), replacement of ileo-femoro-popliteal segments for occlusive disease 32 cases (82%), replacement of ileo-femoral segment for aneurysm 2 cases (100%), replacement of popliteal artery for traumatic contusion 2 cases (100%). Whereas cultures of the grafts obtained at autopsy showed growth of bacteria of a great variety, all the cultures obtained after sterilization were negative. No wound infection was observed.

Method of Storage.—The oldest method of storing homografts is that utilizing some nutrient fluid medium.[35] This method originated in the days when great importance was attached to the viability*** of the graft and every effort was exercised to assure the persistence of this quality until the time of use. Viability of grafts can actually be preserved for two to three weeks after the beginning of storage but it is now quite unanimously held that it is not a quality essential for successful clinical use. The

*The buffered saline solution is prepared by adding 1.68 gm. $NaHCO_3$ per 100 ml. of saline, or 4.2 gm. for 225 ml. and 8.4 gm. for 450 ml. of solution. For indicator phenol red is used (5 mg. per 100 ml. of saline.)

**To make 10% BPL solution, add 2.2 ml. of concentrated BPL (sp. gr. 1.140) to 25 ml. of ice-cold water. This solution must be made fresh and kept cold (on ice) until used. (Betapropiolactone can be purchased from the B. F. Goodrich Company, Brecksville, Ohio.)—A practical way to store BPL is to seal it in 2.2 ml. ampoules (enough to make 25 ml. of 10% solution) and keep the ampoules in the refrigerator.

***Viability is an elusive term. It is generally taken to mean the capacity of the graft to display growth in tissue culture.

great drawback of wet storage is its time limitation; while opinions vary as to the exact length of safe storage it is agreed that preservation in fluid medium for more than sixty days is unsafe; we believe that thirty days is the safe limit. Because of this time limitation wet storage is not suitable as the sole method of preservation for artery-bank practice.

Longer storage time without deterioration of the graft is possible with quick freezing at very low temperatures (—70°C) and placement in a deep freeze.[36,37] A graft can be safely stored in this manner for six to twelve months. The disadvantage of quick freezing is that once the graft is brought back to normal temperature it cannot be refrozen without sacrificing some important physical qualities. Other minor disadvantages are the difficulty of transporting the graft and the fact that the conditions of storage are often conducive to contamination.

The generally most satisfactory long-term storage method is freeze-drying (or lyophilization).[38-42] This method consists in quick-freezing the graft at temperatures around —70°C and in the dehydration of the graft under vacuum. The dehydrated graft is then stored in vacuum or in a nitrogen atmosphere. Storage can be maintained almost indefinitely but certainly as long as two years. The reconstitution of the graft is accomplished by placing it in saline for a period of from 30 to 45 minutes. If the graft is not used after being reconstituted, refreezing it again jeopardizes its physical qualities.

Freeze-drying kills the tissue cells and, therefore, in effect the process turns the arterial segment into a dead prosthesis. Very extensive studies have failed to show that this influences the rate of clinical successes adversely. Indeed it has been suggested, not very convincingly, that termination of the viability of the graft tissues is an advantage.[43] Perhaps the only serious disadvantage of the freeze-drying method is its cost, lyophilizing equipment ranging in cost from one to five thousand dollars.

In the artery bank of the Henry Ford Hospital a combined method of preservation has been in use. In spite of its disadvantages, wet storage offers some definite if minor advantages: it permits the quick use of the graft, without the waste of time required for reconstitution or thawing, and if the graft is not used, it allows resterilization or/and replacement in the storage solution without loss of the graft. In order to make use of these advantages, we store our sterilized arterial grafts in Hanks' solution[2] up to but not over thirty days. If the graft is not used by then, it is freeze-dried. In this manner the waste of graft due to wrong choice of segments is reduced to a very small figure.

