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Metatarsal Transplantations Following Mandibular Unilateral Condylectomies in Macaca Mulata Monkeys

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Metatarsal Transplantations Following Mandibular Unilateral Condylecctomies in Macaca Mulata Monkeys

by

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A Thesis Submitted to the Faculty of the Graduate School of Loyola University in Partial Fulfillment of the Requirements for the Degree of Master of Science June 1969
Dedication

To my parents, whose sacrifices, guidance, and encouragement have made my education possible.
Dr. Richard C. Shukes was born in Cicero, Illinois, December 24, 1942. Having moved to Chicago during his high school education, he was graduated from Saint Mel High School, Chicago, June, 1960.

His pre-dental education was obtained at Loyola University, Chicago, from September 1960 to June 1963. In September, 1963, he began dental school at Loyola University School of Dentistry, Chicago College of Dental Surgery, and was graduated in June, 1967 with the degree of Doctor of Dental Surgery.

Following graduation he began graduate studies in the Department of Oral Biology at Loyola University, Chicago, Illinois. In June, 1968, he was chosen as the first recipient of the Chmiel Fellowship.

Upon completion of his graduate studies he will begin two years of active duty with the United States Navy.
Acknowledgments

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Chapter I

Introduction

It has been well documented that the condyle acts as a growth center in the normal growth and development of the mandible. In order to better treat condylar injuries, more investigation is required to achieve a greater understanding of condylar growth.

Because the Macaca mulatta monkey has such a close anatomic relation to man, it has been used in previous studies of the mandibular and masticatory apparatus.

There have been many discrepancies found in studies of condylectomies, autogenous grafts, and fracture dislocations of the condyle. Although previous investigators have transplanted autografts to the site of the mandibular condyle, and have studied the donor site, rate of growth, and type of growth presented by each graft, these areas need further investigation.

The metatarsal bone has been used in previous studies by Robinson (1961), but his gross and radiographic studies had shown no evidence of growth. Stuteville (1957) performed a metatarsal graft to the condyle in a child and found growth to be maintained.
The purpose of this experimental study is to obtain detailed information on the metatarsal's growth potential following transplantation to the condylar site. Histologic studies were made to determine if growth is maintained following transplantation. The time of the studies ranged from 4 weeks to 52 weeks postoperatively.

It is felt that this information will help to understand better growth center transplants and to treat more successfully condylar injuries in the young child with the view toward preventing future facial deformities.

Also it is felt that understanding of the types of growth of cartilage and bone is needed.

Interstitial growth of cartilage is a multiplication of cartilaginous cells by mitosis and an increase in the mass of the intercellular substance. The cartilage grows from within itself.

Appositional growth of cartilage is a constant transformation of layers of the perichondrium (connective tissue covering the cartilage) into cartilage. The immature cells of connective tissue lose their spindle shape and change into spherical cells and thus are transformed directly into chondroblasts which synthesize cartilage.

Appositional growth of bone refers to the formation of bone tissue by osteoblasts from the periosteum (connective tissue covering the bone) in connective tissue,
replacing cartilage matrix or upon bone itself.

Bone, being a hard calcified tissue, cannot grow from within itself (interstitial growth). However, bone as a tissue develops into two ways: intramembranous ossification: a transformation to bone from connective tissue, and endochondral ossification: a replacement of cartilage by bone (Bloom, 1962).

Although the condyle grows by appositional growth of condylar cartilage, endochondral ossification is present to replace the cartilage with bone. The metatarsal shows evidence of endochondral ossification at its epiphyseal plate and below its articular hyaline cartilage (Hoerr, 1962). A discussion of the metatarsal growth will be presented later in this paper.
Chapter II

Review of the Literature

Histologic Studies of Transplant

Studies pertaining to grafting procedures first became prominent during the early twentieth century.

Phemister (1914) published an article pertaining to bone and its regenerative capacity. At that time he pointed out a bone transplant must be placed in function in order to survive, and suggested the term "creeping substitution" for the process of bone resorption and replacement.

Gallie (1914) reported on the use of boiled bone and concluded that nonvital bone acts as a matrix for the invasion of osteoblasts from adjacent host tissue.

Gill (1915) found that following transplantation of bone, the graft grows and moulds itself to perform its function more efficiently. He concluded that young connective tissue cells are the chief factor in regeneration of new bone in transplants and that the graft must be maintained vital by the invasion of vascular channels.

Both Davis (1917) and Ely (1924) found that bone transplants degenerate following subcutaneous implantation. They concluded that this was due to the fact that the trans-
Plants were non-functional.

Straub (1929) reported a case of epiphyseal growth following a bone graft to the tibia. He felt that function was needed to maintain the epiphysis and growth.

Hass (1931) contradicting Straub, concluded that the epiphyseal cartilaginous plate loses its function of producing growth after transplantation and should not be used for the purpose of obtaining longitudinal growth.

Also, Bisgard (1939) using a goat, failed to notice any growth in length following an epiphyseal transplant from the femur to the shaft of the tibia.

Peer (1939) in one of his early works compared vital and nonvital autogenous cartilage. He found no invasion or resorption of the autogenous graft but observed partial resorption and the presence of fibrous connective tissue replacing the nonvital cartilaginous graft. He concluded that an autograft is superior for use in plastic repair.

Bank (1941) found that following excision of the epiphysis with its articular cartilage, only slight bony regeneration is seen; however, no articular cartilage and no further longitudinal growth of the epiphysis was evident. He also noted that once hyaline cartilage is destroyed it does not regenerate but is replaced by fibrous connective tissue or fibro-cartilage with neither acting as a growth center.
Haldeman (1933) considered periosteum the most important factor in growth and survival of a bone graft. He believed that in "creeping substitution" bone cells of a graft die, leaving a framework of the transplant. From the periosteum and enlarged haversion canals of the host bone, living bone cells invaded the matrix revitalizing the graft.

Mowlen (1941) said that epiphyseal bone transplants undergo resorption because bone cells are young and active and have a higher metabolic rate and therefore do not survive the short transitional period during which nutrition is absent or seriously decreased.

May (1942) found with joint transplants that osteoblasts transformed dead bone to new bone by "creeping substitution" and that outer layers of the joint remained vital while inner layers died. Eventually the articular cartilage was replaced by fibrocartilage and the bone regenerated from ingrowth of vessels and osteoblasts.

Peer (1946) stated that all forms of cartilaginous grafts maintain their basic structure following transplantation, but that these grafts lose their growth potential and never grow in size.

Lacroix (1951) performed two experiments, first he transplanted epiphyseal cartilage together with its peripheral area and secondly, he grafted the central part
of the epiphyseal cartilage. Comparing the two he found that the grafts containing only the epiphysis exhibited growth for a shorter time and began resorption at a quicker time than the grafts containing the epiphyseal cartilage and its surrounding tissue. Resorption was evident in both grafts and as neither was functional, Lacroix explained their lack of growth to an absence of physiological stress.

Herdon and Chase (1952, 1954) and Allbrook and Kirkaldy (1956) considered the histologic picture of whole joint transplants and found that "creeping substitution" occurs until reorganization is complete which requires 6 to 9 months. Articular cartilage remains as islands of cartilage while the meniscus is replaced by fine fibrous connective tissue and later transformed to fibrocartilage.

