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The Krukenberg Procedure in the Juvenile Amputee*

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The ideal rehabilitation of the upper-extremity amputee is restoration of strong prehension (grasp) with good sensation [13,14,15]. Prehension can be restored quite satisfactorily with ordinary prosthetic fitting [4], but the lack of tactile gnosis experienced by the double amputee with artificial limbs makes his rehabilitation less than ideal.

The patient who has had a Krukenberg procedure [9] demonstrates abilities in his daily living pattern that convince one that this procedure should be used more frequently [3,7]. The patient with bilateral hand loss frequently needs the readily available, sensitive prehension the Krukenberg procedure provides. The lack of interest and almost universal antipathy toward this procedure should be overcome; it is a useful operation which should be available to more of these unfortunate patients.

It is generally recognized that the blind patient with bilateral hand loss is a candidate for the Krukenberg procedure [1,7]. The procedure is also considered useful in regions where prosthetic services are unobtainable [6,12]. However, any patient with bilateral hand loss and a forearm long enough for conversion into the forceps-like mechanism of a Krukenberg stump will find the function obtained from this procedure of great help [8,10,16], especially in dressing, bathing, eating, and toilet activities.

An artificial limb is recommended for the opposite upper extremity as an assistive hand. If the patient desires to wear an artificial limb over the Krukenberg stump, a standard prescription can be utilized without difficulty, but the patient still has the facility of a Krukenberg stump during his home activities. The patients in this series, however, have used the Krukenberg stump as a dominant hand and have not shown any desire to wear an artificial limb over it.

The simple mechanical principle of chopsticks, used for eating by more than one billion of the world's population, is employed by the patient with a Krukenberg stump with amazing dexterity and facility.

This procedure should be performed in children as soon as feasible. Experience has shown that reconstructive surgery for malformations of the hand can be performed safely in the second year of life. The parts are large enough for easy handling and surgery is tolerated well at this age. The very rapid, useful, functional patterns of prehension developed in this series of cases demonstrates that there is no reason to postpone surgery. The epiphyses are not disturbed if the procedure is done carefully so that growth considerations should not be a limiting factor.

Operation

The objective in the operative procedure is to convert the forearm into a strong, active forceps with the radial ray opposing against the ulnar ray [8,11]. Tactile sensation should be present between the tips and, therefore, the skin here should be full-thickness with good nerve and blood supply. If digits are present, they should

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be left intact with nerve, vessels, and tendons unmolested. The forceps should spread wide enough to accommodate ordinary objects such as a drinking glass and should be strong enough to hold common objects securely. If the forceps is made too long, it may lack strength; if it is too short, there may not be enough useful distal spread.

I have used the muscle belly of the pronator radii teres as the factor limiting the depth of the forceps proximally. The length of the forceps is, therefore, dependent on the length of the radius and ulna distal to the belly of the pronator teres muscle. The length of the forceps in the patients presented here ranged from one-half to three-fifths the length of the forearm.

Incision

A tourniquet is used to provide a bloodless field. The incision is designed to divide the forearm longitudinally into halves. The separation of the two rays and their covering with skin is similar to the syndactylism procedure designed by Bunnell to separate web fingers [2]. The incision on the flexor aspect of the forearm is

