May 1955

Artificial Limbs

ADVISORY COMMITTEE on ARTIFICIAL LIMBS

National Academy of Sciences

National Research Council

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Engineering — Hope of the Handless

EUGENE F. MURPHY, Ph.D.[1]

THE human hand, with its elaborate control system centered in the brain, is doubtless the most widely versatile machine that has ever existed anywhere. Its notorious deficiency lies in its persistent inability to create a similar machine as versatile as itself. This circumstance accounts for the fact that, while there has been from earliest times a great need for hand replacements, all attempts to produce successful hand substitutes have thus far ended in only a rather crude imitation of a very few of the many attributes of the living counterpart. For want of complete knowledge of the natural hand-brain complex, and of the ingenuity requisite even to the most modest simulation of the normal hand, artificial hands have always resembled the natural model in a superficial way only. Voltaire is said to have remarked that Newton, with all his science, did not know how his own hand functioned.

But the science of Newton, basic as it was, is itself remote from the advanced technology of our own day. Failure in hand prosthetics, though owing in part to the difficulty of replacing any living organ with an inanimate contrivance, stems also in part from failure to apply intensively the principles of modern science generally, and of engineering in particular, to the problems of artificial-hand design. Because in general the engineering profession had not theretofore been much concerned with the development of improved artificial limbs, the hand prostheses available a decade ago represented no appreciable improvement over those to be had at the end of World War I.

In all fields of human endeavor, the problems for which men have found tentative solutions in the past often merit the attention of the engineer of today. A new look by competent technologists usually yields gratifying results, for the solutions found by our forebears, while seemingly adequate at the time, do not reflect the progress made in the development of methods of experimental analysis, in the measurement of behavioral characteristics, in the establishment of criteria, in the development of materials, and in the evolution of forming techniques for application of the materials to the needs of man. Just so in the

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field of prosthetics, where the problem of matching a device to the human system is particularly acute and where, consequently, the application of new methods holds special promise.

Perhaps the most compelling reason today for the importance of engineering in prosthetics research lies in the approach and methodology now implicit in the profession. Introduction of the requirements of man in a quantitative manner without neglect of the qualitative, subjective aspects places design on a rational basis for the first time in history. During World War II there arose the problem of designing numerous complicated systems to be operable within the limits of human capabilities. In that urgent work, a substantial number of engineers had occasion to become acquainted with certain important physiological and psychological characteristics of man, so that by the end of the war the stage was set for the impact of the engineering profession on the development of prosthetic devices, which is, after all, a unique and particularly challenging field of biomechanics.

When, therefore, in 1945, the then Committee on Prosthetic Devices undertook to conduct basic studies toward the provision of better hand substitutes, it enlisted the services of engineers to cooperate with the medical profession and others in developing the necessary data and in applying the results to improved hand design. In the Artificial Limb Program, principal responsibility for the development of improved hand substitutes has almost from the beginning resided with the Department of Engineering at the University of California, Los Angeles Campus, and with the Army Prosthetics Research Laboratory, Walter Reed Army Medical Center. Out of this cooperative effort have now come not only new and improved devices but also, and perhaps more important, a set of criteria which lay down the basic principles of hand design toward further improvements in the future.

Because of the importance of the hand in all human activities, because of the critical nature of adequate hand replacement in the rehabilitation of upper-extremity amputees, and also because of the rather striking advances that have been made in the design of artificial hands in recent years, this issue of ARTIFICIAL LIMBS is devoted entirely to a little symposium on the hand and its substitutes. The mutual cooperation of the several contributors toward a unified approach to the whole subject is typical of the cooperation that has characterized the Artificial Limb Program since its inception.

The work in prosthetics will, it is to be hoped, serve as a pattern for further investigations jointly by the medical and engineering professions wherever developments in materials, controls, and systems in general can be brought to bear to augment human functions which an individual can himself no longer provide. One continuing problem is that of convincing able young people now studying engineering that a satisfying future exists for them in such cooperative ventures with the medical profession designed to rehabilitate the less fortunate throughout the world. Those now engaged in prosthetics development can be of great help in presenting to these young men and women the perspective of the future in such a manner that fresh engineering graduates might elect to carry forward the work now already so well under way.

Finally, it ought to be noted that, despite the distinct accomplishments evident at this, the tenth anniversary of the establishment of the Artificial Limb Program, only the first faltering steps have been taken toward the "ideal" prosthetic hand. Structural elements and prehensile function are not enough. It remains to provide some reasonable substitute for the sensory-motor apparatus which, in the living hand, is of such consummate perfection as to beggar description. A problem like this should charge the imagination of any young engineer in search of a field of application for service. To him belongs the future in prosthetics research.

The Anthropology and Social Significance of the Human Hand

ETHEL J. ALPENFELS, D.Sc.[1]

A DEFINITIVE study of the anthropology of the human hand has yet to be written. Certain investigators, notably Krogman *(17),* Schultz *(28,29),* Ashley-Montagu *(2),* Clark (5), and Huxley *(13),* have done intensive work on specific aspects of the morphology of the human hand. Nevertheless, the paucity of published studies, the fragmentary nature of the research, and the failure to attempt any but the most general conclusions make it difficult to summarize in a short article the present status of the hand in human evolution. Authorities differ both in opinion and in practice as to the value of anthropometric measurements in tracing the lines along which specialization has moved in the evolution of the hand. Published materials on the social significance of the hand are, however, numerous, and the importance of the hand as an organ both of performance and of perception has been recognized in all fields of the social sciences.

Man alone has a hand. He uses it as a tool, as a symbol, and as a weapon. A whole literature of legend, folklore, superstition, and myth has been built up around the human hand. As an organ of performance it serves as eyes for the blind, the mute talk with it, and it has become a symbol of salutation, supplication, and condemnation. The hand has played a part in the creative life of every known society, and it has come to be symbolic or representative of the *whole* person in art, in drama, and in the dance. Students of constitutional types have used the hand as a means of classification, and the correlation between mental ability and manual dexterity has been the subject of much research. At the University of Pennsylvania, Krogman, using x-rays of the hand, currently is demonstrating new and important aspects of the interrelation of a child's growth and mental age. Thus the hand, perhaps because it is also dominant in the world of action, has come to be interpreted and understood best in its social aspects.

But in a sense the human hand is a paradox. Although it is said to be the highest achievement of primate evolution, research to date shows it to be no more than a variation of a primitive vertebrate plan. The successive stages of evolution give proof, if proof be needed, that our sensitive and mobile hands, with their opposable thumbs, are part of man's vertebrate ancestry.