Allbrook (1958) implanted cartilage to replace an excised joint and found the graft to be invaded initially by fibroblasts and fibrous tissue from deep and peripheral areas - periosteum, capsule, and medullary canals. Following invasion of the cartilage, the fibrous connective tissue was converted to cartilage and later, by endochondral ossification converted into cortical bone. He believed that replacement of an excised joint with a smooth cartilage implant was better for joint function than when left unrestored. In both cases, however, repair was the same.
Peer (1954) found osteocytes survive in bone grafts when transplanted into soft tissues, and suspected that they survive when the grafts are transplanted in contact with the host bone. He concluded that the process of "creeping substitution" of the graft structure in the host bone may not be as active in autogenous bone grafts as previously considered. He felt also that bone grafts in children increase in size through appositional growth, whereas cartilaginous grafts do not. This substantiated his earlier investigation. Concluding his article he reported on a survey he had taken at that time which showed that the majority of investigators believed that 1) autografts were preferred over homografts, 2) periosteum was not required for acceptance of the graft, and 3) in autogenous grafts, osteocystes of the graft are replaced by new matrix and by new osteocystes from the host bone.

With experimental animal studies, Barr (1954) showed radiographic evidence that an autogenous epiphyseal transplant did grow to the point that dislocation of the involved joint had occurred.

Entin (1962) experimentally and clinically transplanted 121 metacarpophalangeal joints. He found that after 15 weeks postoperatively narrowing of the joint space, widening of bone end, invasion of the joint by fibrous tissue, and in some joints complete destruction
of the architecture of the joint had occurred. Retardation of growth was seen in all cases. He concluded, as other previous investigators had, that function has to be maintained in order to prevent resorption of the graft.

Finally Ware and Taylor (1966) listed three factors to be considered when proposing a transplant:

"1) The transplant should approximate the size and growth rate of the part to be replaced.
2) Removal of the donor growth center should not result in deformity.
3) The effects of transplantation and altered function on the growth potential of the donor tissue should be quantitative and predictable."

The Condyle and Mandibular Growth

The condyle being a primary growth center must be considered in its relationship to mandibular growth in order to understand the importance of maintaining the growth site in surgical procedures involving the condyle.

Sicher (1947) stated that proliferation of the condylar cartilage causes the mandible to grow longer, higher, and wider. Cartilage as it grows is replaced by bone, and bone tissue itself is laid down at the posterior border of the ramus, upper border of the coronoid process and on the alveolar crest. The downward and forward growth path of the mandible opens the amount of space
between the jaws. This space is filled in by both maxillary and mandibular alveolar bone containing the erupting dentition. Hence growth of the mandible and its primary growth center, condylar cartilage, contribute to the development of the entire face.

Baume (1951) studied the growth of the mandible in Macaca mulata monkeys. He called the endochondral ossification center at the condylar head "the pacemaker and organizer of mandibular growth."

Walker (1957) found that condylar cartilage is a major factor in mandibular growth and that arrested growth causes alterations in basal bone, followed by changes in alveolar bone. Also secondary changes in maxilla, chin angle of mandible, and mandibular contour can occur.

Weinman and Sicher (1964) stated that normal proliferation of the growth cartilage is not only responsible for overall enlargement of the mandible but also is indirectly responsible for the normal vertical development of the entire face and for the normal eruption of the teeth.

Blackwood (1965) studying the vascularization of human condylar cartilage found that vascular channels developed in growing condyles which remain present until the end of the third year of life. The presence of these channels, he believed, enabled a more rapid growth of cartilage to accommodate developing and erupting deciduous
dentition.

Recently a new concept has arisen that the condyle does not function as a primary growth center for the mandible. Does (1968) stated that the condyle is not a primary growth center and not responsible for mandibular growth as a whole, but rather acts as a site of secondary and compensatory growth of the condylar process alone. He said that growth at other areas of the mandible are governed by their own growth processes and independent of condylar growth.

Also Koski (1968) stated that condylar cartilage is not a growth center because if transplanted to a nonfunctional site, it does not maintain its structure and does not behave like condylar cartilage in situ. Finally he mentioned that any abnormalities following condylectomies are not due entirely to the missing condyles but also to abnormal muscular forces.

Condylar Growth Compared to Epiphyseal Growth

Although condylar growth and epiphyseal growth are often equated, a distinct pattern exists for each, as noted by studies of the following investigators.

Rushton (1944) stated that the appearance of cartilaginous cells in the condyle are similar to those of the
epiphyscal cartilage, but they differ in that they do not seem to be organized in a columnar or territorial arrangement as seen in epiphyscal growth. The condyle lacks an epiphyscal line and the cartilage upon bone forms is derived from the precartilaginous connective tissue lying underneath the fibrous articular surface.

Sicher (1947) reported that interstitial growth of a tissue occurs by cells inside the tissue, proliferating and producing more intercellular substance. In this type of growth the tissue grows from within itself. Cartilage may grow in this manner while hard tissues as bone, enamel, cementum, or dentine does not.

Cartilage between connective tissue and hard bone grows by both interstitial and apposition. Appositional growth of cartilage occurs under perichondral surfaces. Interstitial proliferation occurs from within the cartilage by chondroblasts producing more intercellular substance. Surface articular cartilage can grow thicker only by interstitial growth for it lacks a connective tissue covering. According to Sicher (1947), the long bone epiphyscal and articular cartilages grow from within due to the absence of perichondrium at these particular sites. In the condyle, growth occurs by apposition under the perichondrium and possibly interstitially from the chondroblasts. Appositional growth of the mandibular
condyle is greater than interstitial growth. Growth of cartilage in the mandible may or may not be inhibited or stimulated by forces which effect interstitial growth of cartilage in bones as is seen in the chondrodystrophic dwarf. In this condition inhibition of interstitial cartilaginous growth occurs with no suppression of appositional growth. Although the individual may be dwarfed, his mandible is not smaller than normal and continues to develop until the later second decade of life.

More recently Dr. Sicher (1969) states that appositional growth of cartilage in the condyle dominates in its contribution to mandibular and condylar growth and that more investigation is needed to prove that interstitial growth of cartilage is present in the condyle.

Also he mentioned that appositional growth of the condylar cartilage makes the condyle unique in its relation to the other joints of the body. The metatarsal's hyaline cartilage grows by interstitial growth. The amount of intercellular substance as observed in the metatarsal prior to transplantation compared to that of condylar cartilage is greatly increased.

Weinman and Sicher (1955) stated that the mandible is a membranous bone which secondary cartilage develops at a later stage. In the third month of intrauterine life connective tissue covering the boney condyloid proc-
ess differentiates into cartilage and remains giving the condylar articulating surface its fibro-cartilaginous cap.

The condyloid cartilage is unique in that it is not epiphyseal cartilage because it does not separate two bony parts. It is not articular cartilage because it does not form an articular surface but is always covered by a layer of fibrous or fibro-cartilaginous tissue.

Macalister (1955) and Sarnat (1956) stated that most growth of condylar cartilage is by apposition from the deeper layers of the perichondrium as Sicher had stated earlier. Sarnat divided the condylar articulating surfaces into three zones: 1) Chondrogenic - which consists of a connective tissue layer and a few cartilage cells, 2) Cartilaginous - hyaline cartilage, and 3) Osseous - areas of destruction of the cartilage and ossification of bone around the cartilage.

Condylectomies and Condylar Transplants

Sarnat and Engel (1951) following condylectomies in Macaca rhesus monkeys, concluded several points. They found that the regenerated mandibular condyle fulfills articular function but lacked growth potential and anatomical configuration. To compensate for a lack of vertical growth a new joint was formed anterior to the original joint.
Also they found that when insufficient bone is removed from the condyle, ankylosis is likely to result. They advocated the insertion of fascia or cartilage to prevent this process from occurring.

Jarabak and Vene (1957) studied histologically the reparative and regenerative process following condylectomies in rats. The condylar fossa filled with the clot and by the ninth day reorganized to a loose fibrous tissue. Osteoclasts removed the jagged corners of bone and about the sixteenth day cartilage cells appear in the connective tissue above the stump. The cartilaginous cells formed an area of distinct organization and, by approximately the thirty-fourth day, the fibrous capsule thickened over the cartilage.