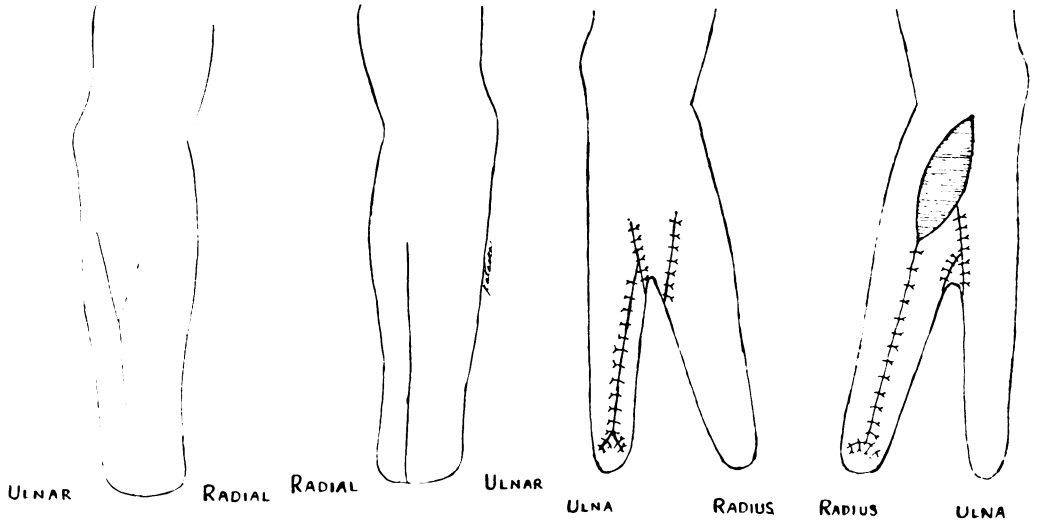


FIG. 1-A FIG. 1-B FIG. 1-C FIG. 1-D

Fig. 1-A: Skin incision on dorsal surface of forearm is slightly to the ulnar side. V-shaped, secondary incision is made at the time of skin closure to determine its proper size more accurately.

Fig. 1-B: Skin incision on flexor aspect of forearm is made slightly on the radial side.

Fig. 1-C: Skin closure on dorsal surface shows the suture lines away from the contact surfaces. The secondary skin flap is rotated into the axilla of the wound. The skin folded over the end of the ray is noted.

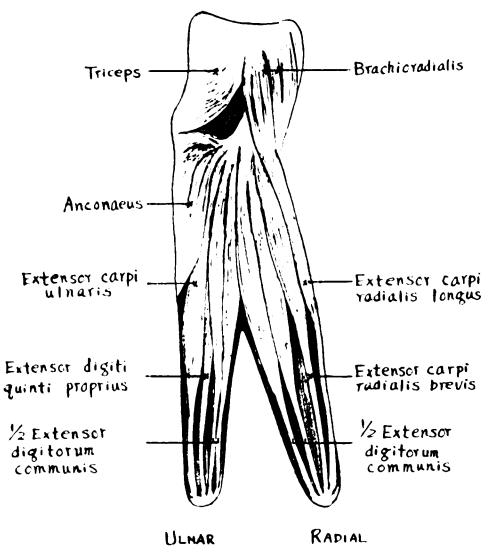
Fig. 1-D: Skin closure on flexor aspect of forearm shows split graft needed for closure on the radial ray.

slightly toward the radial aspect (Fig. 1-B); the dorsal incision is slightly toward the ulnar aspect (Fig. 1-A). One or two secondary V-flaps, according to the Bunnell technique, are used at the proximal end of the wound to provide full-thickness coverage in the axilla of the forceps (Figs. 1-C and 1-D). The distal portions of the rays are covered by skin flaps rolled onto the opposing surfaces so that the distal tips of the forceps will not have scar-tissue lines on their opposing surfaces. There is usually an abundance of skin in limbs with congenital malformations so that coverage of the distal end of the ray is easily accomplished. A small, split-thickness skin graft has been found necessary to cover a portion of the wound on the proximal

volar aspect of the radial ray (Fig. 1-D). Skin flaps should be defatted and rotated carefully. Closure and fashioning of the secondary flaps are done with the tourniquet deflated. This allows observation of the blood supply of the skin in this important portion of the procedure.