SUMMARY

Without the expansion of the field of vascular surgery, the need for vascular grafts is becoming more widespread. With current methods of sterilization and preservation it is possible to establish a solvent blood vessel bank in most general hospitals with a hospital population over 250 and autopsy percentage of not less than fifty percent. Such a bank can assure an adequate supply of arterial homografts, the type of arterial substitute still the nearest to the ideal. The criteria of selection of grafts, a method of graft sterilization utilizing betapropiolactone, and the combined method of wet storage and lyophilization are described. The results in sixty grafting operations in terms of early patency utilizing arterial homografts processed in the manner described are summarized.

BIBLIOGRAPHY

1. Carrel, A.: Latent life of arteries, J. Exper. Med. 12:460, 1910.

2. Gross, R. E., Bill, A. H., Jr., and Pierce, E. C., II: Methods for preservation and transplantation of arterial grafts; observations on arterial grafts in dogs; report of tranplanation of preserved arterial grafts in 9 human cases, Surg., Gynec. & Obst. 88:689, 1949.

3. Gauthier—Villars, P., and Oudot, J.: Greffes arterielles homogenes et autogenes (etude experimentale), Presse med. 59:1227, 1951.

4. Enjalbert, L., Enjalbert, A., and Eschapasse, H.: La conservation des arteres; role du laboratoire et resultats experimentaux, Preese med. 60:571, 1952.

5. Cooke, F. N., and others: Blood vessel bank, U.S. Armed Forces M. J. 2:1779, 1951.

6. Hiertonn, T.: Arterial homografts; an experimental study, Acta Orthop. scand (supp. 10) 22:1-114, 1952.

7. Graham, A. J. P.: Arterial homografts; experimental study, Guy's Hosp. Rep. 101:186, 1952.

8. Swan, H.: Arterial grafts, Surg., Gynec. & Obst. 94:115, 1952.

9. Johnson, J., Kirby, C. K., and Horn, R. C.: The growth of preserved aorta homografts; and experimental study, Surgery 31:141, 1952.

10. Mortensen, J. D., Grindlay, J. H., and Kirklin, J. W.: The arterial homograft bank, Proc. Staff Meet., Mayo Clinic 28:713, 1953.

11. Kahle, H. R.: Arterial banks; an essential feature of arterial homografts, Bull. Tulane M. Fac. 13:58, 1954.

12. Williamson, R. G.: Artery bank, J. Maine M. A. 45:146, 1954.

13. Collins, H. A., and Foster, J. H.: Establishment of an arterial bank using eyophilization and ethylene oxide sterilization, Am. Surgeon 20:820, 1954.

14. Miller, H. H., Callow, A. D., Welch, C. S., and McMahon, H. E.: Fate of arterial grafts in small arteries; experimental study, Surg., Gynec. & Obst. 92:581, 1951.

15. McCune, W. S., and Blades, B.: Viability of long blood vessel grafts, Ann. Surg. 134:769, 1951.

16. Parsons, H. G., Gerbode, F., and Cox, A. J., Jr.: Studies in aortic autografts and homografts; do homografts survive? Angiology 3:306, 1952.

17. Henrotin, E., and Veroft, R.: Greffes vasculaires et banque d'arteres; etude experimentale, Acta chir. belg. 52:175, 1953.

18. Ibid. 52:197, 1953.

19. McCune, W. S., Thistlethwaite, J. R., Keshishian, J. M., and Blades, B.: Nutrition of blood vessel grafts; india ink injection study of their vascularization, Surg., Gynec. & Obst. 94:311, 1952.

20. Bencini, A., and Bellinazzo, P.: Experimental studies of the fate of arterial homografts, Angiology 4:483, 1953.

21. Sautot, J., Bost, J., and Touraine, Y.: Greffes arterielles heterogenes, Presse med. 60:244, 1952.

22. Bost, J., Sautot, J., and Touraine, Y.: Transplantation hetero-plastique d'arteres refrigerees, C. rend. Soc. biol., Paris 146:267, 1952.