Sarnat (1957) noted that 35 months postoperatively following unilateral condylectomies that there was a severe lack of growth on the operated side. This resulted in the lack of development of facial and neurocranial bone complexes and a marked asymmetry.

Jolly (1961) stated that osteophytic growth at the resected mandibular neck can be stimulated by the imbalance of muscle function. These abnormal forces are transmitted from bone to connective tissue to cause osteophytic growth. He concluded that several centers of calcifying tissue for the regenerating condyle existed: the man-
dibular neck, the cut surface of the mandibular neck, the severed end of the lateral pterygoid fascia, the surface of the articular fossa, and the lateral wall of the cranium opposite the new articular process.

Following condylectomies, Sarnat and Laskin (1964) saw no evidence of the transformation of cartilage to bone on the regenerated condyle, but the cartilage was covered by a layer of dense fibrous tissue. Again restoration of articulation was noted with the lack of any growth potential.

Choukas, Toto, et al. (1966) found a new condyle to form following animal condylectomies. Growth was noted, but undetermined whether it was of an adaptive or developmental type.

Skuble (1968) concluded his work on Macaca rhesus monkeys by stating that following condylectomies normal mandibular growth is retarded and that younger animals possess a greater potential for forming a new functional articulating condyle than the adult.

New (1927) was one of the first investigators to graft the iliac crest to replace a condyle following extensive loss of bone due to osteomyelitis.

Byers (1943) used an autogenous rib with costal cartilage on the articular surface to replace a hemisectioned mandible. In each case lack of continued growth
of the graft was noted.

Lanfranchi (1955) used a femur graft to the condyle and found that this donor site was poor for replacing the condyle due to the fact that it had to be reduced and contoured thus increasing the chance of injuring or destroying the growth center. He recommended the use of the metatarsal due to its closeness in size and shape to the condyle.

Stuteville and Lanfranchi (1955) used a second metatarsal graft to surgically correct the loss of a condylar growth center by a traumatic fall to a seven year old negro girl. Two years postoperative records showed bone growing with no apparent deviation.

Roy (1956) suggested the costochondral junction in a rib for growth center transplantation to the mandible; however, since there are different donor sites each has its own growth rate which must be considered before any grafting procedures.

Stuteville (1957) used the fourth metatarsal bone to replace the condyle in two patients. No growth was evident in either case.

Robinson (1961) transplanting metatarsals to the condyle in five Macaca rhesus monkeys and studying his results anatomically and radiographically, demonstrated successful growth in only two cases. In his three unsuc-
cessful cases he concluded that the abnormal position of
the metatarsal in the condylar fossa created abnormal
forces in the joints which led to resorption of bone under
these stresses. He believed that the metatarsal graft
for growth was inadequate in the young patient, but satis-
factory in restoring function of the joint in the adult.

Green (1961) and Mare (1965) removed and replaced
the mandibular condyle in the same operation. Growth of
the mandible continued postoperatively following the re-
section. They both concluded that the growth potential
of the mandibular condyle remained even after replantation.

Kendrick (1962) used the fifth metatarsal for trans-
plantation following a condylectomy. He found that dense
fibrous connective tissue replaced portions of the graft
and that the articular cartilage of the metatarsal provided
the major source of growth. The epiphyseal plate growth
of the metatarsal contributed very little.

In one of his cases deviation occurred suggesting
that the transplanted growth center exceeded the control
side. However, he felt this resulted not from the growth
of the transplant increasing the height of the mandible,
but due to the enlargement of the boney epiphysis of the
metatarsal.

Dingman (1964) transplanted the metatarsal bone to
replace the condyle in four patients; however, no substan-
tial growth was observed. Later that year Dingman and Grabb (1964) reported a case of a twenty-nine year old white woman whose condyles were removed for recurrent dislocation. Using fifth metatarsal bones following bilateral condylectomies, he obtained normal protrusive and lateral movements with a good occlusion. However, no growth was evident as would be expected in the adult patient.

Peskin and Laskin (1965) using contralateral autogenous condylar grafts, found intramembranous bone formation contributing to the reconstruction of the condyle. During this time mandibular growth remained retarded. Not until cartilage reformed properly did growth of the mandible begin to attain a more normal rate. They concluded that cartilage alone can initiate longitudinal growth, and that appositional and intramembranous bone formation produce local changes in shape during functional reconstruction. They stated that for interstitial and appositional growth of condylar cartilage function must be maintained.

More and Taylor (1966) grafting cartilaginous growth center in monkeys found that postoperatively the transplants failed to show the preexisting epiphyseal line of the metatarsal. Characteristics of the metatarsal had disappeared. The cartilaginous cap had greatly thickened and maintained some slight characteristics of epiphyseal
cartilage. They reported also that following rib and metatarsal transplants, each graft became a functional part of the mandible.

Later (1966) they reported on two cases where transplants were used to replace congenitally missing condyles. The fibular head, acting as the donor tissue, had to be trimmed circumferentially due to its large size. Two cases were also reported using the costochondral junction on patients who had ankylosis of the temporomandibular joint. Growth was apparent in both cases in which the fibular head was used, but ankylosis had reoccurred in the patients with the rib transplants.

Van Reenen (1968) used a rib for a graft for a growth site in restoring a condylar head which began to resorb one year prior to examination. Surgery was performed restoring the condyle. No evidence of continued growth was apparent.
Chapter III

Materials and Methods

Animals

Six Macaca mulata monkeys, obtained from Shamrock Farms, Inc., Middletown, New York, were used in this investigation. Three males and three females were used and their approximate ages were estimated from 3 to 6 months. Arbitrarily they were numbered 1 through 6.

Unilateral condylectomies were performed on the left side of each monkey, after which the head of the third metatarsal of the left paw was transplanted to replace the excised condyle. The right unoperated condyle was used as a control in each of the 6 cases. Animals were sacrificed at 4, 8, 16, 24, 36, and 52 weeks postoperatively. The exact times and postoperative periods are listed in Table 1 (appendix).

The animals were housed in stainless steel cages in an environment of approximately 80°F. They were maintained on Rockland Primate Diet which was supplemented daily with oranges or bananas.
Anesthesia

Anesthesia used in this investigation was obtained by the use of intravenous Nembutal Sodium (Abbott). Utilizing the great saphenous vein for intravenous injection, 50 mg. or 1 cc. of a 5% solution of the barbiturate was injected using a 25 gauge needle. In most cases, where the animal was difficult to handle, supplemental doses of 100 mg. were administered intraperitoneally using a 22 gauge needle. Anesthesia was obtained in 15 to 30 minutes.

Preoperative Records

Preoperative records included age, sex, time of operation, deviations and surgical sites (Table I, appendix).

Surgical Procedure

After proper anesthesia was obtained, the operated side of the face was shaved, scrubbed with Phisohex soap and wiped with Zepharin preparations. Local anesthetic, 40 mg. Xylocaine with .02 mg. epinephrine (Astra) was injected subcutaneously over the surgical site. A pre-auricular incision was used and careful dissection, pro-
Figure 1.
Mandibular condyle and metatarsal

Figure 2.
Location of resection on mandibular condyle and material.

Figure 3.
Position of Metatarsal head wired to mandibular ramus
testing the branches of the facial nerve, led to exposure of the temporomandibular capsule. A vertical incision was made through the capsule. The condyle was exposed by retraction of the capsule and ligament.

After adequate exposure of the condyle and its size determined by visual examination, the wound was packed with sterile gauze moistened with physiologic saline solution.