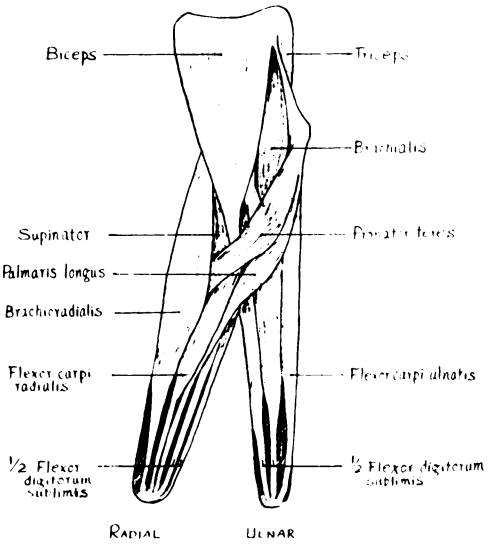
If, in an adult, severe scarring of the distal end of the stump is present after traumatic amputation, some shortening of the radius and ulna may be necessary to get good closure and rotation of skin with tactile sensation between the ends of the forceps. Shortening of the radius and ulna in the juvenile patient cannot be done distally because of the epiphyses.

If a single digit is present, it should be retained as in two of the cases reported here. The presence of this single digit may improve the patient's prehensile patterns a great deal. This was noted especially in Case 1. This patient was able to use



DORSAL

FIG. 1-E



FLEXOR

FIG. 1-F

Fig. 1-E: Muscles separated into two moieties for the radial and ulnar rays on the dorsal aspect.
Fig. 1-F: Division of muscles on flexor aspect into radial and ulnar rays.

the single digit for delicate activities, such as buttoning his shirt and handling small objects. If the digit can be rotated and angled to a more useful position so that it will oppose the opposite ray of the Krukenberg stump, this should be done as in Case 4. The poorly developed extensor tendons of this digit were sutured to the periosteum on the ulnar side of the radial stump. This brought the digit into closer relationship to the ulnar ray so that the minimum available active flexion of the digit could provide some opposition against the opposing ray.

Nerves

The ulnar nerve goes with the ulnar ray and the median nerve with the radial ray as the forearm is divided into two separate moieties. It may be desirable to resect the distal ends of these nerves in traumatic amputation stumps to prevent neuroma formation in the distal ends of the rays.

Muscles

The muscles and tendons are easily divided between the radial and ulnar rays

(Figs. 1-E and 1-F). The radial half of the flexor digitorum sublimis and the extensor digitorum communis, the flexor carpi radialis, the extensor carpi radialis brevis and longus, the brachioradialis, the palmaris longus, the pronator teres, and, occasionally, the muscles to the thumb go to the radial ray. The ulnar half of the flexor sublimis and the extensor communis, along with the flexor carpi ulnaris and the extensor ulnaris, go to the ulnar ray. The pronator quadratus, the flexor digitorum profundus, the flexor pollicis longus, abductor pollicis longus, and extensor pollicis brevis may be resected if they do not motivate a single digit or if they make the stump too bulky and thus prevent easy wound closure. Care is taken to avoid disturbing the pronator teres as this muscle is one of the strongest adductors of the radius for this procedure. Its muscle belly is the limiting factor in the proximal portion of the wound and forms the floor of the axilla of the forceps. The distal ends of the tendons of the retained muscles in each ray are securely sutured to the periosteum and capsular tissues of the distal end of the radius or ulna.

Interosseous Membrane and Bone

The interosseous membrane is divided throughout its length along its ulnar periosteal attachment, exercising great care to avoid the interosseous vessel and nerve. The ulnar and radial rays are then spread six to twelve centimeters at their tips, depending on the size of the forearm. This motion occurs at the radiohumeral and proximal radio-ulnar joints. The distal ulnar and radial epiphyses, in the juvenile cases, are carefully preserved. The epiphyseal plate should not be crossed in the dissection and great care should be exercised in the preparation of the tips of the forceps to avoid damaging these important structures.

The opposing ends of each ray should touch for best function. One of the patients in this series had an angulation of the radius, preventing good apposition of the radial ray to the ulnar. An osteotomy was done later to correct this. This consisted in a partial-cut osteotomy on the dorsal surface of the mid-radius, angulating the bone ulnarward and filling in the open-wedge defect with bank bone. This resulted in much improved function for small-object prehension.

