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SYMPOSIUM: AAOS 75TH ANNIVERSARY TRIBUTE TO PAST PRESIDENTS

The Classic

Follow-Up Study of the Use of Refrigerated Homogenous Bone Transplants in Orthopaedic Operations*†

Philip D. Wilson MD (1886–1969)
The 3rd President of the AAOS 1934

Philip Duncan Wilson was born in Columbus, Ohio. His father was a family physician who held the Chair of Obstetrics in the Sterling Medical School [1]. The young Philip graduated from Harvard College in 1909 and then served as President of his graduating class at Harvard Medical School. He spent two years as a surgical intern at MGH, after which he returned to Columbus to practice. During WWI he was invited back to Boston to join the Harvard Unit under Harvey Cushing, and served with that unit when it was housed in the Lycée Pasteur. (The members of that unit included Marius Smith-Petersen, who also spent many years at the Massachusetts General Hospital and also became AAOS President.) He rejoined MGH on the staff in 1919. In 1925 he published an influential monograph with W.A. Cochrane (formerly of the Edinburgh Royal Infirmary), entitled, "Fractures and Dislocations" [5].

Toward the end of his years in Boston he helped found the American Academy of Orthopaedic Surgeons. In 1934 he was appointed as Surgeon-in-Chief at the Hospital for the Ruptured and Crippled in New York City. Dr. Wilson was active in many organizations, and reorganized and renamed the hospital he served (Hospital for Special Surgery), oversaw the building of a new hospital at its current site on the Cornell University medical campus, and raised money for a large research building. His zest inspired generations, and he was known for his gracious hospitality.

Dr. Wilson was one of three of the first fifteen Presidents (the others being Drs. John C. Wilson, Sr. and Melvin Henderson) whose son (Dr. Philip D. Wilson, Jr.) succeeded him as a President of the American Academy of Orthopaedic Surgeons.

Dr. Wilson had a long interest in bone grafting and wrote numerous research papers, a few of which are referenced here [2–4]. In the article reprinted in this issue [3], he described the rapid increase in use of a bone bank he developed at the Hospital for Special Surgery in 1946: 19 operations using grafts in 1946, 48 in 1947, 106 in 1948, 134 in 1949, and 259 in 1950. He describes his animal experiments with autogenous grafts in which grafts rapidly incorporated. He further describes biopsies of previously implanted autogenous and homogenous bone transplants in patients undergoing serial fusions for scoliosis. The pathologist (Dr. Milton Helpern) commented they found "...no evidence that the cells in the bone transplants survived..." Autogenous grafts, his evidence suggested, incorporated more rapidly that homogenous grafts, but "...in the end the results are the same." His followup studies suggested successful incorporation of graft in 210 of 248 cases.

Philip Duncan Wilson, MD is shown. Photograph is reproduced with permission and ©American Academy of Orthopaedic Surgeons. *Fifty Years of Progress*, 1983.

Richard A. Brand MD

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Introduction

This report is intended to be the complement of an earlier paper, entitled "Experiences with a Bone Bank", which I read before the American Surgical Association at its Annual Meeting at Hot Springs, Virginia, in April 1947. In that paper, I gave a summary of experience at the Hospital for Special Surgery with the use of homogenous bone grafts which had been preserved by refrigeration at temperatures of between minus 10 and minus 20 degrees centigrade, for varying periods of time, and then used as a substitute for grafts of fresh autogenous bone in orthopaedic operations. While the experience was small, covering a period of only one year beginning May, 1946, and comprising thirty operations on twenty-five patients, the results appeared to be so satisfactory that it was considered justifiable to publish a preliminary report. Since that time we have continued to use this method of bone transplantation almost to the exclusion of autogenous bone grafts, and it seems important to make an additional report based on this much longer and larger experience.

Contemporary Work with Homogenous Grafts

In my former paper, I gave a summary of the previous efforts to find substitutes for autogenous bone grafts, of experiments with various materials, and of the results obtained. Here I shall comment only on those articles dealing with the subject which have appeared since that time.

In 1947, L. F. Bush published a preliminary report on the use of homogenous bone grafts from seventy-three donors in sixty-seven operations at the New York Orthopaedic Hospital. Some of the grafts were obtained from relatives of the patients (syngenesious) and were used immediately, while others were homogenous and had been preserved by implantation under the patient's skin or by refrigeration at minus 25 degrees centigrade for various periods of time in sterile glass jars. A table of the various conditions treated is shown, but there is no summary of the results or any figures indicating the number of grafts implanted by each of these three methods. The results are described as satisfactory. M. O. Henry, in 1948, reported some cases of lesions of the long bones treated by fresh syngenesioplastic bone grafts. In some cases the lesions recurred, but were finally cured by re-operation. Reynolds and Oliver, in 1949, reported on the use of homogenous bone grafts which had been preserved in an aqueous solution of merthiolate. The strength of the solution in which the bone was immersed for the first two weeks was 1:1000; thereafter, it was kept in a solution of 1:5000 which was changed every two weeks until the bone was used. They reported follow-up studies in forty-two patients with six failures; in one case the bone was extruded. In these patients, healing was slower than it would have been had fresh, autogenous grafts been used. Weaver used refrigerated, homogenous grafts which had been obtained from amputated limbs or from fresh cadavera. For the most part, these were used as massive, onlay grafts in the treatment of ununited fractures. Aside from several infections, which were the result of an imperfect technique in the early part of the work, good results were obtained.

The experience at the Hospital for Special Surgery up to April 22, 1949 covers a period of three years and comprises 202 operations on 160 patients. In addition, I have included results from the Veterans Hospital, Kingsbridge Road, New York City, where a bone bank has been in operation since September 15, 1947. The technique followed there is similar to that used at the Hospital for Special Surgery. This gives an additional seventy-six operations on fifty-four patients, or a total of 278 operations on 214 patients. The data concerning this clinical material are listed in Table 1.