The metatarsal site was thoroughly cleaned with a Zepharin preparation and local anesthetic was administered around the metatarsal.

A vertical incision was made exposing the metatarsal, which was then removed by blunt dissection. The phalanxes of the particular digit were removed leaving a flap of skin so that closure might be obtained following amputation. Following irrigation of the wound, the closure was made with No. 000 silk sutures. During the closing of the wound the metatarsal bone was maintained in a saline solution.

Using a 700 tapered fissure bur, a drill hole was then placed inferior to the neck of the condyle in the ramus of the mandible and a 28 gauge wire passed. Using the same size bur and sterile saline as a coolant, a horizontal cut was performed through the mandibular neck of the condyle. The free condyle was then removed following
detachment of the disc, periosteum, and lateral pterygoid muscle.

Using a rongeur forceps the head of the metatarsal was cut to approximate the size of the excised condyle. Using a 699 fissure bur a hole was placed through the graft and with the 700 tapered fissured bur a second hole was placed in the mandible. After passing the 28 gauge wire through the second hole the graft was slid along the wire and positioned within the articulating fossa with the cut of the transplant approximating the cut surface of the mandibular ramus. The metatarsal was then wired in place with the remaining stub of wire bent over and tucked inward into the first hole drilled so as not to injure the surrounding soft tissue.

Deep tissues were closed with interrupted No. 000 chromic catgut sutures and the skin with interrupted No. 000 black silk sutures evertting the wound. No intermaxillary fixation was used.

Immediately following surgery prophylactic intra-muscular injections of 1,200,000 units of long acting Bicillin (Wyeth) was given.

Following surgery and 6 weeks postoperatively the animals were placed on a soft diet of mush, bananas, vitamins, and supplements. The animals were watched postoperatively for infection, edema, pain or dysfunction.
At certain points of the surgical procedure, photographs were taken with a Kodak Startech Camera using Kodachrome II film.

**Sacrifice**

After each designated postoperative time period, the animal was anesthetized and sacrificed. Five animals were sacrificed by the injection of 10% formalin into the left ventricle. One monkey was sacrificed with the use of 7% sodium citrate and 10% formalin.

A Y-shaped catheter was placed into the aorta via the left ventricle. No. 000 silk sutures were tied around both the aorta and the catheter. The sodium citrate was then passed through the catheter, following which the descending aorta and left subclavian artery were clamped. An incision was then made into the right atrium. Passage of clear sodium citrate from the superior vena cava indicated the time for stoppage of the sodium citrate and to start flow of the formalin through the aorta. When the odor of formalin was noted in the area of the right atrium, the formalin was stopped and the animal was decapitated.

Skin and fascia were then removed. Prior to X rays, the skull was hemisected in a sagittal plane. Brain and
pharyngeal structures were removed and the sections placed in 10° formalin solution.

Roentgeography

Both control and graft sections of the hemisected skulls were radiographed. A 3 by 10 inch cassette with an intensifying screen was used with 3 by 10 inch Kodak medical X ray film. The radiographs were taken at a target film distance of 39 inches with the kilovoltage set at 90 and the milliamps at 15 for a half a second.

Dissections

Both sides of each specimen were dissected and the gross appearance of the condylar regions were carefully studied. Photographs were again taken and following adequate dissections the condyle and the articulating fossa were removed with the use of a diamond disc and dental handpiece from the remaining portion of the hemi-sector skull. At this time the wire on each operated specimen was removed.
Histology

Following removal of the block sections of the temporomandibular joints and maintenance in 10% for at least 2 days the specimens were decalcified in a 10% solution of formic acid for three weeks. The tissue was then washed in water for 24 hours and dehydrated in increasing concentrations of ethyl alcohol. Cleared in xylene they were embedded in paraffin. Frontal sections were cut at 6 microns and stained with hematoxylin and eosin stain. Sections of each specimen were studied and photomicrographs taken at this time.
Chapter IV

Findings

Postoperative Findings

All animals survived the surgical procedure. Animal No. 3 acquired an infection with resulting tuberculosis during the postoperative period. No evidence of tuberculosis was found in the other five animals.

In each case no sign of facial nerve damage was observed. Edema was present from 1 to 2 days postoperatively. Five of the monkeys were kept on a soft diet for at least 1 month, and then placed on a normal hard biscuit diet. Animal No. 3 after 1 month was unable to manage the diet of biscuits and was kept on the soft meal throughout the entire postoperative period.

No deviations of the mandible were observed in any of the animals (Table 2, appendix). Facial appearance was normal; however, the infected monkey had developed an ulceration under the right eye and eventually became blind on the effected side.

The occlusion remained normal in four of the animals. Animal 1 and 4 developed anterior open bites of approximately 3 mm. At the time of sacrifice, all ani-
mals had acquired their permanent first molars. Animal 1 and 4 had lost their deciduous incisors and the permanent incisors were in the process of erupting (Plate XIX, Figure 40).

Roentgenographic Findings

Control sides

Lateral head roentgenographs of the hemisected skull revealed a condyle within an articulating fossa. The profile of the condylar process appeared in a normal position within the articular fossa.

Operated sides

The length of the 4 week matatarsal graft appeared to be shorter than the control condyle, with a posterior tilt in relation to the mandibular neck. It was found positioned in the posterior portion of the articular fossa.

The 8 week graft appeared in a normal position within the condylar fossa. The graft was shorter and wider than the control.

The 16 week graft appeared shorter than the control, but appeared to be in a normal position within the condylar.
fossa.

The 24 week graft showed a condyle normal in size compared to the control. The articulating surface of the graft appeared flattened in a lateral-medial direction.

The 36 week graft appeared shortest of all the previous grafts with the lack of a prominent condylar process. The transosseous wire appeared to be inferior and anterior to its location in previous specimens.

The 52 week graft appeared to be tilted slightly posterior within the condylar fossa. It was normal in size compared to the control side. Again the transosseous wire appeared inferior and anterior to its location in previous specimens.

Post Mortem Findings

Gross Findings

Control joints

Following the removal of the masseter and temporalis muscles, a thin capsular covering was observed covering the temporomandibular joint. The capsule was attached to the temporal bone at the anterior, medial, and lateral ends of the articulating tubercle. The thickened lateral portion of the capsule is the temporomandibular ligament,
which attaches superiorly to the zygomatic process of the temporal bone and inferiorly to the condylar neck.

Removal of the temporomandibular ligament revealed two chambers separated by a small white thin disc. At the posterior end of the disc a loose tissue connected the disc to the posterior portion of the capsule. A portion of the upper part of the lateral pterygoid muscle was connected to the disc on its anterior medial surface.

The apex of the coronoid process extended upward from the ramus approximately 4 mm, above the level of the condyloid process.

4 week graft (Animal No. 6)

Following removal of the masseter muscle, an encapsulated sac filled with a yellowish-gray exudate was observed over the remaining stub of the transosseous wire on the lateral surface of the ramus. Removal of the sac revealed a bony crater on the lateral surface of the ramus, below the sigmoid notch (Plate 1).

The graft was covered by a dense fibrous capsule. Upon removal of the capsule, a thick fibrous-like band was seen to attach on the posterior neck of the graft.

The articular disc and retrodiscal pad had thickened. Scar tissue was prevalent on the lateral, medial, and
posterior borders of the graft (Plate II, Figure 6).

The apex of the coronoid process extended 9 mm. above the level of the condyloid process.

The graft appeared to have attached to the mandibular neck on its posterior surface.

8 week graft (Animal No. 5)

Removal of the masseter, temporalis, and overlying fascia revealed shiny, white, firm connective tissue covering the capsule. The capsule had thickened, along with the articulating disc and retrodiscaII pad.