Skin Closure

With the tourniquet off, the skin is rotated around the rays and approximated, resecting excess muscle substance, usually from the profundi and thumb, outcropping muscles, excess fat, and fibrous tissue to allow wound closure without tension on the skin flaps. The distal flaps are rotated across the ends of the rays; the secondary flaps are made to cover the axilla of the wound. If a small defect is found on the palmar aspect of the radial ray, it is covered with split-thickness skin from the abdomen or thigh.

Dressings

Small rubber drains are left in the wound and a voluminous compression dressing is applied, separating the rays at their tips six centimeters or more. The limb is usually elevated for three days to improve venous return. The wounds healed *per primam* in all patients except one in whom a small area of secondary-intention healing along the radial wound required simple protective dressings for three weeks; this did not interfere with the training program.

Rehabilitation

A training program is started within two to three weeks. The patients seem to acquire the ability to grasp and release naturally. Pronation and supination are strong, normal, movements; abduction and adduction of the rays, however, are the

FIG. 2-A

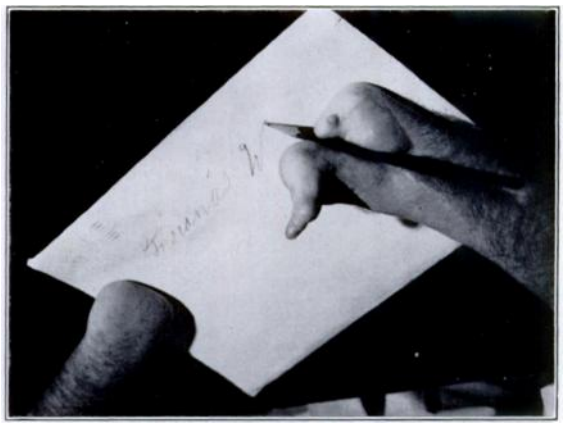


FIG. 2-B

Fig. 2-A: Case 1. This man, twenty-seven years old, was born without hands. A Krukenberg operation was performed on the right in May 1951, when he was fourteen years old. The single digit was left on at the patient's request and he finds it invaluable in helping to accomplish some of his daily activities. He uses the Krukenberg stump in his work as a part-time carpenter and has found the grasping mechanism it provides invaluable in his activities of daily living.

Fig. 2-B: The patient demonstrates the strong, useful prehension which he has gained.

FIG. 3-A

FIG. 3-B

Fig. 3-A: Case 2. This two-year-old child has congenital absence of the hands and feet. She also has the residuum of a cleft palate and harelip and right microphthalmia.

Fig. 3-B: After a right Krukenberg procedure, performed when she was two years and two months old, and fitting with a wrist disarticulation prosthesis for the left upper extremity. The child uses the Krukenberg stump as her primary hand and the prosthesis as an assistive member for all of her activities. With a Krukenberg procedure, her potential for rehabilitation is greater than if she had been treated with bilateral upper-extremity prostheses.

important motions to be learned if the patient is to obtain the most benefit from his Krukenberg stump. The occupational therapist is invaluable in training these patients and in stimulating them to early and proper use of the Krukenberg forceps.

The major adduction-abduction motion of the Krukenberg stump is accomplished by the radius moving toward or away from the relatively fixed ulna. In strong gripping, however, ulnar adduction is also of importance. The patients very

rapidly learn their own combinations of adduction-abduction, pronation, and supination to accomplish daily activities.

The abductors of the radius are the brachioradialis, the extensor carpi radialis longus and brevis, the radial portion of the extensor digitorum communis, and the biceps.

The adductors of the radius are the pronator teres, supinator, flexor carpi radialis, the radial part of the flexor digitorum sublimis, and the palmaris longus.

The abductors of the ulna are the extensor carpi ulnaris, the ulnar part of the extensor digitorum communis, and the triceps.