In the suborder Lemuroidea, both recent and extinct, are found pawlike hands. The fourth digit[2] is elongated and, together with the first digit, acts like a pair of pincers to grasp a bough. Hooten *(12)* has pointed out that this is an adaptation found in all the

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[2] Meaning that digit corresponding to the "ring finger" in man. Among anatomists generally, at least two systems for identifying hand digits are in accepted scientific usage, often interchangeably by the same writer. A common convention is to number the digits from I to V, beginning with the thumb as digit I and ending with the little finger as digit V (Fig. 1). But many competent writers, thinking of the hand as having a "thumb" and four "fingers," label the "fingers" as first, second, third, and fourth, meaning the index finger, the middle finger, the ring finger, and the little finger or pinkie, respectively. Throughout this issue of ARTIFICIAL LIMBS, it is considered that the normal hand has five digits, one of which is a "thumb," the other four being "fingers." A "digit" is here referred to with the understanding that digit I is the thumb "Fingers" are referred to as being numbered beginning with the index finger as the first finger.—ED.

Fig. 1. One conventional method of identifying the digits of the hand. Some authorities prefer to think of the hand as possessing a thumb and four fingers. Both methods of nomenclature occur throughout this issue of ARTIFICIAL LIMBS.

lemurs, enabling them to maintain a more secure hold on boughs of large diameter. In lemurs, all of the digits are flat-nailed (except in the aye-aye, which has kept a number of primitive anatomical features), and several modifications appear in the carpal pattern.

In the suborder Tarsioidea, entirely arboreal, specialization of the hind limbs for hopping frees the hands not only for grasping but for feeding as well. The hind limb is longer than the forelimb, all of the terminal phalanges are flat-nailed, and the terminal digital pads have curious discs, almost like suction cups, enabling the tarsier to support himself on a smooth surface.

These and other adaptations foreshadow higher primate development (Fig. 2), but we must look further to find man's place in the primate scheme. The suborder Anthropoidea, the third and highest of the primate group, includes larger arboreal forms. Longer forelimbs, together with a relatively shorter thumb (approaching atrophy in some forms), provide a means of brachiation. It has been suggested that the short thumb is related to the specialization of the hand as a grasping mechanism, permitting a quick release of the hand in swinging from one branch to another. But in this suborder the hands still retain their primitive features, and only in certain of the Old World Monkeys do the proportions of the digits approach those of man. The emancipated hands of the anthropoids, with thumbs that rotate and oppose the other finger tips, are directed by a more complex nervous system and a larger and better-developed brain. Liberation of the hand may have been one of the decisive forces in the descent of certain anthropoids to the ground.

THE EVOLUTION OF THE HAND

LINKS WITH THE PAST

Man's hand retains the ancient pentadactyl pattern found in early vertebrates. Geological records show that, during the Devonian period of Silurian times, primitive sharks appeared having typical paired fins corresponding to the paired limbs in man, and these organs were destined to give rise to later and higher forms. But there is a great difference belween the paired limbs of the early forerunners of present-day fishes and the pentadactyl limbs of other vertebrates. All of the steps are not yet clear, and the gap between the ancient fishes and the amphibians has not yet been bridged, but it appears that in the early amphibians the migration from water to land led to adaptations and modifications, especially in the area of the shoulder and pelvic girdles.

These early ancestors of the primates had short legs, which grew progressively longer in the mammalian stage *(26),* and they walked flat-footed. The ability of the limbs to rotate brought about changes in the entire body. Striking homologies can be found in the hand and arm of man, the wing of a bat, and the foreleg of the frog. Where there are fewer digits, as in the hoof of the horse or the wing of the bird, the reduction has been due to adaptation to special environmental conditions *(5,13, 26).* Such reductions make for greater speed in the specialized limbs of the horse.

UPRIGHT POSTURE AND DIFFERENTIATION

The release of the hand from the requirements of locomotion, accompanied by the specialization of the foot and hind limbs for that purpose, led to upright posture (Fig. 3). Evidences of divergent evolutionary trends in the primate order are clearly distinguishable in the primate hand, especially those relating to limb length and trunk length (Fig. 4). Only the mountain gorilla has a hand shorter than that of man, not only with respect to limb length but in relation to trunk length. The longest hands among the great apes are those of the gibbon, the orangutan, and the chimpanzee. Specialists in the evolution of the hand