The graft tilted laterally and appeared slightly larger than the control condylar process (Plate III, Figure 8).

A thick fibrous band attached the posterior portion of the graft to the posterior wall of the capsule.

The apex of the coronoid process extended 4 mm. above the level of the condyloid process; the same height as the control.

16 week graft (Animal No. 4)

Removal of the masseter, temporalis, and overlying fascia revealed a temporomandibular ligament which ap-
peared considerably thicker than that of the control.

A dense white fibrous attachment was noted on the anterior portion of the graft at the line of boney union. This tissue connected the graft to the thickened anterior wall of the capsule.

The articulating disc and retrodiscal pad were thicker and appeared more fibrous than the control. The graft appeared to be in a normal position within the articulating fossa.

The apex of the coronoid process extended 5 mm. above the level of the condyloid process.

24 week graft (Animal No. 3)

Gross dissections of both the unoperated and operated temporomandibular joints revealed slightly disorganized joints as compared to those observed in previous specimens.

On both sides, the articulating surfaces of the condyle and the graft appeared slightly flattened in a lateral-medial direction (Plate V, Figure 13).

The capsule of the control appeared looser and less well defined than the control capsules of the previous specimens. The articulating disc appeared to be composed of a looser tissue which remained indefinite. The retrodiscal tissue seemed to be absent all together.
The operated side showed a more defined joint, compared to the unoperated side. The articulating disc appeared to be fibrous and attached to the capsule. The retrodiscal pad appeared to be highly fibrous in nature. Lateral pterygoid muscle fibers were seen attaching to the anterior medial surface of the disc. The posterior portion of the capsule showed signs of a heavy scar tissue.

On both the control and operated sides the apex of the coronoid process extended 4 mm. above the level of the condyloid process.

36 week graft (Animal No. 2)

Removal of the masseter, temporalis, and overlying fascia on the surgical side showed a thickened, fibrous temporomandibular ligament.

The transosseous wire appeared to be in a anterior and inferior location in comparison to previous specimens.

Removal of the capsule revealed the articulating disc to be slightly thicker than the disc on the control side (Plate VI, Figure 14).

The graft appeared shorter than the control condyle but remained in relatively good position within the condylar fossa.

The apex of the coronoid process extended 4 mm.
above the level of the condyloid process.

52 week graft (Animal No. 1)

Following the removal of the masseter, temporalis, and overlying fascia, the temporomandibular ligament was exposed on the surgical side. The capsule was slightly thicker than the control and a heavy fibrous scar-like tissue was observed as in the other animals (Plate VII, Figure 16).

The transosseous wire remaining in the ramus was anterior and inferior to its original position (Plate VII, Figure 16).

Removal of the capsule showed the graft to be posteriorly inclined. Bony union was achieved. On the mid-posterior surface of the graft a cleft was noted with a fibrous band projecting from the cleft to the capsule (Plate VII, Figure 17).

The articulating disc was slightly thickened, but appeared normal in its relation to the graft and temporal bone.

The apex of the coronoid process extended 4 mm. above the level of the condyloid process.
FIGURE 4

Photograph of dissection of animal No. 6.
(Graft - 4 week P.O.)

A. Abscess tissue
B. Transossseous wire
C. Fibrous tissue covering metatarsal

FIGURE 5

Photograph of dissection of animal No. 6.
(Graft - 4 week P.O.)

A. Bony crater
B. Coronoid process
FIGURE 6

Photograph of posterior dissection in animal No. 6. (Graft - 4 week P.O.)

A. Posterior dense tissue covering metatarsal

FIGURE 7

Photograph of condyle in animal No. 6. (Control - 4 week P.O.)

A. Articular disc
B. Lateral pterygoid fibers
C. Condyle
FIGURE 8
Photograph of lateral tilt of metatarsal in animal No. 5. (Graft - 8 week P.O.)

FIGURE 9
Photograph of condyle in animal No. 5. (Control - 8 week P.O.)
FIGURE 10
Photograph of transplanted metatarsal in animal No. 4. (Graft - 16 week P.O.)
A. Metatarsal

FIGURE 11
Photograph of condyle in animal No. 4. (Control - 16 week P.O.)
FIGURE 12

Photograph of transplanted metatarsal in animal No. 3. (Graft - 24 week P.O.)

FIGURE 13

Photograph of condyle in animal No. 3. (Control - 24 week P.O.)

A. Flattened articulating surface
FIGURE 14

Photograph of posterior aspect of the transplanted metatarsal in animal No. 2.
(Graft - 36 week P.O.)

FIGURE 15

Photograph of condyle in animal No. 2.
(Control - 36 week P.O.)
FIGURE 16

Photograph of dissection of animal No. 1.
(Graft - 32 week P.O.)

A. Fibrous temporomandibular
ligament
B. Transosseous wire

FIGURE 17

Photograph of posterior aspect of the
transplanted metatarsal in animal No. 1.
(Graft - 32 week P.O.)

A. Posterior cleft
FIGURE 18

Photograph of condyle in animal No. 1.
(Control - 52 week P.O.)

In all cases some form of bone growth was discernible. Five specimens showed endochondral ossification, appositional bone growth, and endochondral growth of bone. While in animal No. 3 only appositional bone growth was evident in both operated and normal sides.

In this series operated condyles all appeared more or less bone-like structures.

Control animals showed little or no evidence of bone growth.

The condyle and the temporal bone form the joint, i.e., one is connected with the other by ligaments, lined by a membrane, and by articular cartilage (bone, 1944). A fibrous connective tissue diaphragm was present between the articulating bones.

The articulating surface of the temporal bone consisted of a compact bone covered by a thin layer of fibrous connective tissue with some cartilage cells interposed between the fibers. The articulating disc, dividing the joint space into two compartments, consisted of dense fibrous tissue. Posterior to the disc, an area of loose connective tissue -
Histologic Findings

In all cases some form of bone growth was demonstrated. Five specimens showed endochondral ossification, appositional bone growth, and appositional growth of cartilage, while in animal No. 3 only appositional bone growth was evident on both operated and control sides.

In the remaining five cases, the unoperated condyles all appeared normal with respect to histologic features.

Control side

The joint formed by the mandibular condyle and the temporal bone was observed to be a diarthrodial joint; i.e., one in which bones are held in apposition by ligaments, lined by a synovial membrane, and covered by articular cartilage (Goss, 1962). A fibrous connective tissue disc was present between the articulating bones.

The articulating surface of the temporal bone consisted of thin compact bone covered by a thin layer of fibrous connective tissue with some cartilage cells interposed between the fibers.

The articulating disc, dividing the joint space into two compartments, consisted of dense fibrous tissue. Posterior to the disc, an area of loose connective tissue -
the retrodiscal pad (Choukas, 1958), attached the disc to the posterior segment of the capsule (Plate XI, Figure 24).

The condylar process was covered by a fibrous connective tissue. The superficial layer consisted mainly of collagenous fibers with the deeper layer being predominantly fibroblasts, mesenchymal cells, chondroblasts, and chondrocytes (Plate XI, Figure 23).

Beneath the perichondrium chondroblasts were seen forming cartilage. Within the cartilage, areas of a more deeply basophilic stained intercellular substance were observed. Beneath the cartilage, chondrocytes had undergone hypertrophy and degeneration. Chondroclasts were observed in areas of irregular cartilage which appeared to have been resorbed. Osteoblasts were seen surrounding the remaining spicules of cartilage.

The bone of the condyle consisted of an outer compact bone and an inner cancellous bone. The marrow spaces were filled with hemopoietic tissue. The outer layer of compact bone was covered by the periosteum.