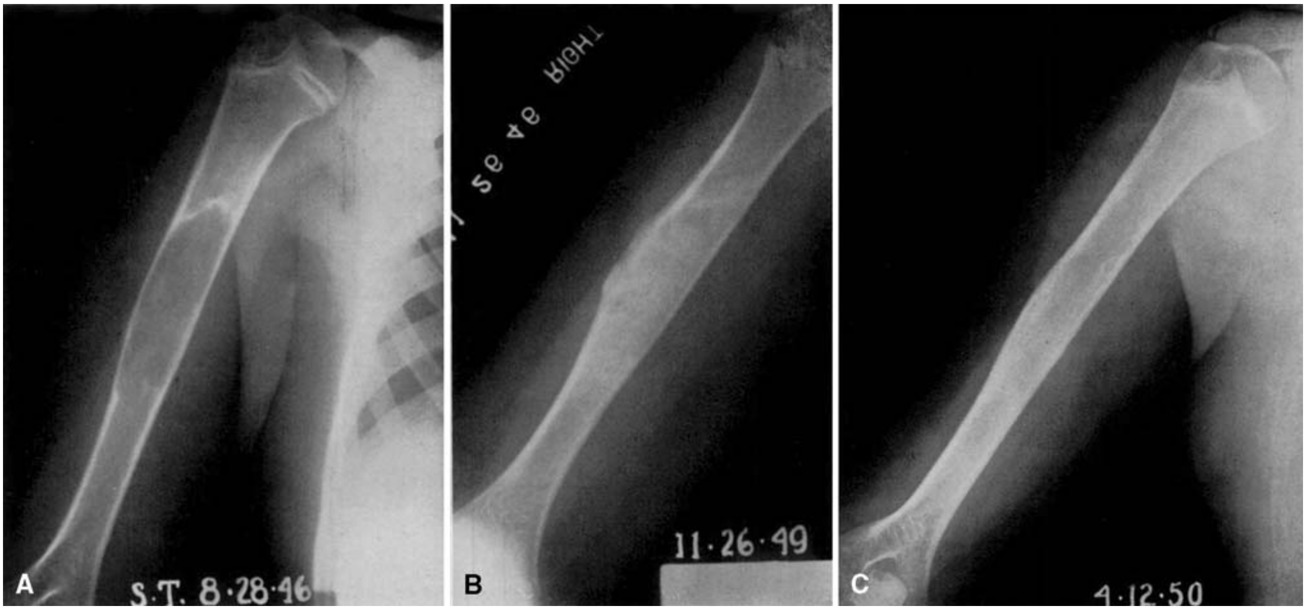

Fig. 1A–C The patient, a boy of eleven years, was admitted to the Hospital for Special Surgery in September 1946, with recurrent osteitis fibrosa cystica of the humerus. He had been operated upon in November 1938; the cyst had been curetted and the cavity packed with autogenous bone chips from the tibia. Later, there was a recurrence of the cyst which was watched for a number of years before consent for an operation was obtained. At operation, performed in September 1946, the cyst was cleaned out and the cavity was packed with cancellous bone chips from the bone bank. (**A**) (August 28, 1946) shows the condition before operation. (**B**) (November 26, 1949) shows the appearance two years later. (**C**) (April 12, 1950): The medullary cavity has been fully reestablished.

Method of Bone Preservation

We have continued to use the same technique for the preservation of bone as is described in my earlier paper. These bone donations are taken from any operative procedure in which healthy, uninfected bone is excised,—especially amputated limbs or ribs removed during the course of operations on the thorax. The amount of bone obtained from wedge osteotomies or arthrodeses on the feet is small in most instances but is large in the aggregate, and the bone is thus worth saving. In addition, we frequently find it possible to remove portions of the iliac crest in adults, when this region is exposed during an operation upon the hip, since this facilitates closure of the wound without tension. When amputations are to be performed in "clean" cases, a special surgical team is alerted to go to work on the amputated extremity and to prepare the bone for storage. This work is laborious, but it presents an excellent opportunity for the resident doctors to perfect their technique in the use of motor-driven, cutting instruments. They are inspired by the knowledge that as a result of their efforts the bone bank will be enriched. Thus, if the surgeons of any hospital are vigilant and cooperative, they will find many opportunities of obtaining bone for the bank. By this means we have been able to keep abreast of our demands at the Hospital for Special Surgery, although

Table 1. Patients, operations, and wound healing (April 1946 to March 9, 1949)

	Hospital for special surgery	Veterans administration hospital	Total	Per cent. of operations
Patients	160	54	214	
Operations	202	76	278	
Bone donors	197	84	281	
Wound complications				
Wounds healed without loss of bone	4	0	4	1.4
Wounds in which sinus still persists	1	1	2	0.7
Wounds in which there was loss of bone	2	0	2	0.7
Total with wound drainage	7	1	8	2.8
Average period of refrigeration	69 days	29 days		
Longest period of refrigeration	649 days	150 days		

at times by a narrow margin. We have not yet been able to make use of bones from cadavera since this is generally prohibited by the difficulty of surmounting the legal restrictions within the short period of time when such bone should be obtained.

As for the preparation of the bone, it should be cleaned of all soft tissue and cartilage, which is much easier to do when it is in the fresh state. Cortical bone is cut into strips from one-half inch to three-quarters inch wide and from four inches to eight inches long; the marrow and endosteal tissues are left undisturbed. Cancellous bone is generally preserved in whatever size the fragments are obtained originally.

The bone may be cultured by rubbing sterile cotton swabs over its surface. We have found that this method yields a high contamination rate, because of the difficulty of sterilizing cotton to a degree where all spores are killed and also because of the facility with which the cotton may pick up air-borne contamination. Formerly, we used this method, but more recently, on the advice of Dr. K. Magill of the Boston City Hospital, we have employed the method of cutting away a small fragment of the bone and dropping it in a sterile-broth medium.

The bone is then placed in a sterile jar. We generally make use of the regular five-inch and ten-inch flat-topped glass jars, with screw caps, that are made for the refrigeration of foods. If the piece of bone is too large for these jars, as is frequently the case with ribs, we employ a glass jar of the sort used for pathological specimens. After the cap has been screwed in place, the cap and the upper part of the jar are covered with a piece of sterile rubber sheeting which is held in place by a rubber band. This seals the jar and allows its humidity to he retained, while at the same time the sterility of the upper part, near the cap is preserved. It is important to distribute several bone specimens among different jars in order to avoid the danger of contaminating the remainder when only a small piece of bone is taken from the jar. As soon as the jar is sealed, it is placed in a refrigerator where the temperature is maintained at a level of between minus 10 and minus 20 degrees centigrade.