The adductors of the ulnar ray are the flexor carpi ulnaris, the ulnar part of the flexor digitorum sublimis, the brachialis, and the anconeus.

This new functioning and grasping mechanism with skin sensibility stimulates cooperation by the patient so that rehabilitation is relatively easy and rapid. The patient is encouraged to use standard implements and to learn to adapt to a normal environment. Two-handed activity is encouraged, using the hook on the opposite side. Patterns of activity to accomplish daily living requirements are practiced. It has been found that dominance of activity moves to the Krukenberg side because of the easy prehension and, especially, the tactile gnosis which it offers.

Cosmetic Effect

Patients have displayed little, if any, concern about the appearance of the Krukenberg stump. It is acknowledged that these are young patients, mainly concerned with function. The parents also have been enthusiastic about this procedure and all are pleased with the results. They have been asked about the cosmetic effect of the operation and the reply has always been that the Krukenberg stump is no less appealing than the useless stump or hook. They do not consider the appearance of the stump to be a problem. They are so enthusiastic about the improved function the procedure gives the child that they have appeared somewhat surprised when asked about cosmetic appearance.

In this series, the patient with the longest follow-up (thirteen years) said that he lost his concern about the appearance of the stump several months after the operative procedure; he has not hidden it in public and uses it as naturally as one would a hand.

Case Histories

CASE 1. R. K., a boy, born in 1937 (Figs. 2-A and 2-B), was operated on by me and followed in the Indiana University Orthopedic Clinics. He was born with left upper acheiria, right upper monodactylia, and left apodia [5]. He had been fitted with a below-the-knee prosthesis. In May 1951, a Krukenberg procedure was done on the right upper extremity, sparing the single digit and leaving its motor supply intact. He was then fitted with a wrist disarticulation prosthesis on the opposite side but subsequently discarded it. When last examined, in November 1961, he had a two and one-half inch opening and could approximate his radial and ulnar rays with a force of ten pounds. The rays were approximately one-half the length of the forearm stump. He also had excellent tactile gnosis on the opposing surfaces of the rays and was able to differentiate small coins in his pocket and remove them. He could dress and feed himself and was able to take care of all of his toilet needs, including using toilet paper. He was trained as a paint sprayer; however, he had been unable to obtain employment and was doing odd jobs as a carpenter as well as helping in his parents' home. This young man would be benefited by a wrist disarticulation prosthesis on the left as an assistive member. He has, however, developed an amazing pattern of activity using the Krukenberg stump in combination with the wrist stump on the opposite side. He said that he has benefited tremendously from the Krukenberg procedure and that he and his parents do not object to the appearance of the stump.

CASE 2. G. H., a girl, born on August 27, 1957, was brought into the Area Child Amputee Clinic from another state (Figs. 3-A and 3-B). She was born with bilateral acheiria, bilateral apodia, cleft palate and harelip, microglossia, and microphthalmia. She had been placed in an institution

FIG. 4-A

FIG. 4-B

Fig. 4-A: Case 3. This seven-year-old boy was born with left upper partial hemimelia and right acheiria in addition to right lower hemimelia and left apodia. Previously he had been fitted with bilateral upper-extremity prostheses with hooks as well as lower-extremity prostheses.

Fig. 4-B: The child uses the Krukenberg stump as his dominant hand. He and his parents are pleased with the improved function with strong prehension and sensation obtained from the Krukenberg procedure.