Lining the joint space was a thin layer of connective tissue containing blood vessels and capillaries, the synovial membrane.
4 week graft (Animal No. 6)

Evidence of continued endochondral ossification of the graft was observed. Zones of cartilage proliferation, degeneration, and resorption were evident. A fibro-cartilaginous perichondrium overlying the articular surface of the condyle was observed (Plate XII, Figure 26).

At the posterior aspect along the neck of the condyle, a fibrous cleft was seen, which appeared to attach to the joint capsule. In the connective tissue surrounding the neck of the graft, numerous inflammatory cells were observed.

Osteoblasts were seen lining the trabeculae of the cancellous bone, the deep surface of the periosteum over the outer compact bone, and the cartilaginous spicules in the area of endochondral ossification.

Areas of chondroblastic activity in the articulating cartilage were surrounded by a more basophilic stain of the intercellular substance.

The articulating disc appeared greatly thickened by the presence of dense collagenous fibers and was considerably thicker than the control disc.

Although appositional bone growth was evident on the anterior border of the graft, high osteoclastic activity was seen on the posterior border of the metatarsal.
A diarthrodial joint appeared to have been maintained with the use of a metatarsal head.

The articulating disc remained relatively unthickened and appeared normal in size and density.

A fibro-cartilaginous perichondrium was observed covering the articulating surface of the transplant.

Endochondral ossification was demonstrated in the articulating cartilage, with appositional growth of cartilage on the anterior surface of the graft.

Although healing of bone and union of the graft to the mandibular neck was apparent, a posterior cleft was again noted. A fibrous band attached the cleft to the capsule.

Osteoblasts were seen to line the bony trabeculae, outer compact bone, and cartilaginous spicules (Plate XIV, Figure 29).

Areas of cartilaginous cells were seen within the bone marrow spaces, with no evidence of a perichondrium or endochondral proliferation. An increased amount of intercellular matrix was observed to surround the cartilaginous cells (Plate XIII, Figure 28).
16 week graft (Animal No. 4)

Histologic findings showed a diarthrodial joint enclosed by an articular capsule.

The articulating disc appeared the same as that of the control joint.

A thick fibro-cartilaginous perichondrium was observed covering the entire articulating surface of the graft. Beneath the tissue evidence of a endochondral zone was noted with a semiterritorial arrangement of the cartilage cells being more apparent than the other transplants (Plate XIV, Figure 30).

Residual areas of interstitial growth of the metatarsal's cartilage were observed. An increased amount of intercellular matrix was seen to surround the cartilaginous cells.

A fibrous band and bony cleft was observed on the anterior portion of the graft. The fibrous band appeared to attach the bone of the graft to striated muscle fibers (Plate XV, Figure 31).

Bony healing of the metatarsal to the mandible was complete, and a more definite condyle and articulating surface was apparent.
24 week graft (Animal No. 3)

In this particular animal, both the unoperated side and operated side showed no evidence of any endochondral ossification. Any signs of cartilaginous cells were absent on both sides.

Over the articulating surfaces of the condyle and graft was a periosteum with osteoblasts and osteoid below the fibrous connective tissue covering (Plate XV, Figure 32 and Plate XVI, Figure 33).

On the unoperated side areas of complete disorganization were seen in the disc and retrodiscal pad (Plate XVI, Figure 34). Tubercules containing giant cells were seen scattered within the connective tissue filling the joint space (Plate XVII, Figure 35). No tubercules were observed on the grafted side.

Cartilage of the endochondral ossification of the metatarsal had disappeared. Also no evidence of interstitial growth of the metatarsal's cartilage was observed.

The articulating disc on the grafted side appeared more defined than the meniscus on the control side.

36 week graft (Animal No. 2)

The specimen showed a diarthrodial joint with evi-
dence of endochondral ossification and appositional growth of bone and cartilage. The chondrogenic, cartilaginous, and osteogenic zones were seen within the articulating cartilage of the graft. The cartilaginous areas appeared thicker than the control. A fibro-cartilaginous perichondrium was observed covering the articulating surface with evidence of appositional growth of cartilage.

Both the fibrous disc and the retrodiscal pad thickened and enlarged, with an increase in collagenous fibers being evident (Plate XVII, Figure 36).

Osteoblasts producing osteoid were observed on the trabeculae of cancellous bone, under the periosteum of the outer compact bone, and upon spicules of cartilage. Bone union was complete.

No evidence of residual interstitial growth of the metatarsal's cartilage was observed.

52 week graft (Animal No. 1)

Histologic studies demonstrated a normal joint with both endochondral ossification and appositional growth of cartilage and bone (Plate XVIII).

Comparing the operated side to the control side, a fibro-cartilaginous perichondrium, which had previously been absent in the metatarsal, covered the articulating
surface (Plate XVIII, Figure 38). Continued growth of the graft was maintained by the appositional growth of cartilage beneath the perichondrium. The chondrogenic, cartilaginous, and osteogenic zones covered the entire articulating surface with the same relative thickness as the control. Normal endochondral ossification was evident (Plate XVIII, Figure 38).

Osteoblasts continued to lay down new bone by apposition. The marrow spaces appeared normal in size and cell population.

The thickness and density of the capsule, disc, retrodisical pad, and articulating space appeared similar to that of the control.
FIGURE 19
Photomicrograph, 40 X, of hyaline cartilage of metatarsal head.

FIGURE 20
Photomicrograph, 40 X, of articulating surface of metatarsal head.
FIGURE 21
Photomicrograph, 40 X, of endochondral growth of metatarsal head.

FIGURE 22
Photomicrograph, 40 X, of perichondrium on the lateral surface of the metatarsal head.

A. Perichondrium
FIGURE 23

Photomicrograph, 40 X, of normal condylar structures.

A. Articular disc
B. Fibrous covering (perichondrium)
C. Hyaline cartilage
D. Bone marrow

FIGURE 24

Photomicrograph, 40 X, of the retrodiscal pad (Control).

A. Temporal bone
B. Loose connective tissue
C. Synovial membrane
FIGURE 25
Photomicrograph, 40 X, of endochondral ossification and bony apposition of the graft in animal No. 6. (Graft - 4 week P.O.)
A. Endochondral zone
B. Osteoblasts
C. Spicule of bone

FIGURE 26
Photomicrograph, 40 X, of the articulating surface of the graft in animal No. 6. (Graft - 4 week P.O.)
A. Appositional growth of cartilage
B. Synovial membrane
C. Endochondral zone
FIGURE 27

Photomicrograph, 40 X, of articulating disc and endochondral ossification in animal No. 5. (Graft - 8 week P.O.)

A. Temporal bone  
B. Articular disc  
C. Endochondral zone  
D. Appositional growth of cartilage

FIGURE 28

Photomicrograph, 100X, of cartilaginous cell nest in bone marrow of animal No. 5. (Graft - 8 week P.O.)

A. Cartilage cells
FIGURE 29
Photomicrograph, 100 X, of osteoblasts lining bony trabeculae in animal No. 5. (Graft - 8 week P.O.)
A. Osteoblasts
B. Trabeculae
C. Bone marrow space

FIGURE 30
Photomicrograph, 40 X, of endochondral ossification in animal No. 4. (Graft - 16 week P.O.)
A. Territorial arrangement of chondrocytes
B. Fibro-cartilaginous perichondrium
C. Appositional growth of cartilage
FIGURE 31

Photomicrograph, 40 X, anterior cleft with attachment to striated muscle fibers in animal No. 4. (Graft - 16 week P.O.)

A. Cleft
B. Loose connective tissue attachment
C. Striated muscle fibers

FIGURE 32

Photomicrograph, 40 X, of appositional bone growth over surface of metatarsal in animal No. 3. (Graft - 24 week P.O.)