As far as the refrigerator is concerned, the author believes any of the standard commercial models, which are capable of maintaining the desired temperatures, may be used. We were fortunate to obtain a custom-built model one year ago with a wide-opening front door, fitted with shelves which allow for a more orderly arrangement of the

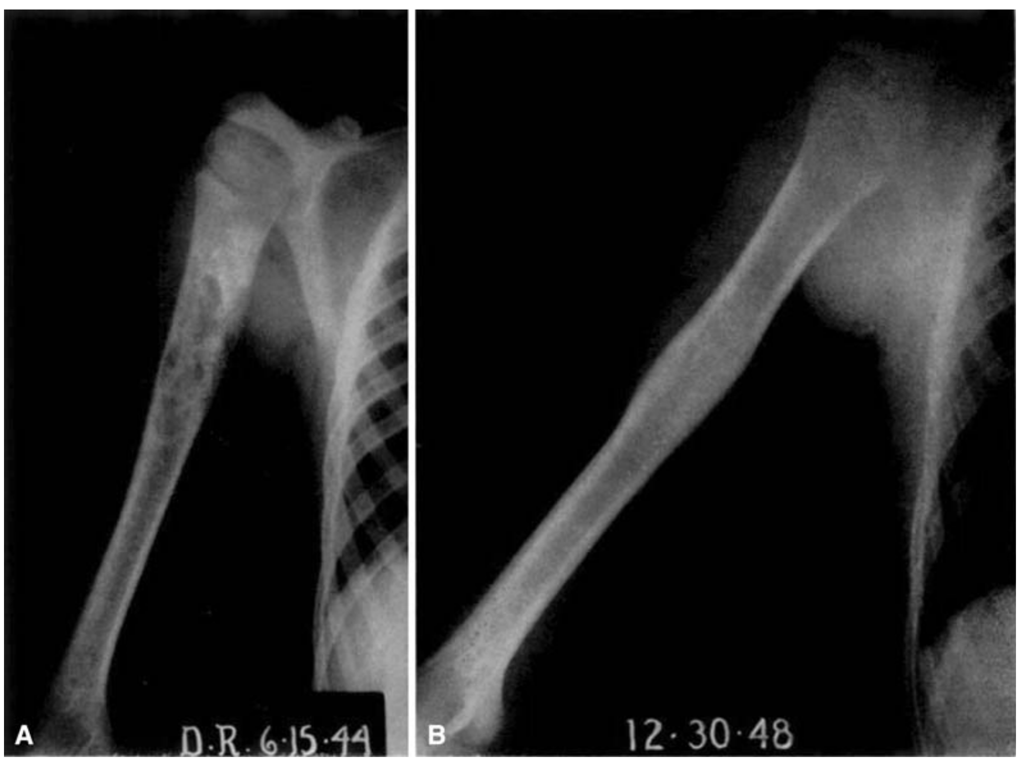

Fig. 2A–B The patient, first seen in 1942, at the age of six years, had cystic disease of the humerus with a fracture through the cyst. When he was operated upon, the cavity was curetted and filled with autogenous bone chips. The cyst recurred and he was again operated upon June 15, 1944. The cyst was then cleaned out and cauterized with carbolic acid. However, the cyst recurred within six months, but no further treatment was carried out until October 30, 1947, when he was re-admitted to the Hospital because the cyst was enlarging. The cyst was again operated upon and the contents cleaned out through a large opening. The cavity was filled with cancellous bone chips from the bone bank. One year later, a roentgenogram revealed complete healing. (**A**) The roentgenographic appearance in 1944, three years before operation. (**B**) The appearance thirteen months after operation.

stored bone than was possible with our former top-opening model. It has the disadvantage that its temperature rises quickly when the door is opened, but this makes little difference if one is careful to keep this period to the minimum. Our refrigerator is fitted with a recording thermometer which provides a record of the fluctuations of temperature over a period of one week.

The freshly obtained bone is stored on a special "hold" shelf until a bacteriological report of the specimen is obtained from the laboratory, releasing it for use. Then it is moved to shelves designated for cancellous or cortical bone available for use. In the laboratory, the bone is cultured in broth media under aerobic and anaerobic conditions for a period of four days. If at the end of this time there is no

Table 2. End-result study of 144 patients (179 operations)

	No. of patients	No. of operations	No. of successful operations	Insufficient time for follow-up	Failure of operation	Failure of operation (Per cent.)
Spine fusions for:						
Scoliosis	37	66	57	6	3	4.5
Tuberculosis	8	12	7	2	3	25.0
Low-back pain	33	33	27	3	3	9.0
Cervical lesions	2	2	2	0	0	0.0
Miscellaneous conditions	2	2	2	0	0	0.0
Total spine fusions	82	115	95	11	9	8.4
Filling of bone cavities (benign)	24	26	19	1	6	23.0
Osteomyelitis	9	9	7	1	1	11.0
Joint arthrodesis	12	12	7	2	3	25.0
Ununited fractures	14	14	13	0	1	7.0
Miscellaneous	3	3	3	0	0	0.0
Total	144	179	144	15	20	11.0

Table 3. An analysis of results in spine fusions

Indications	Result of operation						Vertebral spaces				
				Failures					Failures		
	No. of patients	No. of operations	Successes	(No.)	(Per cent.)	Insufficient time for follow-up	No. of fused	No. of successes	(No.)	(Per cent.)	Insufficient time for follow-up
Scoliosis											
Poliomyelitis	16	36	32	2	5	2	189	175	7	3.7	7
Idiopathic	14	16	12	0	0	4	103	84	0	0.0	19
Congenital	2	4	4	0	0	0	19	19	0	0.0	0
Spina bifida	2	5	4	1	20	0	18	15	3	16.0	0
Round back and Morquio's disease	3	5	5	0	0	0	29	29	0	0.0	0
Total for scoliosis	37	66	57	3	4.5	6	358	322	10	2. 7	26
Tuberculosis	8	12	7	3	25	2	51	39	12	23.0	0
Low-back pain (the fourth and fifth lumbar and sacrum)	33	33	27	3	9	3	67	52	10	13.0	5
Cervical lesion	2	2	2	0	0	0	6	6	0	0.0	0
Miscellaneous	2	2	2	0	0	0	4	4	0	0.0	0
Total	82	115	95	9	8.4	11	486	423	32	6.6	41

Fig. 3A–E The patient, a child of two years, had osteitis fibrosa cystica of the humerus and was operated upon September 8, 1947. The cavity was curetted and packed with bone chips from the bone bank. (**A**) shows the original condition. The child returned in November 1949 with a small recurrence in the middle of the shaft of the humerus (**B** and **C**), which was again operated upon by the same method. (**D**, **E**) Roentgenograms, August 16, 1950, show complete healing of the lesion.