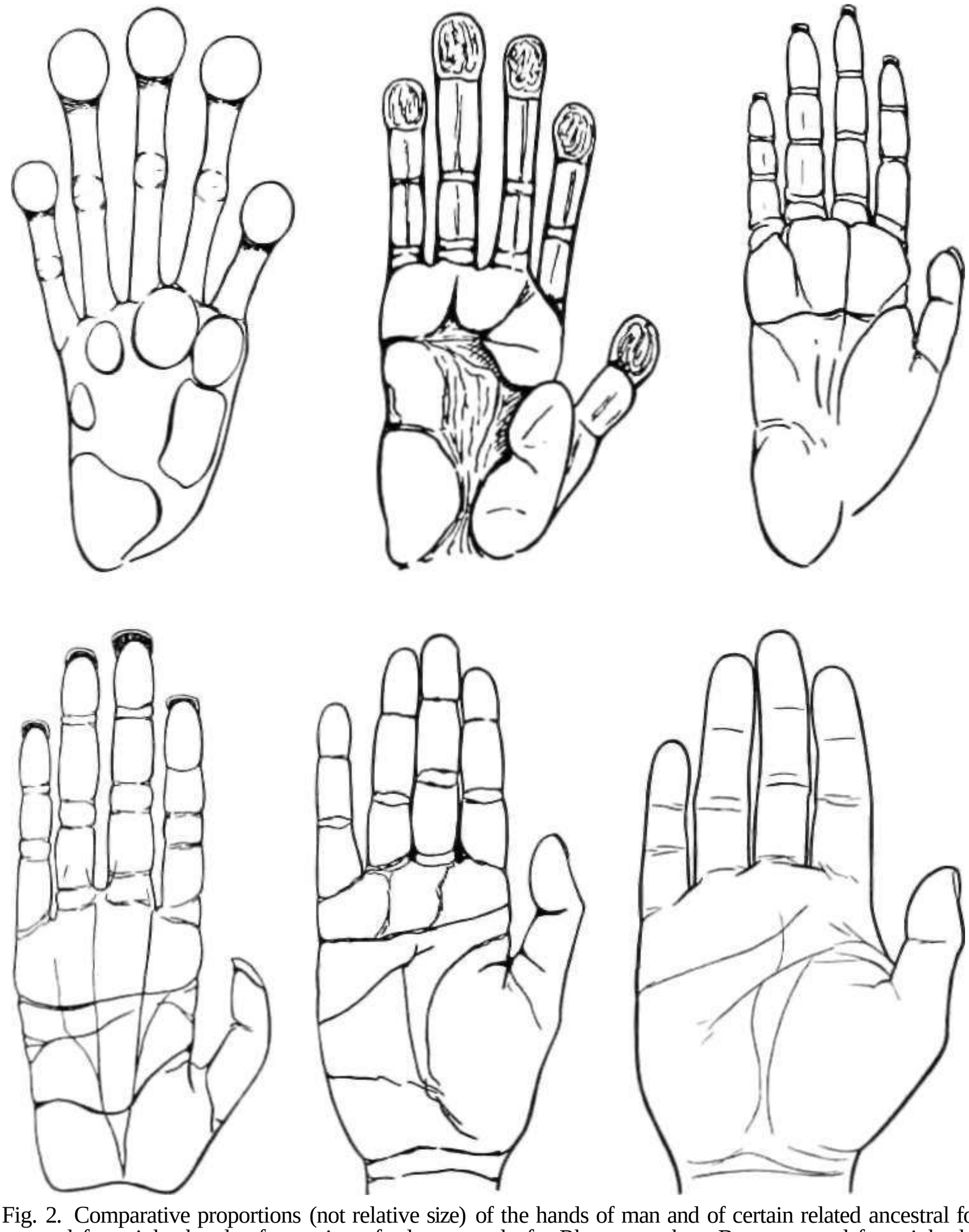

Fig. 2. Comparative proportions (not relative size) of the hands of man and of certain related ancestral forms. Top row, left to right, hands of a tarsier, of a lemur, and of a Rhesus monkey. Bottom row, left to right, hands of a chimpanzee, of a human with atypical simian characteristics, and of normal man. In all cases except that of the lemur, the digital formula is 3 > 4 > 2 > 5 > 1. From Jones *(14)*, by permission of Bailliere, Tindall, and Cox, Ltd.

have attributed the long, slender hands of these genera to brachiation and suspension, behavior that elongates not only the arms but the hands as well, especially the fingers and the metacarpal bones.

As for the length of the thumb, man and the other great apes show sharp divergence, especially when the thumb is considered with respect to hand length. As contrasted with the short thumb of the anthropoid apes, man's

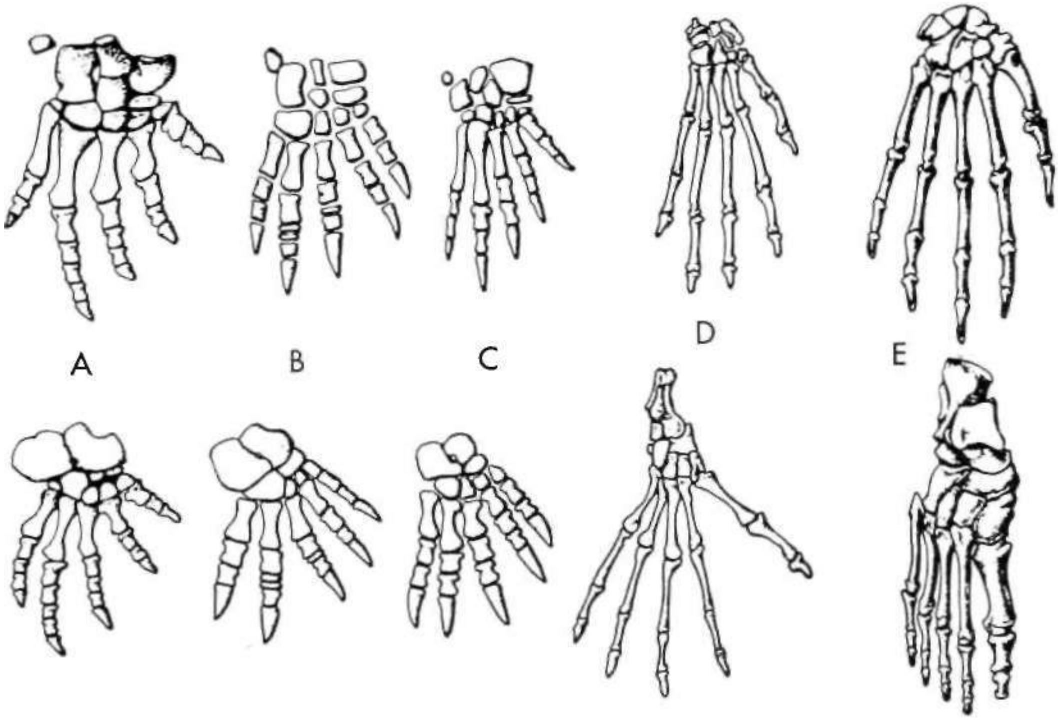

Fig. 3. The evolution of the hand (top row) and foot (bottom row), as revealed in skeletal structure. *A*, a primitive reptile; *B, C,* mammal-like reptiles; *D,* a lemur, representing a primitive mammalian type; *E,* man. Note the reduction in the number of joints in the toes, the specialization of the proximal ankle bones in mammals, some reduction in the number of wrist and ankle bones, and the variations in the thumb and great toe From Romer *(25),* by permission of The University of Chicago Press

thumb is long and well developed. Attempts to explain this difference have led to an either-or position. Either the thumbs of the apes have atrophied as a result of their arboreal life or man's thumbs have lengthened in the evolutionary process.

THE SHOULDER AND UPPER ARM

In man the shoulder and upper arm are adapted for strength. As for the other portions of the arm down to and including the hand, the more distal the part the more it is adapted for complex and delicate functions and the less for strength. The pectoral girdle in man consists of three bones. The scapula is directed dorsally, the coracoid process extends forward and downward to meet the sternum, and, anterior to the coracoid, the clavicle connects scapula and sternum. Because the pectoral girdle is not joined directly to the spine, though it may articulate with the sternum, the structure permits great freedom of motion in the shoulder area. Briefly, the human arm, supported and controled by a large number of muscles, together with the elbow and wrist joints, gives freedom to a hand that has become the willing servant of the human intellect.