A. Appositional bone growth
FIGURE 33
Photomicrograph, 40 X, of appositional bone growth over condylar head in animal No. 3.
(Control - 24 week P.O.)
A. Remnants of articular disc
B. Appositional bone growth

FIGURE 34
Photomicrograph, 40 X, of joint space and retroliseral pad location in animal No. 3.
(Control - 24 week P.O.)
FIGURE 35
Photomicrograph, 100 X, of tubercules within joint space in animal No. 3. (Control - 24 week P.O.)
A. Tubercle

FIGURE 36
Photomicrograph, 100 X, of endochondral ossification in animal No. 2. (Graft - 36 week P.O.)
A. Articular disc
B. Fibro-cartilaginous perichondrium
C. Endochondral ossification zone
FIGURE 37
Photomicrograph, 40 X, of endochondral ossification in animal No. 1. (Graft - 52 week P.O.)

A. Articular disc
B. Perichondrium
C. Endochondral ossification zone
D. Bone marrow
E. Appositional growth of cartilage

FIGURE 38
Photomicrograph, 40 X, of endochondral ossification in animal No. 1. (Graft - 52 week P.O.)

A. Articular disc
B. Fibro-cartilaginous perichondrium
C. Endochondral ossification zone
D. Bone marrow space
E. Bone trabeculae
FIGURE 39

Photomicrograph, 40 X, of temporal bone and articular disc in animal No. 1. (Graft - 52 week F.O.)

A. Temporal bone
B. Articular disc

FIGURE 40

Photograph of anterior open bite in animal No. 1. (Graft - 52 week F.O.)
Chapter V

Discussion

In five healthy monkeys, endochondral ossification of the grafted metatarsal was maintained. In all six cases, bony union of the metatarsals to the mandibular necks were achieved. Up to this time there has been no report of a histologic study which examines the metatarsal's growth potential following transplantation to the condylar fossa.

The metatarsal was chosen in this investigation due to its similarity of growth and approximate size to the condyle (Plate XXIV, Figure 49). Little contouring, with less danger of injuring the growth center, was needed prior to wiring the graft in the condylar fossa.

Lanfranchi (1955) used a femur head of the monkey as a graft for transplantation to the condylar fossa. However, he reported that a large amount of cutting and shaving was necessary to achieve the size desired. He recommended the use of a metatarsal head.

No immobilization of the mandible was used for fear that the fibrotic scar tissue formation would limit proper joint function if immobilized, and perhaps result in ankylosis.
By having immediately placed the graft in function scar tissue was orientated along a curved plane corresponding to the surface of the condyle.

Straub (1929) felt that mechanical factors of physiologic function, pressure, and weight bearing areas were important for development of an adequate endochondral ossification in long bones.

Baume and Derichewieter (1961) found that cartilaginous growth responded to functional therapy. They also supported Weinman and Sicher (1955) in thinking that change in function alters the form and structure of bony architecture.

Radiographs in this investigation were used solely for the purpose of observing each graft's position within the articulating fossa at the time of sacrifice. Although radiographs of animal No. 1 and 2 showed the transosseous wire to be anterior and inferior to the wires of the other specimens, one would assume that the downward and forward growth of the mandible was maintained by the graft. However, no definite statement can be made as to the radiographic evidence of growth, due to the lack of immediate postoperative radiographs showing the position of the wire after surgery.

Over the transosseous wire stub in animal No. 6 a localized infection had occurred. A sac filled with exudate
was observed on gross dissection (Plate I, Figure 4). Pressure of the sac probably caused a resorption of the underlying bone of the ramus forming a bony crater below the sigmoid notch (Plate I, Figure 5). The presence of a localized infection was confirmed by presence of a high concentration of inflammatory cells seen in the histologic sections.

The 3 week graft had a posterior tilt and when viewed under the microscope, evidence of osteoclastic resorption was seen on the posterior surface with osteoblastic activity on the anterior surface. During masticatory function the graft had moved from its proper position, but maintained its condylar function. The graft was being recontoured to achieve a more normal position. Although the graft was reorganizing, endochondral ossification was maintained in the articulating cartilage.

The articulating disc of animals with shorter postoperative periods had thickened, but remained functional. The collagenous fibers had orientated themselves in line with the functional plane of the condyle. By maintaining movement of the joints following surgery, the fibrous scar tissue had thickened and organized to form functionally thickened meniscus, retrodiscal pad, and joint capsule.

Prior to transplantation the articulating surface of the metatarsal had lacked a perichondrium (Plate IX,
Figure 19). A fibro-cartilaginous perichondrium had formed in the transplanted metatarsal from five healthy monkeys. The loose connective tissue which invaded the blood clot following surgery had orientated itself in a functional plane over the articulating surface of the metatarsal. The reserve cells within this loose connective tissue proliferated and differentiated into fibroblasts and chondroblasts forming a fibrous connective tissue with cartilage cells interspersed between the collagen fibers. Deeper layers of the connective tissue adjacent to the cartilage showed a high proliferation of chondroblasts with appositional growth of the cartilage. A source of appositional growth on the articulating surface of the cartilage had formed, which previously had been absent (Plate XVIII, Figure 3B).

Areas of a more basophilic staining hyaline cartilage were observed deep to the articular cartilage surface. It is suggested that these areas may represent sites of remaining chondroblastic activity of interstitial growth of metatarsal's hyaline cartilage. Also the cartilaginous cell nests with the bone are apparently remnants of the thick interstitial growing cartilage of the metatarsal head (Plate XIII, Figure 28). The metatarsal's hyaline cartilage, while normally is thicker than the condyle cartilage and grows by interstitial


growth, had assumed an appositional growth under the fibro-cartilaginous perichondrium while maintaining its interstitial growth of cartilage and endochondral ossification. Peer (1955) also found that chondrocytes do survive in cartilage grafts, and once transplanted undergo cell division associated with the production of additional matrix. He concluded that cartilaginous grafts increase in size or grow following transplantation.

In all five healthy animals, areas of osteoblastic activity were observed. Osteoblasts and osteoid were seen lining the deep surface of the periosteum over the compact bone, surrounding the trabeculae of the cancellous bone and around the cartilaginous spicules in the areas of endochondral ossification. Areas of new bone apposition and old bone resorption were observed in all of the specimens (Plate XIV, Figure 29).

With appositional bone growth being maintained by the activity of the osteoblasts, the bone of the metatarsal was replaced slowly by the action of bone resorption and apposition from within. Weinman and Sicher (1955) stated that even if an implanted bone could remain vital, it would gradually be replaced by new bone. With this turnover of bone, the graft recontours itself to maintain a more functional position.

The clefts on the posterior surface of the grafts
in animals No. 6, 5, 1 and on the anterior surface in animal No. 4 are remnants of the normal anatomical groove of the metatarsal. During the healing of the surrounding tissue, fibrous tissue apparently had formed within the cleft and attached to the capsule of the joint.

The fibrous attachment to the cleft on the anterior surface of graft No. 4 was continuous with strands of the lateral pterygoid muscle fibers (Plate XV, Figure 31). It appeared that this specimen demonstrated a reattachment of the lateral pterygoid to the anterior surface of the graft. Sicher (1960) stated that the majority of the lateral pterygoid muscle inserts on the anterior surface of the mandibular neck.