growth, it is reported sterile. When evidence of bacterial contamination of the specimen is reported from the laboratory the question of whether this is the result of air-borne contamination or whether the specimen itself is infected must be answered. For this purpose, the jar is reopened in the laboratory under sterile conditions, the bone is

Table 4. An analysis of results of filling bone cavities

	No. of patients	No. of operations	No. of successes	No. of failures
Cavities caused by:				
Osteitis fibrosa cystica	10	11	8	3
Fibroma of bone	1	1	1	
Osteoid osteoma	3	3	3	
Hemangioma	2	2	2	
Enchondroma	3	3	2	1
Fibrous dysplasia	3	3	1	2
Giant-cell tumor	1	1	1	
Screw holes (congenital pseudarthrosis)	1	1	1	
Total	24	25	19	6

extracted, and fresh swabbings are made for reculture. By this means, we have been able to salvage a number of specimens which were at first reported to be contaminated. When a specimen has been proved to be contaminated, it should be discarded. Bacteriologists are in agreement that many strains of bacteria, including the common pathogens, are resistant to freezing and may survive and grow after being exposed to temperatures as low as 50 or 60 degrees below zero for weeks or months.

Other precautions followed with bone donors include a serological test for syphilis and a questioning of the patient to rule out any history of malaria or of recent acute infectious diseases including infectious hepatitis. Each jar is labelled as to its contents. Further, careful records are kept of every piece of bone, showing the name of the donor, the donor site, the date when it was obtained, the date when it was used, the name of the patient, and the result as far as wound healing is concerned.

Our records show that the average period of refrigeration for all the bone specimens used at the Hospital for Special Surgery was sixty-nine days, and for those at the Veterans Hospital, twenty-nine days. Several specimens were used after preservation for more than one year, while the longest period of preservation of a specimen used was 649 days or 1.7 years. The results from the use of such an antique specimen seemed to be as good as when the bone is used after a very short period of storage.

Complications of Wound Healing

As shown in Table 1, wounds healed by first intention in all but eight cases of the 278 operative procedures. In these eight there was drainage, but four healed spontaneously after varying periods without effect upon the final result. Two of the wounds were still draining through small sinus when last seen, but in two cases there was a definite infection of the wound and it was necessary to re-operate and to clean out the bone graft in order to obtain healing. One of the latter patients was "clean", but the other had chronic osteomyelitis with sinus formation at the time of operation and was, therefore, infected from the first. This gives an infection rate of 1.4 per cent. which compares favorably with the figure of from 1 to 2 per cent. frequently stated to be the average experience with infections in "clean" orthopaedic operations.

We reviewed the records of the patients for evidence of general or local reactions, other than infection, which might be attributed to the implantation of the homogenous bone, but found only one. This patient had a high, sustained fever, following operation, which persisted for more than two weeks without adequate explanation. It then subsided, but there was never any evidence of reaction about the wound. There were two instances of what may have been infectious hepatitis and one of estivo-autumnal malaria; but, as all of these patients received blood transfusions, it seemed logical to consider that, if there was any transmission of an infectious agent, it was through the blood rather than the bone.

On the basis of this evidence, I think it may he definitely stated that with a careful technique it is possible to obtain and to preserve bone for use in operations by refrigeration without any greater danger than if fresh, autogenous grafts are used. The evidence also indicates that human tissues tolerate these preserved homogenous bone grafts without reaction even when the bone has been preserved for a period of more than one year. The incidence of wound complications was no greater than if autogenous grafts had been used. It did not seem necessary to take into account the blood grouping or the Rh factor.

Bone Healing

In order to determine how well the refrigerated bone fulfilled the desired purpose of serving as a substitute for autogenous bone, we made a follow-up study of all patients in whom homogenous bone grafts were used at the Hospital for Special Surgery, eliminating only those in whom the postoperative period was too short to permit an evaluation of bone healing. Generally, the minimal period for bone healing to be determined was six months, but there were exceptional cases in which clear evidence of healing was noted in a shorter period; such cases were included. The bone bank at the Veterans Hospital has been operating for a shorter period of time than that at the Hospital for Special Surgery; therefore, it was not considered desirable to make a follow-up study of the patients at the Veterans Hospital at this time. It was possible to follow 144 patients who had undergone 179 operations.