MAN'S OPPOSABLE THUMB

The powerful and well-developed thumb of man is one of his few uniquely human characteristics. Through successive stages of vertebrate evolution, the thumb has separated from the other fingers and developed specialized musculature. In the Anthropoidea, the feature of opposability led to greater tactile and exploratory facility. Man's thumb, comparatively twice as long as that of some of the anthropoids, reveals a steady increase in absolute and relative length (Figs. 2 and 4) and, at the same time, the steady development of opposability, extensibility, and flexibility. When the "hand" of the ape is compared with the hand of man it becomes, in the words of Krogman *(17)*, a "misnomer." In the ape, hands are hands by definition only. Although man's hand, the end-product of our evolutionary development, retains the basic, primitive, pentadactyl pattern common to all land vertebrates, it nevertheless is uniquely human. The earliest animal footprint known (from the Permian of the Tambach in Thuringia) is so similar in appearance to that of the human hand that the animal which left the fossil print was named "Cheirotherium," or the "handbeast" *(2,5,12,17)*.

VARIATIONS OF THE HUMAN HAND

The morphological pattern of man's hand shows its affinity to the "hands" of other animals. But while man has kept the primitive pattern, other animals have specialized. In birds, for example, the hand has become a wing, in the horse a hoof, in the whale a flipper, in the dog a paw, and so on. According to Hooton *(12)*, Crawford has demonstrated the difference between tool-using, as in man, and tool-growing, as in most animals. Animals use no tools other than those developed out of the materials furnished by their own bodies. Man, however, was *(12)* "the first animal to grow a limb outside himself by making tools out of wood and stone." Furthermore, the limbs of animals are specialized for single purposes only. The horse can run, the mole can dig, but neither can climb; man makes instruments that are imitations of the body tools of other animals—a digging stick, an awl, a scraper, or a dagger *(34)*. The power and versatility of the human hand rests, in part, upon its generalized pattern. But it is the human brain, with its intricate and elaborated nervous system, that coordinates man's eye and hand. Thus, man is born with a hand free to do the bidding of his expanded brain.

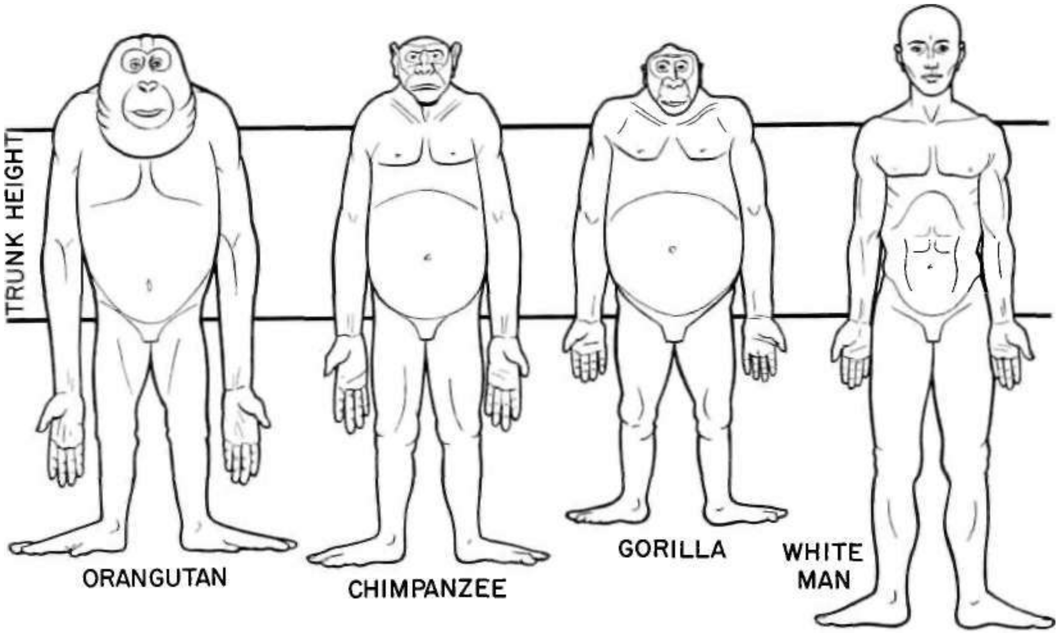

Fig 4. Exact diagrammatic front views of the four largest primates at fully adult age, drawn from detailed measurements on actual specimens, hair omitted, and all reduced to the same trunk height. From Romer *(25)*, by permission of The University of Chicago Press. Originally constructed by A. H. Schultz. Note that, from orang to chimp to gorilla to man, both limb length and hand length generally decrease with respect to trunk height. Only the gorilla has a hand shorter than that of man.

THE ANTHROPOMETRY OF THE HAND

EARLY STUDIES

The past fifty years have seen a gradual increase in the literature devoted to the anthropometry of the human body. But until that time, individual investigators had gone their separate ways, and there was little concurrence on standardization of the measurements to be employed, on the way in which these measurements were to be taken, or on the instruments to be used. Furthermore, just as in the osteological studies conducted in anthropological museums, early research on living animals was devoted largely to the head and facial features, and only later was study extended to the remainder of the body. Hence the dearth of anthropometric studies on the hand is easy to understand. Lacking, also, are routine osteometric recordings and systematic measurements and indices that could provide the comparative anatomical data necessary for a definitive work on the evolution of the human hand.

THE LACK OF DATA

Authorities appear to agree that no part of the human body has been as neglected as has the hand *(2,31)*. The reasons for this situation are many, but perhaps the most important one is the scarcity of fossilized primate hands, probably owing to the fact that these bones are small, fragile, and easily destroyed by the action of the forces of nature. Nor are the anthropological collections of complete hands of the modern anthropoids anywhere near adequate. During the past few years, individual investigators and museums have been attempting to increase the number of complete hands available for study, but the collections still are quite inadequate. Moreover, as was demonstrated at the University of Chicago, skeletons often turn out to be composites of many separate individuals and, therefore, of little use in anthropometric studies *(10)*. These handicaps, together with the complexity and the extreme variations found in the human hand, make it exceedingly difficult to get accurate results.

THE NEW FOCUS

The early work in comparative anthropometry was devoted entirely lo race differentiation *(4)*. At the present time, however, that interest is lagging, and extensive growth studies of the epiphyseal closures of the metacarpals and the phalanges are being conducted at the University of Pennsylvania *(11)*. The x-ray technique, used for many years, has become the major tool by means of which the anthropometrist and anatomist can study living persons. It is dependable and important, especially in studying the highly differentiated parts of the human hand.