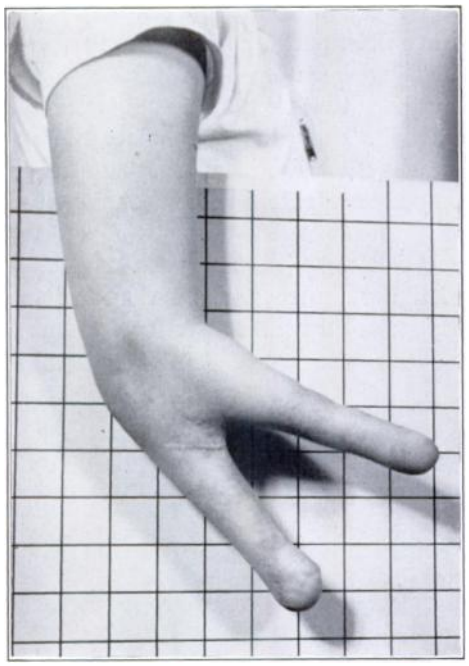


FIG. 4-C

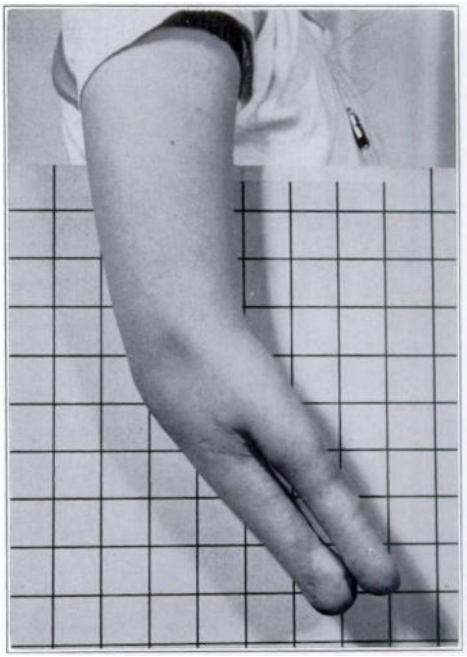


FIG. 4-D

Fig. 4-C: After a right Krukenberg procedure, when seven years and one month old, the child had a two and three-quarter-inch opening. The secondary skin flap used to fill in the axilla of the forceps can be seen.

Fig. 4-D: Apposition of the radial and ulnar ray. On June 10, 1962, one year after the Krukenberg procedure, the child had a secondary osteotomy of the radius to angulate the radius approximately 20 degrees to give him better apposition at the tips. He has a six-pound pinch.

for handicapped children by her parents because they believed nothing could be done for her. Originally, the child was fitted with bilateral upper-extremity prostheses and bilateral Syme's-type lower-extremity prostheses. On November 2, 1959, a Krukenberg operation was performed on the right upper extremity. She had primary healing of the wounds and started her training approximately two weeks after the operation. The occupational therapist said that the child showed a

FIG. 5-A

FIG. 5-B

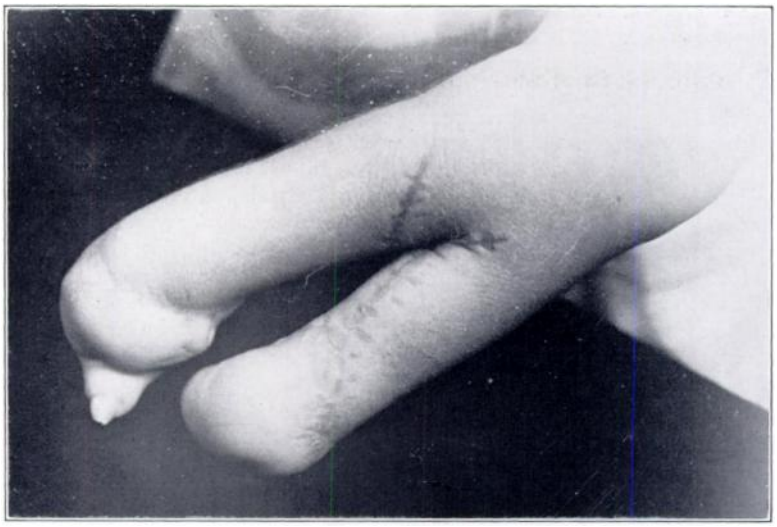


FIG. 5-C

Fig. 5-A: Case 4. This two-year-old child was born with left upper partial adactylia and right upper partial hemimelia in addition to left lower amelia and right lower hemimelia. Originally, she was fitted with bilateral upper-extremity prostheses. A Krukenberg procedure was performed on the left on September 24, 1961, when she was three years and three months old.