23. Hufnagel, C. A., Rabil, P. J., and Reed, L.: Method for the preservation of arterial homo- and heterografts, S. Forum (1953) p. 167, 1954.

24. Voorhies, A. B., Jr., Jaretzki, A., III, and Blakemore, A. H.: Use of tubes constructed from vinyon "N" cloth in bridging arterial defects, Ann. Surg. 135:332, 1952.

25. Blakemore, A. H., and Voorhies, A. B., Jr.: Use of tubes constructed from vinyon "N" cloth in bridging arterial defects; experimental and clinical, Ann. Surg. 140:324, 1954.

26. Shumacker, H. B., Jr., and King, H.: Use of pliable plastic tubes as aortic substitutes in man, Surg., Gynec. & Obst. 99:287, 1954.

27. Hufnagel, C. A., and Rabil, P.: Replacement of arterial segments, utilizing flexible orlon prothesis, A.M.A. Arch. Surg. 70:105, 1955.

28. Trump, J. G., and Vande Graff, R. J.: Irradiation of biological materials by high-energy roentgen rays and cathode rays, J. App. Physics 19:599, 1948.

29. Hui, K. K. L., and others: Early results of experimental studies of the action of high intensity electrons on aortic homografts, S. Forum (1951) p. 255, 1952.

30. Brunnen, P. L.: The preparation and preservation of arterial homografts, Guy's Hosp. Rep. 102:194, 1953.

31. Hartman, F. W., LoGrippo, G., and Kelly, A. R.: Preparation and sterilization of blood plasma, Am. J. Clin. Path. 24:339, 1954.

32. Trafas, P. C., Carlson, R. E., LoGrippo, G. A., and Lam, C. R.: Chemical sterilization of arterial homografts, A.M.A. Arch. Surg. 69:415, 1954.

33. Lo Grippo, G., Overhulse, P. R., Szilagyi, D. E., and Hartman, F. W.: Procedure for the sterilization of arterial homografts with beta-propiolactone, Lab Invest. 4:217, 1955.

34. Szilagyi, D. E., Overhulse, P. R., Shonnard, C. P. and LoGrippo, G. A.: The sterilization of human arterial homografts with beta-propiolactone; experimental and clinical observations, S. Forum (1954).

35. Peirce, E. C., II: Use of viably preserved tissue for homologous arterial grafts, Ann Surg. 136:228, 1952.

36. Eastcott, H. G., and Hufnagel, C. A.: I. Experimental vascular surgery of the great vessels; the preservation of arterial grafts by freezing, S. Forum (1950) p. 269, 1951.

37. Deterling, R. A., Jr., Coleman, C. C., Jr., and Parshley, M. S.: Experimental studies of the frozen homologous aortic graft, Surgery 29:419, 1951.

38. Marrangoni, A. G., and Cecchini, L. P.: Homotransplanation of arterial segments preserved by freeze-drying method, Ann. Surg. 134:977, 1951.
39. Pate, J. W., and Sawyer, P. N.: Freeze-dried aortic grafts; a preliminary report of experimental evaluation, Am. J. Surg. 86:3, 1953.
40. Brown, R. B., Hufnagel, C. A., Pate, J. W., and Strong, W. R.: Freeze-dried arterial homografts; clinical application, Surg. Gynec. & Obst. 97:657, 1953.
41. Pate, J. W., and Sawyer, P. N.: Some elastic characteristics of fresh and freeze-dried aortic grafts, Am. J. Surg. 86:653, 1953.
42. Kremer, K.: Probleme der freien Gafasstransplantation; unter-schliedliches Verhalten von frischen und konservierten homioplastichen Arterienimplantaten, Beit. klin. chir. 187:340, 1953.
43. Sawyer, P. N., and Pate, J. W.: Electrical potential differences across the normal aorta and aortic grafts of dogs, Am. J. Physiol. 175:113, 1953.