CLASSIFICATION

The morphology of the hand has proved useful in classifying hand types. Wechsler's system *(17)* is based upon four hand dimensions (Fig. 5). From all possible combinations of length and three breadths, he derives six index categories, as shown in Table 1. Thus, the long, narrow hand type in man would be, for example, 1-1-1-2-4-3, that of the short, broad hand 4-4-4-4-4-4.

HANDEDNESS IN MAN

RIGHT AND LEFT—GOOD AND EVIL

The cultural world in which man lives, both in preliterate and in technologically advanced societies, tends to be a "right-handed" world. Cross-cultural studies reveal that different sides of the body, the left or the right, are associated with different social activities. In India, the right side and the right hand perform tasks considered to be "clean," while the left side and the left hand perform tasks considered to be "unclean." The two types of activities are separated rigidly. The right hand, for example, is used for cooking and eating, whereas the left hand is used in bathing, elimination, or activities associated with sex. Indeed, it is common in many areas of the world to find food related to the right hand, while the left hand is associated with sex *(19)*.

The right and left hand have come to symbolize good as opposed to evil, gods as opposed to demons. Hence, they are considered as two forces constantly at war with one another. The shadow plays of the Balinese illustrate the widespread association of good and evil with the right and left side respectively. The mystic story teller takes the marionettes out one by

Fig. 5. Hand measurements according to Wechsler. From Krogman (//), by permission of *Ciba Symposia.*

1. *Stylion radiale,* at tip of radial styloid process.
2. *Stylion idnare,* at tip of ulnar styloid process.
3. *Interslylion,* mid-point of line connecting 1 and 2.
4. *Daclylion III,* at tip of third finger.
5. *Metacarpale radiale,* at metacarpophalangeal junction of index finger.
6. *Metacarpale ulnare,* at metacarpophalangeal junction of little finger.
7. *Proxindicion,* at proximal interphalangeal junction of index finger.
8. *Ulnoquintion,* at intersection on ulnar side of little finger of line perpendicular *[sic]* to length dimension, drawn from 7.
9. *Dislindicion,* at distal interphalangeal junction of index finger.
10. *Ulnoquartion,* at intersection on ulnar side of ring finger of line perpendicular *[sic]* to length dimension, drawn from 9.

one, placing the "good" and "noble" characters at his right side and, at the left, the "evil" and "sinister" characters. In the end, truth and goodness always win, which demonstrates the triumph of the magical powers of the right side. At all important life crises—birth, death, marriage, initiation ceremonies—this magic balance between left and right is maintained. Among the Tiv of Nigeria, the afterbirth of a

Table 1

WECHSLER'S HAND INDICES

Length-Breadth Index I	
(Hand breadth I × 100/Hand length)	
1. Hyperdolichocheir (hdch)	x–40.9
2. Dolichocheir (dch)	41 0–43.9
3. Mesocheir (mch)	44 0–46 9
4. Brachycheir (bch)	47.0–49.9
5. Hyperbrachycheir (hbch)	50 0–x
Length-Breadth Index II	
(Hand breadth II × 100/Hand length)	
1. Ultralongiman (ulm)	x–32.9
2. Longiman (lm)	33.0–36.9
3. Medioman (mm)	37.0–40.9
4. Breviman (bm)	41.0–44.9
5. Ultrabreviman (ubm)	45.0–x
Length-Breadth Index III	
(Hand breadth III × 100/Hand length)	
1. Hyperdolichaktin (hda)	x–23.9
2. Dolichaktin (da)	24.0–26.9
3. Mesaktin (ma)	27.0–29.9
4. Brachyaktin (ba)	30 0–32 9
5. Hyperbrachyaktin (hba)	33 0–x
Hand-Breadth Index A	
(Hand breadth II × 100/Hand breadth I)	
1. Very strongly convergent	x–78.9
2. Strongly convergent	79.0–82.9
3. Mid-convergent	83.0–86.9
4. Weakly convergent	87 0–90.9
5. Very weakly convergent	91.0–94.9
6. Parallel	95.0–x
Hand-Breadth Index B	
(Hand breadth III × 100/Hand breadth II)	
1. Hektoklin (hkl)	x–65.9
2. Pemptoklin (pekl)	66 0–68.9
3. Tetartoklin (tekl)	69 0–71 9
4. Tritoklin (trkl)	72 0–74 9
5. Deuteroklin (dtkl)	75.0–77 9
6. Protoklin (prkl)	78 0–x
Hand-Breadth Index C	
(Hand breadth III × 100/Hand breadth I)	
0. Ultrafortistrikt (ufst)	x–49.9
1. Fortistrikt (fst)	50 0–53.9
2. Subfortistrikt (sfst)	54 0–57.9
3. Mediostrikt (mst)	58.0–61.9
4. Sublevistrikt (slst)	62.0–65.9
5. Levistrikt (lst)	66.0–69.0
6. Ultralevistrikt (ulst)	70.0–x

boy child is always buried to the left of the door in order to propitiate the evil spirits residing there. In Bali, a boy's placenta is buried on the right and a girl's on the left side of the entrance to the house *(6).*

CASTE AND THE HAND

The symbolism of the hands in ceremonial rites has, in various ways, come to indicate social class and caste. Among the Balinese, for example, it is a mark of social distinction to wear long nails, but only the priest may wear them on both hands. The giant-god of pre-Hindu times is believed to have carved out all of the caves with the fingernails of his left hand. The Indian caste system is noted for a unique feature in that many of the castes are divided into two sections called the "right-hand" (Balagai) and the "left-hand" (Yedagai) castes. Certain socially lower artisan castes, such as workers in leather, belong to the left-hand subgroup *(21).* Among the Motu of Papua, the moieties are grouped by the left and right hand. Members of the right-hand moiety have senior status in matters of inheritance, while members of the left-hand moiety have junior descent status *(27).*

OTHER INFLUENCES

Music for the piano usually is written in such a way that the melody is carried by the right hand. Threads in bolts, pipes, and even in glass jars are right-handed. Soup and gravy ladles, fish forks, and meat grinders—in fact, the majority of our manufactured products—are designed for the right-handed individual. Can the custom of men buttoning their coats on the right side and women on the left be a survival from our primitive past when the right was reserved for men because it was "good" and the left for women because it was "evil"? Our society is belatedly recognizing the right of sinistrodextral people to full participation in our culture. Banks are issuing left-handed checkbooks, left-handed armchair desks have been introduced in schools, and left-handed scissors and other implements and tools now are available.