Fig. 5-B: The child learned grasp and release within three weeks after the operation.

Fig. 5-C: An early postoperative photograph of the dorsal surface of the Krukenberg stump demonstrates the opposing tactile skin free of scars.

great deal of functional and emotional growth during her hospitalization. On admission she was negativistic and displayed frequent temper tantrums; her attention span was short and she was uncooperative. At the time of discharge it was evident that she had been able to form associations with staff personnel and had started to relate to other children. With the Krukenberg stump, which gave her a new grasping mechanism, the prosthesis on the contralateral upper extremity, and her new ability to walk, she became more independent and out-going; she began to investigate her environment. She was more cooperative, her attention span increased, and she had fewer temper tantrums. At the time of writing, she used the Krukenberg stump as her primary hand and the prosthesis as an assistive member in all activities, including dressing. She ate independently, painted and colored pictures, used scissors, played with dolls, dishes, blocks, strings and beads, and used a swing, tricycle, doll carriage, and rocking horse, all in ways commensurate with her age.

She had a one-and-a-half-inch opening of her stump with a pinch force of three pounds. She was able to pick very small objects, including needles, off the floor. She had not learned to speak and the staff psychologist considered her trainable but not educable. She was discharged to the care of her family. On subsequent visits to the Clinic, the parents requested that a Krukenberg procedure be performed on the opposite forearm.

CASE 3. D.L., a boy, was born on May 4, 1954, with left upper partial hemimelia, right acheiria, left apodia, and right lower hemimelia (Figs. 4-A through 4-D). In September 1957, he was fitted with prostheses for the upper and lower extremities. The child quickly developed a good bilateral pattern of activity with his hooks. It was then decided that he would benefit from a Krukenberg procedure on the right upper extremity. This procedure was accepted by the parents after they had observed the function of another child with a Krukenberg stump. The operation was performed on June 19, 1961. The wound healed by primary intention except for one small area around the distal end of the radius which closed in approximately six weeks. Training was started during the third postoperative week. This child had a dorsal angulation of the radius which prevented good apposition of the rays. An osteotomy was done to angulate the distal portion of the radius approximately 20 degrees on June 10, 1962. This improved small-object grasp. The child has approximately a three-inch opening of the stump. The rays are approximately three-fifths the length of the forearm. He has a grasp of six pounds, is able to feed and dress himself, use scissors, and pick up small objects with speed and agility. He has quick, repetitive opening of his rays and is extremely well coordinated. He can pick up objects and identify them while blindfolded. He uses the Krukenberg stump as naturally as two fingers of a normal hand. He throws a baseball with the Krukenberg stump and plays outfield on his school team at recess.

CASE 4. P. D., a girl, was born June 7, 1958, with left upper partial adactylia (monodactylia), right upper partial hemimelia, left lower amelia, and right lower hemimelia (Figs. 5-A, 5-B, and 5-C). She was two years old when first seen in this Clinic, at which time she was fitted with upper-extremity prostheses with 12P hooks. She was considered to be a good candidate for a Krukenberg procedure on the left upper extremity and this was performed on September 24, 1961. The wounds healed by primary intention. Training was started two weeks after the operation. The child developed a spread of one and one-half inches at the ends of the rays with a two-pound force at closure. She had essentially no difficulty in training and developed a good adduction-abduction pattern. She has learned to feed herself independently and has rapidly gained a two-handed pattern, using the prosthesis on the right side as an assistive member. The small digit on the radial ray was rotated into some flexion at operation by suturing the capsular structures to the end of the radius. She has obtained some added function and small object prehension using this digit. She demonstrates the advantage of retaining whatever functional anatomical structure is present. She had minimum subluxation of the radial head, noted before operation. This has not interfered with function of the Krukenberg stump. She has good tactile gnosis on the stump and is able to identify small objects while blindfolded. In the two-point discrimination test she can differentiate the two points at seven to eight millimeters on the stump. This severely handicapped child benefited greatly by the addition of the Krukenberg procedure which gave her a natural grasping mechanism. There has been no cosmetic concern either by the child or by the parents.