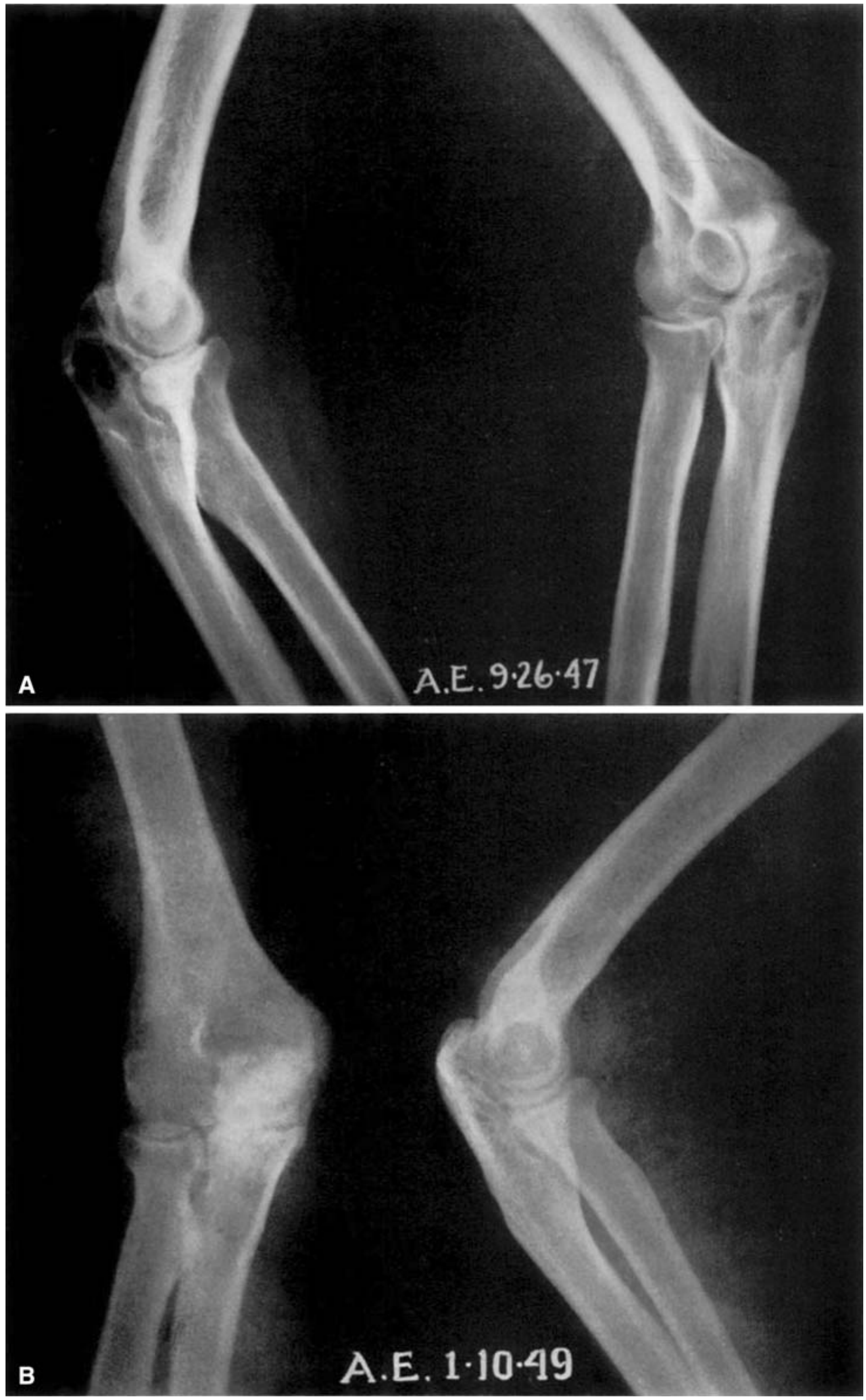

Fig. 4A–B The patient, a man of forty-two years, had a benign cystic lesion of the proximal end of the ulna which had been proved by biopsy. He was operated upon in january 1948 and the lesion was curetted and packed with bone chips from the bone bank. (**A**) September 26, 1947. The appearance of the lesion before operation. (**B**) January 10, 1949. Complete healing had been obtained.

A list of the operative procedures and an analysis of the results obtained are shown in Table 2. There were twenty operative failures found or 11 per cent, but four of the failures were due to surgical error and, thus, the figure should be reduced to sixteen or 8.8 per cent.

Spine Fusions

It may be noted from Table 2 that, more than one-half of the operations were spine fusions, but there was a wide variety of conditions for which these operations were

Fig. 5A–D The patient, a man aged thirty-seven years, was admitted to the Hospital in April 1948, with an ununited fracture of the right radius of four months' duration. He was operated upon April 22, 1948. The fragments were realigned and fixed with a Kuntschner nail. A rib from the bone bank, three inches long, was split into four fragments, which were placed about the fracture site, and were held by closure of the soft tissues. The distal end of the ulna was also resected. **A** and **B** (April 21, 1946), show the fracture at the time of admission. **C** and **D**, made nearly one year after operation (March 16, 1949), show that the grafts have healed, forming a large amount of callus. The nail was removed later, and the result is excellent.

performed. The author thinks that, in general, regardless of what operative technique is employed, it is difficult to secure a solid fusion of any desired area of the spine, and the chances of failure increase with the number of vertebrae included in the area of fusion. Our own opinion, which is probably shared by many orthopaedic surgeons, is that the secret of a successful fusion lies in having an abundance of bone available for grafting, in addition to whatever autogenous bone may be obtained in the area of operation. Since the availability of the bank bone answers the requirement of an abundance of bone fully, it is only natural that it should be utilized extensively for this purpose. In addition, spine fusion is a serious operation in which the surgeon is eager to avail himself of any short cut to avoid the necessity of a secondary operation upon the patient, which may add to hemorrhage and shock.

In Table 3, the author has presented an analysis of the various conditions resulting in scoliosis for which spine fusion was performed and also an analysis of such pathological lesions as necessitated spine fusion. It will be seen that the highest failure rate in this group was found in those patients who had spine fusions performed for spina bifida and tuberculous spondylitis. While the number of patients who were treated for these conditions is too small to make the figures significant, it is well recognized by orthopaedic surgeons that there are good reasons to explain the high incidence of failure in these patients. We think we have reason to be proud of the low rate of failure in the operations for scoliosis, which amounted in the aggregate to 4.5 per cent. This is largely accounted for by the fact that these operations were performed by one surgeon who has had a large experience in this field of work. It also proves that refrigerated, homogenous bone serves as well as autogenous bone, when good technique is used in the operations.

The results of fusion of the fourth and fifth lumbar vertebrae to the sacrum for low-back pain have been subjected to criticism in recent years, since when the patients were examined roentgenographically, with the spine in flexion

Fig. 6 The patient had residual paralysis of the hand after poliomyelitis. It was necessary to stabilize the thumb with reference to the index finger. This was accomplished by placing a graft from the bone bank between the first and second metacarpals. The roentgenogram shows the complete healing of the graft one year later.

and extension, the results have shown a high percentage of failures. All of the cases listed in this category were examined in this manner, and the results were evaluated according to the written opinions of our roentgenologist, Dr. Raymond Lewis, who is noted for his fearless reporting of findings. On this basis, our record of three failures, or 9 per cent., in thirty-three operations in which reliance for supplemental bone was placed entirely on refrigerated bone, surpasses reports by other surgeons where autogenous bone grafts were used. Looking at the total of nine failures in 115 operations for spine fusion, we think we have reason to claim that the results from the use of refrigerated, homogenous bone grafts are as good as any results from the use of autogenous grafts which have been published.

Filling of Bone Cavities

In Table 4 are shown the results obtained from the treatment of twenty-four benign lesions, chiefly involving the long bones. It will be seen that this category includes a variety of different lesions, of which osteitis fibrosa cystica is the most common, with osteoid osteoma, fibrous dysplasia, and enchondroma the next most common, in that order. The eradication and cure of these lesions necessitates the removal of all tumor tissue and the filling of the cavity with osteogenic material in order to obtain an obliteration of the defect. Many of the cavities are large; therefore, it is often difficult to obtain sufficient autogenous bone to fill them completely. Even with the best technique, recurrences are not uncommon; and, in our experience with the use of autogenous grafts, it has been necessary in some instances to re-operate more than once in order to obtain final complete healing.