HANDEDNESS IN EARLY MAN

Whatever the reasons for associating right with "good" and left with "evil," the fact remains that man is predominantly right-handed, a fact that appears to have been true even in prehistoric times. Early writers explained the enigma of right-handedness in the Lamarckian sense of "use and disuse." They noted that, since the heart was located on the left side of the body, the warrior carried his shield in his left hand. The right hand was free and, through more frequent use, developed in both size and dexterity. This "acquired" characteristic was passed on to succeeding generations.

During the nineteenth century, as the authenticity of plant and animal fossils was established, and with the growth of anthropology as a more exact science, numerous archaeological sites were excavated. By the beginning of the twentieth century, thousands of artifacts had been uncovered, more precise data were available, and the picture of life in prehistoric times began to emerge in greater detail. The oldest implement found in Europe was beveled for grasping between the right thumb and first finger. The implements of primitive Paleolithic sculptors were found to approximate in number and in form those of modern sculptors. All of the tools uncovered in a Spanish cave, said to have been inhabited during Solutrean times, are designed to fit the hand, and, from the almost perfect adaptation of these instruments, we may infer that these ancient artists were right-handed *(22).* Based upon the frequency of left-handed flint tools found *in situ* in France, other authorities, Krogman *(17)* for example, note that the incidence of left-handedness increased during the New Stone Age.

HANDEDNESS IN APES

During the past three decades, handedness in the apes has been studied extensively in the United States. Yerkes *(35),* in his classical work on the apes, found that handedness appears in chimpanzees. He points out that they use one hand consistently for certain purposes and the other hand for other activities. He says, however, that right-handed dominance has not been demonstrated and that the three types of motor activity found in man (right- and left-handedness and ambidexterity) occur with about equal frequency.

THE CHICK EMBRYO

The problem of left- and right-handedness in chickens has been reported. At about the 38th hour in the chick embryo, certain processes are initiated that result in what may be termed very loosely a "right-handed embryo." In certain chemicals, the molecular structure is "left-handed" in that it is of the nature of the mirror image of the "right-handed" counterpart. After a number of hours of incubation, fertile chicken eggs exposed to such "left-handed" chemicals evidence a "left-handed" type of flexure of the developing brain.

ASYMMETRY

Yerkes *(35)* holds with the current opinion that asymmetry of the left and right hand (Fig. 6) is related to a general asymmetry of the entire body. The right and left leg in man, for example, also differ in strength and in dexterity. Similarly, the right lung is slightly heavier, the abdominal viscera are heavier on the right side, both the spine and pelvic regions display asymmetry, and hence the center of gravity of the body is slightly to the right. Kahn *(15)* reports a number of experiments which demonstrate that, owing to this asymmetry, every blind wandering ends in a circle. Thus, man cannot write, nor walk, nor drive a car blindfolded without becoming a victim of his physical asymmetry.

Endocranial casts of the brain cavities of fossil and of modern man support this evidence, and here too asymmetry appears. The left occipital portion of the brain predominates to produce right-handedness, a fact established by Smith *(30)*. One school of thought claims that this asymmetry of the brain represents a primitive character in the higher apes and man. According to Clark (5), however, Keith maintains that, on the contrary, asymmetry represents an evolutionary advance.

The general physical asymmetry of the body is associated with a social asymmetry in our human prejudice against the left side. The human preference for right-handed tools and artifacts has, somehow, invaded the social and moral life. There also is a *sinistra* and *dextera* view of the world now fixed in our vocabulary.

HANDEDNESS IN LANGUAGE

We speak of dexterity (from the Latin "dexter," connoting "right," "favorable") in referring to skill, and this idea has been traced back to Sanskrit, the ancient literary language of India. From the category of physical things, the right hand has reached out to influence many other areas of human life. To be "orthodox" is to follow the "right" or "true" opinion. The concept of legal justice comes from the French "droit," meaning "right" or "law." Contrariwise, the word "left" symbolizes "evil," "weak," "awkward." The word for "left" in French is "gauche," meaning "awkward." The Latin "sinister," meaning "left," rarely applies to that which threatens but, rather, to that which is known to act covertly or insidiously. The bar sinister is the heraldic symbol of bastardy. A man who marries below his social rank gives his left hand, not his right, to his bride. Thus, in our own culture today there survive in our language and customs the social implications that historically have characterized handedness in man.

THE HAND AS A SENSORY ORGAN

THE SENSORY EXPERIENCE

Although prehension is the major function of the hand, the hand is, at the same time, one of man's primary sense organs. This tactile quality provides sensory experience that may be grouped into four general categories *(16)*. The first consists of "surface sensations"—stimulation generated by touching tangible objects. The second is termed "space-filling"—stimulation generated by pulling the hand through liquid substance. "Spacelike sensations," comprising the third category, relate to the touch of distinctively shaped objects felt through a heavy material. Finally, there are "penetrable-surface sensations," experienced, for example, by a physician as he palpates some part of the body to locate, through the outer layer of flesh, some abnormal condition in deeper tissue.

Movement is indispensable in sensory experience, and experimentation demonstrates that even the "imaginary" touch sensations are located in the finger tips. According to Katz *(16)*, it is quite impossible to call up the image of touch without, in imagination, moving the hand. The moment we imagine our hands at rest, the image becomes uncertain or disappears.