Animal No. 3 acquired tuberculosis and showed no evidence of endochondral ossification on either the operated or control sides. Although this particular specimen should have been disregarded in the project it has been included in this presentation because of the interesting effect the Mycobacterium tuberculosis have on joint function. Tuberculosis arthritis has been found to affect joint structures with the tubercule bacilli entering the joint space. A destructive lesion develops within the joint space causing damage to the cartilage and bone, resulting in a progressively increasing joint dysfunction (Sodeman, 1961).
Diagrammatic Development of the Metatarsal

Distal

Proximal

Distal

Proximal

Composite from:

Bloom, W., and Fawcett, D. (1962)
Anson, B. (1966)
Animal No. 3 had evidence of tubercle lesions in its joint space with the presence of large concentrations of inflammatory cells (Plate XVI, Figure 34; Plate XVII, Figure 35). An articulating disc was completely absent on the control side, and the articulating cartilages had disappeared completely in both joints. Although endochondral ossification was absent in both joints, appositional bone growth was observed on each articulating surface (Plate XV, Figure 32; Plate XVI, Figure 33).

The human third metatarsal bone develops from a cartilaginous framework (a). The primary nucleus for the ossification of the body of the metatarsal begins in the middle of the cartilaginous framework during the second or third month of intrauterine life (b). A cortical bony collar forms around the shaft of the metatarsal (b, c). At birth each extremity is cartilaginous (c). The proximal end ossifies by an extension of the primary nucleus of ossification (d, e, f). The distal end of the third metatarsal ossifies from a secondary nucleus that appears during the fourth year (d). The epiphyseal plate (x) remains until growth and development of the metatarsal is complete (f).

The development of the metatarsal bone in the monkey is believed to be similar to the metatarsal bone in the human in that an epiphyseal plate forms on the distal end
at approximately one to two years of age. No evidence of an epiphyseal plate was seen in any of the grafts. Although this investigation has shown histologic evidence that following transplantation of the head of the metatarsal bone to the condylar fossa, continued research is needed to determine a more definite picture of the metatarsal's growth after grafting. A study of the metatarsal's epiphyseal plate in conjunction with a comparison of the normal growth of the metatarsal to that of a grafted metatarsal is needed to determine its contribution to growth following transplantation to the condylar fossa.
Chapter VI

Summary and Conclusions

Six transplantations of the third metatarsal head following unilateral condylectomies in young Macaca mulata monkeys were performed. The postoperative periods ranged from 1 month to 12 months. In each case the right condyle served as the control, with the left condylar fossa being the site of transplantation.

Each animal was sacrificed after its appropriate postoperative period. Radiographs, gross dissection, and histologic sections were done on both condylar joints in each specimen. One animal had contracted tuberculosis during its 24 week postoperative period.

The following results were obtained:

1) Four of the monkeys were able to masticate a normal hard biscuit diet after 6 week postoperative period.

2) No deviations of the mandible were observed throughout the postoperative periods.

3) Anterior open bites were observed on the two animals which had lost their deciduous incisors.

4) Although size and inclination of the grafts varied, radiographs showed all metatarsals to be in good position within the articulating fossa.
5) Histologic studies showed that endochondral ossification had been maintained in the metatarsal following transplantation to the condylar fossa.

6) The formation of a fibro-cartilaginous perichondrium over the articulating surface of the metatarsal following transplantation to the condylar fossa was observed.

7) Appositional growth of cartilage of the metatarsal was observed under the fibro-cartilaginous perichondrium.

8) Areas of remaining interstitial growth of cartilage were also observed in the metatarsal following transplantation.

9) Histologic evidence of the metatarsal's bony resorption and apposition were observed.

From this research project the following conclusions were made:

1) A fibro-cartilaginous perichondrium forms over the articulating surface of the metatarsal following its transplantation to the condylar fossa.

2) Appositional growth of the articulating cartilage occurs under the newly formed fibro-cartilaginous perichondrium in the transplanted metatarsal.

3) Some remaining interstitial growth and endochondral ossification of the metatarsal is maintained
following transplantation to the condylar fossa.

4) Although the metatarsal maintains an endochondral ossification, it is gradually replaced by new bone.

5) Normal functional mandibular movements may be maintained with transplantation of the metatarsal following condylectomies for a period of at least 1 year post-operatively.
Appendix
<table>
<thead>
<tr>
<th>Animal No.</th>
<th>Sex</th>
<th>Approximate Age at Time of Surgery</th>
<th>Mid Line</th>
<th>Surgical Side</th>
<th>Post Operative Period</th>
<th>Approximate Age at Sacrifice</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Female</td>
<td>6 Mo.</td>
<td>Normal</td>
<td>Left</td>
<td>52 Wk.</td>
<td>18 Mo.</td>
</tr>
<tr>
<td>2</td>
<td>Male</td>
<td>7 Mo.</td>
<td>Normal</td>
<td>Left</td>
<td>36 Wk.</td>
<td>16 Mo.</td>
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<td>3</td>
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<td>8 Mo.</td>
<td>Normal</td>
<td>Left</td>
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<td>14 Mo.</td>
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<td>Female</td>
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<td>Normal</td>
<td>Left</td>
<td>8 Wk.</td>
<td>16 Mo.</td>
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<tr>
<td>6</td>
<td>Female</td>
<td>16 Mo.</td>
<td>Normal</td>
<td>Left</td>
<td>4 Wk.</td>
<td>19 Mo.</td>
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<td>Animal No.</td>
<td>Postoperative Period</td>
<td>Dentition</td>
<td>Mid Line</td>
<td>Distance Coronoid Paccess Above Graft Level</td>
<td>Type of Histologic Growth of Graft</td>
<td></td>
</tr>
<tr>
<td>-----------</td>
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<td>-----------</td>
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<td>------------------------------------------</td>
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<tr>
<td>1</td>
<td>52 Wk.</td>
<td>deciduous, 6's and erupting open</td>
<td>Normal</td>
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<td>Endochondral ossification Appositional (Cartilage and Bone)</td>
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<td>2</td>
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<td>5 mm.</td>
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<tr>
<td>3</td>
<td>24 Wk.</td>
<td>all deciduous and 6's</td>
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<td>Appositional (Bone)</td>
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<td>Endochondral ossification Appositional (Cartilage and Bone) Remaining interstitial (Metatarsal Cartilage)</td>
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<td>5</td>
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<td>4 mm.</td>
<td>Endochondral ossification Appositional (Cartilage and Bone) Remaining interstitial (Metatarsal Cartilage)</td>
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<td>9 mm.</td>
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The following prints of the surgical procedure were taken of the right side of an animal which is being used in future studies on metatarsal transplantations. Note: in our study the left condyles were operated.
FIGURE 41

Photograph of indicated incision line.

FIGURE 42

Photograph of deep fascia covering the temporomandibular joint.
FIGURE 43
Photograph of the exposed condyle.

FIGURE 44
Photograph of the amputated toe.
FIGURE 45
Photograph of the third left metatarsal.

FIGURE 46
Photograph of the closure following amputation.
FIGURE 47
Photograph of the sectioned condylar neck.

FIGURE 48
Photograph of the condyle removed and empty condylar space.
FIGURE 49

Photograph comparing condylar head to metatarsal head.

A. Condyle
B. Distal head of third metatarsal bone

FIGURE 50

Photograph of wiring the metatarsal head to mandibular neck being made.
FIGURE 51
Photograph of metatarsal head wired to mandibular neck within the articular fossa.

FIGURE 52
Photograph of closure of preauricular incision.
FIGURE 53
Photograph of occlusion following surgery.

FIGURE 54
Photograph of animal No. 6 four weeks postoperatively.
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Approval Sheet

The thesis submitted by Dr. Richard C. Shukes has been read and approved by three members of the faculty of the Graduate School.

The final copies have been examined by the director of the thesis and the signature which appears below verifies the fact that any necessary changes have been incorporated, and that the thesis is now given final approval with reference to content, form, and mechanical accuracy.

The thesis is therefore accepted in partial fulfillment of the requirements for the Degree of Master of Science.

April 30, 1969  
Date

Signature of Adviser