Our experience with the use of refrigerated, homogenous bone for the operative treatment of these lesions has been highly successful. The healing and blending of the transplanted bone with the bone of the host has been, in many cases, quite rapid. Its outstanding advantage is that the abundance of bone available allows lavish use. This is quite the opposite of the situation when autogenous bone is used, especially in children. In the present series, there were six failures, of which three were cases of cystic disease and two were cases of fibrous dysplasia. One case, diagnosed as an enchondroma, and treated accordingly, turned out to be a chondrosarcoma. This case is listed as a failure, although this listing is quite unrelated to the healing properties of the transplanted bone. On the whole, the author considers the results obtained in this group of patients to be wholly comparable with the results obtained when autogenous bone is used.

Osteomyelitis

There were nine patients with chronic osteomyelitis, with bone cavities which could not be obliterated by osteoplastic methods. After thorough débridement, the defects were filled with small, refrigerated bone chips, and the wounds were closed. All but one of these wounds healed by first intention; seven of these cases were considered completely successful after periods of one year or more, and one is too recent for evaluation. One case was a failure; there was a persistent sinus and, after a year, a secondary operation was performed in which the bone was removed.

All of these patients had low-grade infections and sinus at the time of operation, and it seems to us that successful results in seven out of the eight cases which were followed, may be considered highly satisfactory. These results prove that refrigerated, homogenous bone is well tolerated by human tissues; otherwise, there would have been more failures.

Joint Arthrodesis

Refrigerated homogenous grafts were used in twelve arthrodeses, as shown in Table 5, with three failures. In two

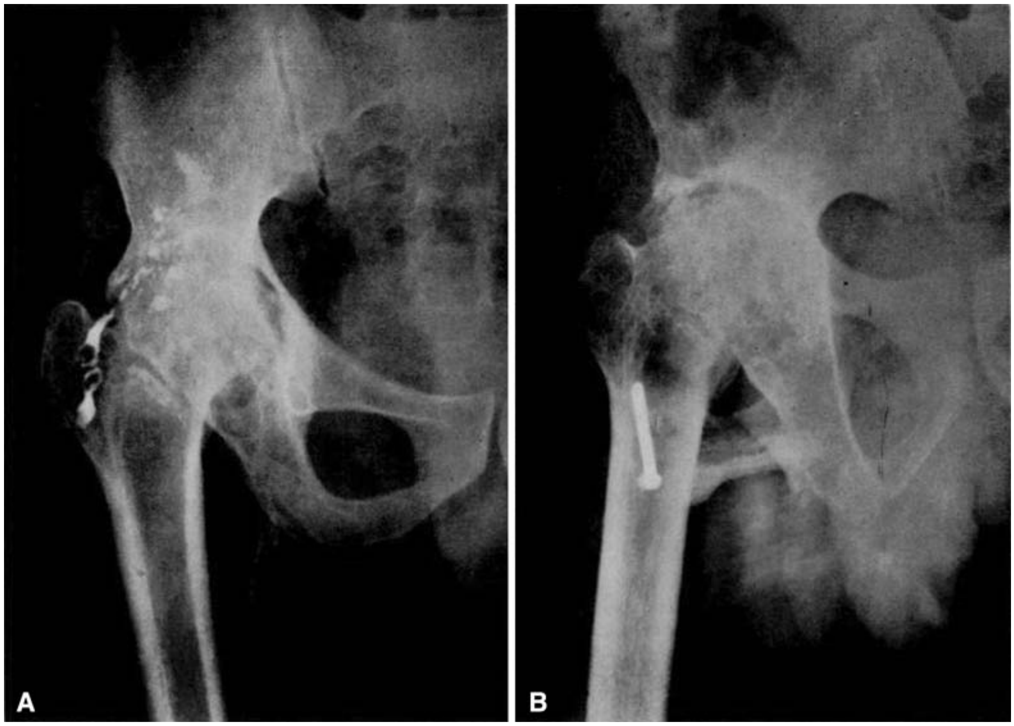

Fig. 7A–B The patient, a man aged thirty-nine years, had tuberculous arthritis of the hip. The hip was fused by the Trumbull procedure, using a tibial cortical graft from the bone bank. (**A**) (June 8, 1949) shows the condition before operation. (**B**) (October 30, 1950) shows the result one year after operation. The graft, has become revascularized and is solidly healed; the hip is beginning to fuse.

Table 5. An analysis of results of joint fusions

Indications	No. of patients	No. of operations	No. of successes	No. of failures	Insufficient time for follow-up
Tuberculosis					
Knee	2	2	1		1
Hip	1	1		1	
Non-infectious lesions					
Wrist	5	5	4		
Knee	1	1		1	
Hip	2	2	1	1	
Foot	1	1	1		
Total	12	12	7	3	2

Table 6. An analysis of results in ununited fractures

Site of fracture	No. of patients	No. of operations	No. of successes	No. of failures
Humerus	2	2	2	
Radius	1	1	1	
Ulna	1	1	I	
Carpal scaphoid	1	1		1
Femoral neck	2	2	2	
Intertrochanteric area	1	1	1	
Femoral shaft	2	2	2	
Tibia	1	1	1	
Fibula	1	1	1	
Medial malleolus	1	I	1	
Metacarpals	1	2	1	1
Total	14	15	13	2

cases, the time was too short following operation to evaluate the results. The first of the failures was in a case of active tuberculous arthritis of the hip, where the grafts were absorbed; the second was in a patient with paralytic instability of the knee, for whom a knee fusion had previously been performed, the result of which had been delayed union. A large, refrigerated, homogenous graft was driven across the joint, but a sinus developed, which is still draining, and the fusion is not solid. A third case is listed as a failure, since the patient died ten days after operation of abdominal complications. Wound healing was complete, and the result is in no way attributable to the use of bank bone.

Ununited Fractures

There were fourteen cases of ununited fractures which were repaired with the aid of refrigerated, homogenous grafts. The distribution of these fractures and the results obtained are shown in Table 6. For the most part, the ends of the fragments were freshened, approximated, and fixed by some form of internal fixation. Then onlay grafts or barrelstave grafts of split ribs were used. There were fifteen operative procedures with two failures. One of these was in a patient with an ununited fracture of the navicular where a peg graft of cancellous bone was inserted, which was later absorbed. The second failure was in a patient who had sustained a band-saw injury of the back of the hand with loss of the distal portions of the metacarpals and of the extensor tendons of all four fingers. Two operations were performed. The first was an excision of the entire second ray and a transplantation of the excised proximal phalanx to replace the end of the third metacarpal. This resulted successfully, and a year later a second operation was performed to replace the distal ends of the fourth and fifth metacarpals and to stabilize these metacarpophalangeal joints by fusion. Phalanges from the bone bank were hollowed out and used as tubular bone grafts. These were fitted over the ends of the metacarpals, and the bases of the phalanges were tapered and inserted into the distal ends of the metacarpals. The result was successful in the fourth metacarpal, but pseudarthrosis developed at the metacarpal end of the graft in the fifth ray. While this is reported as a failure, the function of the hand was greatly improved, and the patient is satisfied with the result.