When body and ambient temperature are equalized, the hand may be used as an instru-

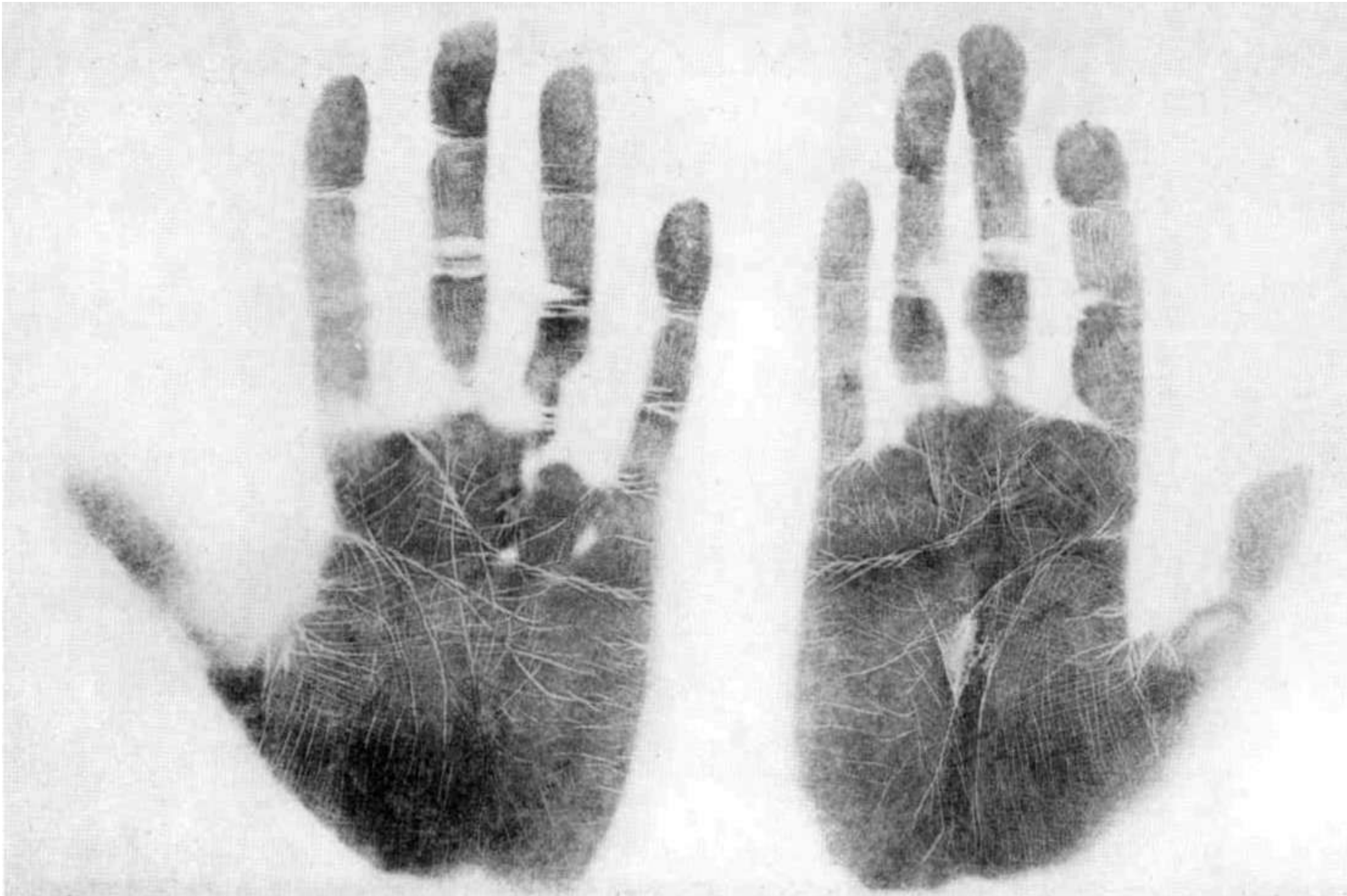

Fig. 6. Typical difference between the right and left hands of a single individual. The right has a shorter palm and longer fingers, and the long longitudinal line is more marked. From Wolff *(33).* by permission of Methucn and Co., Ltd.

ment for the perception of the relative levels of heat and cold. Preliminary determination of body temperature can be determined by placing the hand on the forehead. In folk society, for example, where accurate measures of determining fever temperature are not available, a normal hand placed upon the forehead is used to determine the presence of fever.

A PERCUSSIVE TOOL

The human hand can also be used as a percussion instrument. With an apparatus which he called "the percussion phantom,"[3] von Götzen found that vibratory impulses generated by finger percussion can be felt even when the auditory sense is eliminated.

A VIBRATORY TOOL

Vibratory sensations, as perceived by the hand, are of importance in teaching the deaf to speak. By placing one hand on the larynx of a speaker and the other hand on his own larynx, a deaf-mute learns the vibration patterns of speech sounds. When the patterns "heard" by his left and right hand are identical, the student has succeeded in imitating the sound. Helen Keller utilizes the vibratory phenomena when she "hears" music by placing her hand on the piano.

[3] Katz *(16)* describes the apparatus as a square wooden box, about 60 centimeters long by 8 centimeters deep, and open at the top. Around the top edge a strip of felt is fitted, and over the whole a thick cardboard square is fastened; this side of the box is clamped on with metal clips. The cardboard is strong enough to resist considerable pressure without sagging. On the underside of the cardboard, *i.e.,* inside the box, objects of different shapes—for example, round, elliptical, or heart-shaped objects—are pasted to substantial pieces of lead which appear either as matrices or as patrices, *i.e.,* they are cut into or cut out of lead. The thickness of the plate is chosen according to the degree of difficulty of the percussion task to be presented to the student. In general, the thicker the plate, the easier the task. The plates are so arranged that the figure is located in the middle of ihe underside of the cardboard. Each cardboard is fitted with one figure (if necessary, composed of two parts), so that there are as many cardboards as there are figures required for the test. Students were asked to determine, through percussion alone, the form of figures cut into or out of the lead plates.

THE HUMAN HAND IN ART

Through the ages the human hand has appeared in all of the creative arts of every culture *(1,3,24).* A single line, a schematic portrayal, a simple gesture of the hand, and character and personality stand revealed as clearly as they are seen in the human face. Recently, in the Kefauver investigation of crime in New York City, the television camera focused on the hands of a witness, and millions in the television audience watched while hands expressed feelings that man has taught his face to disguise.

In the creative arts, the hand speaks, and one senses the tremendous power of the hand to convey human emotions. The hands are the organs of the body which, except for the face, have been used most often in the various art forms to express human feeling. The hands point or lead or command; the hands cry out in agony or they lie quietly sleeping; the hands have moods, character, and, in a wider sense, their own particular beauty. From prehistoric times to our own day, in every society known to science, the hands symbolize cultural behaviors, values, and beliefs.

PAINTING AND SCULPTURE

Many studies of the hand appear in the traditions of western art. From schematic and conventional hand portraits, the artists of the fifteenth century began to draw anatomically correct hands, and, slowly but surely, the hand was seen as having a personality and a culture of its own. Albrecht Dürer (1471-1528) devoted a lifetime to the study of anatomy, and in his studies of hands the lines, the curves, the veins, the wrinkles delineate the complexity of the human hand (Fig. 7). In another medium, the French sculptor Auguste Rodin (1840-1917) deliberately used the hands to create unmatched works of art.