Summary

The Krukenberg procedure was performed unilaterally on four juvenile amputee patients with congenital bilateral absence of the hands. These four cases are reported. The opposite extremity was fitted with a standard prosthetic prescription as an assistive hand. In all cases, the Krukenberg stump became the leading hand. The results have been remarkably rewarding to these patients. There has been virtually no concern evidenced by the patient or the parents about the appearance of the stump. The surgical procedure is considered to be reasonably uncomplicated. Postoperative rehabilitation has been simple and rapid.

It is my impression, from observing these patients, that this procedure should be extended to more individuals who have the severe handicap of bilateral hand loss.

References

1. ALLDREDGE, R. H.: The Cineplastic Method in Upper-Extremity Amputations. J. Bone and Joint Surg., **30-A**: 359–373, Apr. 1948.
2. BUNNELL, STERLING: Contractures of the Hand from Infections and Injuries. J. Bone and Joint Surg., **14**: 27–46, Jan. 1932.

(*Continued on page 1610*)

thought to be useful in those situations where the articular surface has been comminuted or separated from its blood supply and where, in the past, a resection would have been performed. The importance of repairing fracture-dislocations within the first three days and the need for accurate reconstruction of the rotator cuff and its attachments is emphasized. In painful degenerative lesions, the results of replacement have been especially good and use of this procedure is favored over arthrodesis in selected instances of osteo-arthritis and avascular necrosis.

REFERENCES

The Krukenberg Procedure in the Juvenile Amputee

(*Continued from page 1548*)

3. Colp, Ralph: Krukenberg Amputation. *In* Transactions of the New York Surgical Society. Ann. Surg., **97**: 277–279, 1933.
4. Frantz, C. H., and Aitken, G. T.: Management of the Juvenile Amputee. Clin. Orthop., **14**: 30–49, 1959.
5. Frantz, C. H., and O'Rahilly, Ronan: Congenital Skeletal Limb Deficiencies. J. Bone and Joint Surg., **43-A**: 1202–1224, Dec. 1961.
6. Henry, A. K.: An Operation for Making the Forearm Prehensile after Loss of a Hand. British J. Surg., **16**: 188–197, 1928.
7. Kallio, K. E.: Recent Advance in Krukenberg's Operation. Acta Chir. Scandinavica, **97**: 165–188, 1948.
8. Kessler, H. H.: Cineplasty. Springfield, Illinois, Charles C. Thomas, 1947.
9. Krukenberg, H.: Über plastische Umwertung von Amputationsstümpfen. Stuttgart, Ferdinand Enke, 1917.
10. Pomeroy, R.: Personal communication.
11. Slocum, D. B.: An Atlas of Amputations. St Louis, The C. V. Mosby Co., 1949.
12. Squires, B. T.: Note on Two Cases of Krukenberg's Operation. British J. Surg., **25**: 464–466, 1937.
13. Swanson, A. B.: Multiple Finger Amputations—Concepts of Treatment. J. Michigan State Med. Soc., **61**: 316–320, 1962.
14. Swanson, A. B.: Restoration of Hand Function by the Use of Partial or Total Prosthetic Replacement. Part I. The Use of Partial Prostheses. J. Bone and Joint Surg., **45-A**: 276–283, March 1963.
15. Swanson, A. B.: Restoration of Hand Function by the Use of Partial or Total Prosthetic Replacement. Part II. Amputation and Prosthetic Fitting for Treatment of the Functionless, Asensory Hand. J. Bone and Joint Surg., **45-A**: 284–288, March 1963.
16. Zanoli, Raffaele: Krukenberg-Putti Amputation-Plasty. J. Bone and Joint Surg., **39-B**: 230–232, May 1957.