Miscellaneous Operations

There were three operations of a miscellaneous nature, including two shelf operations on hips, and one bone block between the bases of the first and second metacarpals to obtain stability of the thumb. In these cases the grafts had only small contact with the host bone, but all showed definite evidence of having become revascularized and incorporated into the hosts' skeletal structure. The results were considered successful.

Discussion

The author has analyzed the results obtained from the use of homogenous bone with the purpose of showing whether or not refrigerated homogenous grafts served as well as autogenous bone grafts in operations upon the bones and joints. We think that the study shows that they are well tolerated and do not cause any adverse tissue reaction when they are free from infection. They heal satisfactorily and become incorporated in the host's skeleton. Whether this transformation is as rapid as with autogenous grafts is difficult to determine. In some of the patients where large, cortical grafts were used, we gained the impression that the healing was slower than would have been the case had autogenous grafts been used. This simply meant that it was necessary to protect the parts by splinting for longer periods of time.

In my previous paper I presented a comparative study of the healing of autogenous bone chips and of homogenous bone chips which had been recovered after different periods of time (during second-stage and third-stage operations for scoliosis. These tissues were studied by Dr. Milton Helpern, Pathologist at the Hospital for Special Surgery, who stated that, as far as he could see, the process of healing was similar and comparable in all instances. We thought that in both the graft died and was then revascularized by the host and that the bone underwent a process of absorption and replacement until it finally had been converted into living bone. How many of the living cells of an autogenous graft survive when it is transplanted to another region of the body is problematical; however, it is extremely doubtful that a large enough number of these cells retain enough vitality to make any substantial difference in the healing of the graft. In the author's opinion, the fate of both types of grafts is the same. Their function is threefold: (1) They have a catalytic function in that their presence promotes and influences the osteogenic reaction; (2) they serve as a framework or scaffolding to guide the invading elements of the host; (3) they serve as a local supply of calcium. If these conclusions are correct, then the survival of a few cells more or less in the graft makes no great difference, except possibly from the standpoint of time.

Another question that is not yet answered is whether or not life remains in any of the elements in the refrigerated grafts. Several unquestioned instances of cells retaining life after long exposures to subzero temperatures have been reported to me by colleagues who are engaged in experimental physiological and pathological studies. Carrel was able to demonstrate the growth of the periosteum and an osteogenic reaction after the tissue had been exposed to low temperatures for some time. On this basis, the possibility that some cells may survive cannot be ruled out. We would not expect such cells, even if alive when transplanted, to play any important part in the healing of the graft. It seems to us that their fate would be the same as those in a homologous skin graft where the immediate result appears to be healing, but loss of the graft follows.

In view of the fact that grafts of non-vital bone may consolidate and play an important role in the healing of fractures, and in the filling of bone defects, and in the fusion of joints, one may ask whether sterile, refrigerated animal bone might not serve as well as human bone? The author believes that, since tissue specifically plays a part in healing, such a graft would not be well tolerated unless all cellular elements were previously removed, in which case it would be comparable to the os purum of Orell. We know from Gallie's and Orell's studies that both boiled beef bone and os purum can be used successfully in the human skeleton; but the number of failures, particularly with the former, is high and, in my opinion, does not compare with the results achieved in this series with the use of homogenous bone.

The advantages of a bone bank in a hospital where there is an active orthopaedic service are multiple. The first and most important is sparing the patient the necessity of a secondary operation elsewhere on the body to obtain bone (such bone is generally obtained from the ilium or tibia). It is well known that operative defects in the latter bone are frequently painful for long periods and that they often weaken the bone to such an extent that fracture may occur. In addition, such operations prolong the procedure and add to the hemorrhage and shock. The second advantage is the constant availability of bone for transplantation whenever needed, and it sometimes happens that the need is not foreseen until the operation is well under way. In connection with this point, it should be added that bank bone is available in such abundance that there is no need to be niggardly in its use; this may make a considerable difference when it comes to packing a bone cavity with bone chips. The third advantage is that the surgeon may select from the stock in the bone bank the exact type of bone that is suited to his operation. This offers a much wider choice than would be the case otherwise,—for example, phalanges and metacarpals may be available for transplantation into the hand (we may even come to the time when whole joints or parts of joints may be preserved for transplantation). This is exemplified by the case of ununited fractures of the metacarpals reported earlier in this paper.

As a final word, I might add that the members of the Orthopaedic Staff at the Hospital for Special Surgery have come to depend upon the bone bank to such an extent that autogenous grafts are rarely used, and yet the number of operations in which grafts are employed has increased. In other words, when bone grafts can be had without the necessity of removing them from the patient's skeleton, more ways will be found of employing them during the course of operations upon the bones, and to the patient's advantage.

Problems in the Operation of a Bone Bank

There are still unsolved problems in connection with the operating of a bone bank. One of these is how to guard against the danger of transmitting the virus of infectious hepatitis or the parasite of malaria. As previously stated, we have had no instance of such complications in any of our patients; but the recent occurrence of several cases of jaundice and one of malaria following blood transfusion emphasizes the fact that the danger exists. The method used by Reynolds and Oliver of preserving the bone in merthiolate solution would presumably eliminate this danger, but it remains to be proved whether bone that is preserved in a chemical solution will serve as well in the host, as bone that is not so treated, notwithstanding the good results listed in the preliminary report of these authors.

Another and recurring problem is whether it is safe to use bone that is not involved in the disease from an extremity that is amputated for a malignant bone tumor. We have used bone from the tibia in an extremity that was amputated for liposarcoma of the femur without any complication, but a medical-legal question of considerable importance is raised here, for which it is difficult to obtain any authoritative answer. We are told by colleagues who are experimenting with tumors in animals that it has been possible to transplant tumors only in mice who are especially bred for that purpose and who show a genetic sensitivity to the tumor.

Similarly there is the problem of whether it is safe to use what appear to he healthy ribs which are obtained from a thoracoplasty for pulmonary tuberculosis.

These and other problems can be answered only by animal experimentation. In the meantime we will have to wait and use our best judgment in settling these matters for ourselves.

Summary and Conclusions

In a study of 214 patients who were subjected to 278 operations in which sterile homogenous bone grafts were used, wound infection occurred in four cases (1.4 per cent.) and there was loss of the grafts in two (0.7 per cent.).

In a follow-up study to determine the final results with respect to healing of the refrigerated homogenous bone grafts, 144 patients were traced who had undergone 179 orthopaedic operations for a large variety of conditions. Considered on a basis of the number of operations, the results were found to be successful in 80 per cent. and unsuccessful in 11 per cent. Fifteen patients (9 per cent.) had undergone operations too recently for a determination of the results. By eliminating four cases in which the failure was unrelated to bone healing, the rate of failure can be lowered to 8 per cent.

This study justified the following conclusions:

1. With careful technique, homogenous bone grafts may be preserved for long periods of time for surgical use.
2. Such grafts are well tolerated by human tissues and the risk of infection is no greater than with autogenous grafts.
3. The healing of such grafts takes place by a process of invasion, absorption, and replacement similar to that of autogenous bone grafts.

4. The results obtained are identical with those from the use of autogenous grafts, except that in some instances the healing appears to be a little slower.
5. The operation of a bone bank is safe and practical. It offers great advantages to the patient and the surgeon from the standpoint of availability, abundance, and the elimination of the necessity of a secondary operation to obtain bone.

Discussion

Dr. J. S. Speed, Memphis, Tennessee: We are indebted to Dr. Wilson for this presentation of the conclusions that he and his colleagues have reached from a careful analysis of a large series of cases in which refrigerated, homogenous bone has been used as a substitute for fresh, autogenous grafts.

Although a large amount of clinical and experimental data concerning this subject has been accumulated in recent years, we must still regard the use of refrigerated bone as a source of graft material in the experimental or formative stage. In the final analysis, the value of this procedure can be determined only by the results of its clinical application to reconstruction problems in the human being. Laboratory studies and animal experimentation are helpful but not conclusive.

The reports of Bush, Wilson, Reynolds and Oliver, Weaver, and others have done much to clarify the uncertainties connected with the use of refrigerated bone and apparently justify the conclusion that there is very little difference theoretically or clinically in the "take" of fresh or refrigerated grafts. The splendid results which Dr. Wilson has reported further confirm such a conclusion. The results which we have had in a similar series of over one hundred cases are so nearly parallel to those obtained by Dr. Wilson that I believe our series could be incorporated into Dr. Wilson's statistical analysis without changing the result percentages. Such uniformity of results in two entirely independent series should encourage the use of this procedure in the treatment of major reconstructive problems. It is in such problems that we most frequently encounter the need for large amounts of graft material, which for various reasons may not be available from the patient. The use of fresh homogenous bone is an excellent solution of the search for graft material so far as the recipient is concerned, but there are many obvious reasons why it is not a comparable experience for the donor. There is still considerable doubt as to just how massive a piece of refrigerated bone can be satisfactorily revascularized and hence successfully transplanted.

Bone grafts consist essentially of three elements: the mineral element, the collagen element, and the cellular element. The mineral and collagen element are probably preserved in their original form by refrigeration; practically all the cellular elements die, just as they do in fresh grafts. There may be in fresh bone some enzymes aiding in callus production, which are destroyed by refrigeration. Observation of bone that has been refrigerated for prolonged periods of time indicates that a slow process of protein autolysis may alter the collagen element. Chip grafts, either fresh or refrigerated, react in essentially the same manner.

We have been particularly interested in the behavior of the large refrigerated grafts of the size ordinarily used for the massive onlay type of graft. We have been able to follow twenty-four of these cases for a long enough period of time to form a comparison with the results of our use of fresh autogenous grafts.

In non-unions we have used the single onlay, refrigerated homogenous graft in fifteen cases with three failures and the dual onlay grafts in nine cases with two failures. There was no obvious difference clinically or roentgenographically in the "take" of these grafts as compared with the fresh autogenous. The percentage of failure was higher in the refrigerated grafts, but this might easily be accounted for by the type of case in which they were used.

Perhaps the best method for comparison was that used in five dual bone grafts, where in each case one graft was a fresh autogenous and the other a refrigerated homogenous graft. No essential difference was noted in the "take" of the grafts and, where the density of both grafts was the same at the time of application, they were usually indistinguishable in the roentgenogram. Both types eventually became incorporated into the host bone.

In spite of all of the favorable evidence which we have accumulated regarding the efficacy of refrigerated grafts, the inconsistency of human judgment is proved by the fact that, in the difficult case where a fresh autogenous graft is available, I still prefer to use it.

Dr. Alan DeForest Smith, New York, N. Y.: I have asked for this brief time simply to tell, in general, of our results at the New York Orthopaedic Hospital which have paralleled in time those of Dr. Wilson's at the Hospital for Special Surgery.

Our experience has been that we have had a higher percentage of failures in our spine fusions with the bank bone grafts than with the autogenous. Garber and Bush, at our hospital, did a series of experiments on rabbits, in which they demonstrated that the "take" of a graft was best in the case of a fresh autogenous, next in a fresh homogenous, next in a frozen autogenous, and fourth in a frozen homogenous graft; so we prefer, when possible, to use fresh autogenous bone. We think the results are better. Nevertheless, we do get good results with the frozen, homogenous bone, and it is a great help to be able to fall back upon it; but I think that we should not regard it as being quite as satisfactory as fresh, autogenous bone. We should use the fresh autogenous bone whenever we can.

The bank is very useful in preserving grafts for spine fusions which are to he done in stages,-as in scoliosis where a good tibial graft is taken at the first operation and a portion of it is preserved to be used in the next procedure.

Dr. Wilson (closing): I was very pleased with Dr. Speed's discussion. He has had a lot of experience with the use of refrigerated bone and, certainly, his experience does parallel our own. Reports from around the country, where a great deal of interest seems to be shown at the present time in bone banks, seem to be in general very encouraging. We know that Dr. Smith and his colleagures are not quite so well impressed with the results as we are, but we think that the experiments on small animals are not conclusive. The practical test of final results in patients seems to me to be more important, and we have presented our results for you to see. It seems to me that they are as good as we could expect if we had used autogenous bone.

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