THE PREHISTORIC ARTIST

Early man left records in shallow caves, in rock shelters, and, in the great period of art during late Paleolithic times, on the walls of the innermost recesses of caves in France and Spain In the ancient engravings and the wall paintings found in caves in eastern Spain, the

Fig. 7, Famed "Hands of an Apostle Praying," by Albrecht Diirer (A.D. 1471-1528). *Courtesy The Public Library, Washington, D. C.* The original hangs in the Albertina Museum in Vienna.

arms and legs perform animated gestures in running, in drawing a bow, in gathering honey, and in the dance.

The human hand appears in quasi magico-religious silhouettes of complete or partially mutilated hands outlined in color on the walls of the grotto of Gargas in the Pyrenees Mountains. The fingers appear to be cut off at the distal end of the first phalanx, with one or more digits missing entirely. Curiously, the thumb never is amputated. The same type of finger mutilation is found in wall paintings in the caves of central Australia. Apparently the practice was customary among the early Aurignacian people of Paleolithic times, and it also is reported in other preliterate tribes. According to Osborn *(22),* Breuil believes that painting had its beginning in these stencilled contours produced by laying the hands against the limestone walls and spreading red and black paint on the surrounding area. In other examples, the hand was covered with pigment and pressed against the wall.

THE DANCE

The formal patterns and definite movements of the dance make it one of the greatest of the interpretative arts. It is, apparently, also one of the oldest arts. Whether viewed from a recreational, religious, or aesthetic standpoint, this expression of culture has attained meaning and intensity through movement of the hands. Joint dances between the sexes are rare among primitive tribes, and the hand thus has been liberated for gestures and symbolic movements. In India, the hands can tell an entire story. In Australia, among one of the most technologically simple tribes, the movements of the hands make the dance merge into drama. Indeed, it is difficult to separate the dance from music and from drama, but in each of these art forms it is the hand that gives meaning to words spoken. Perhaps the rhythm produced by the hands in clapping and in slapping the body originally led to music and to the dance.

THE HAND IN CULTURE AND SOCIETY

LANGUAGE ABSTRACTIONS

Because the human hand is an organ of performance, it is not surprising that the hand should "manipulate" ("to lead by the hand") the human vocabulary. The hand receives the "mandate" (from Latin "manus," for "hand," plus "dare," "to give") from the brain, and to "manage" is to govern, direct, or control. Thus, man "commends" (which originally meant "to place in one's hands") and "commands," both words related to "mandate" and, therefore, to the Latin "manus," for "hand."

With its basic movements for grasping objects (page *33),* the human hand also is "handy" ("dexterous," "to have two right hands") for grasping ideas. To "comprehend" is to "seize" (Latin, "capere," "to seize"), from which we derive such words as "perceive," "conceive," and "receive." Thus, by various shades of meaning, the human hand not only "hands down" information but "picks" it up. The human hand also is an organ of perception and thus lends itself to the most abstract concepts. "Handsome" originally meant "dexterous." "To feel" is connected somehow with the Greek word for hand, "palame." To say in Latin "dicere" means "to point." We touch, feel, handle, finger, thumb, paw, grope, palpate, and stroke objects.

ONE AND ONE ARE TWO

Man's hand not only manipulates and grasps, and makes and points, but it counts as well. Counting is very different from what we loosely term "number sense," an attribute that man shares with other animals. In its real connotation, counting appears to be an exclusively human characteristic, and numbers, like so many abstractions, begin with the human body. The old Roman numerals I, II, III, and IIII[4] are thought to be representations of the fingers. In certain of the less well-known languages, the word for hand gives us the word for five. "Five" also has come to mean "hand," and in English the slang expression "give us five" once meant "to shake hands."

One example of the use of hands in counting is that of the Mafulu mountain people, who do not use pebbles or sticks but instead use the hands and feet *(6).* Here counting is accomplished by the use of two numerals, "one" and "two." In indicating "one," the hand first is stretched open to indicate "nothing," the thumb then is closed down meaning "one," the first digit closed down meaning "two," and so on, until all of the fingers of one hand are closed. The process is repeated with the other hand, and, to count to 20, the clenched fist points to the feet and to all of the right and left toes. If the count is above 20 (usually only when important occasions demand, such as counting pigs for a ceremony) another man is called to stand beside the first. If the number goes as high as 83, five men join. Four men go through the entire process, and the last man closes the first three digits.

MAN THE MEASURE

Equally important has been the use of the hand as a unit of measurement. Tables showing the use of body organs as units of measure have been established for volume, surface. width, and length (Fig. 8). The earliest records show that the use of the index finger for indicating length was a widespread custom. In Europe the height of a man was estimated by a definite number of finger lengths based upon the measurement of the middle finger. In Latvia, the length of the middle finger was used to measure lengths for women's stockings or woolen socks (three times the length of one's middle finger). Sixteen times the length of the middle finger equals the normal human stride. The hand and thumb were used to measure width, 12 thumb widths being equal to one foot. Tools were made by the eldest member of the family and adjusted to the hand grasp. Thus, a scythe blade for an adult man was as long as nine or ten widths of the clenched hand, eight for an adult woman, and seven or eight for an adolescent (Fig. 9). The same pattern is found through much of eastern and northeastern Europe today.

[4] IV is a later development

SOME TRIBAL CUSTOMS

In the Sun Dance of the Plains Indians of the United States, finger joints were occasionally pledged as a thank-offering for recovery from illness or to ensure revenge for a slain relative *(32).* Cole *(6)* reports that individual warriors among the tribes of Mindanao carried home a hand as evidence of a successful fight and that at such times festivals were held to celebrate the event. Among the Tinguian tribes of the Philippine Islands, joints of the little fingers were added to ear lobes and brains to make a liquor that was served to the dancers. Here, as in most areas of the world, the brew was consumed not for nourishment but in order to secure that part of the enemies' bodies thought to house strength and valor.

Such reports may throw light upon the presence of the mutilated hands found on the walls of the European caves and dating from late Paleolithic times. The scarcity of drawings of the human form in cave paintings may be related in some way to the belief, still found among certain of our "primitive" contemporaries, that realistic portraits might give an enemy magic power. Possibly, through some similar process of sympathetic magic, the hand has already become a symbol to be portrayed realistically in religious ritual.

THE FINGERPRINT

Human hands have been used in various cultures as a means of positive identification.

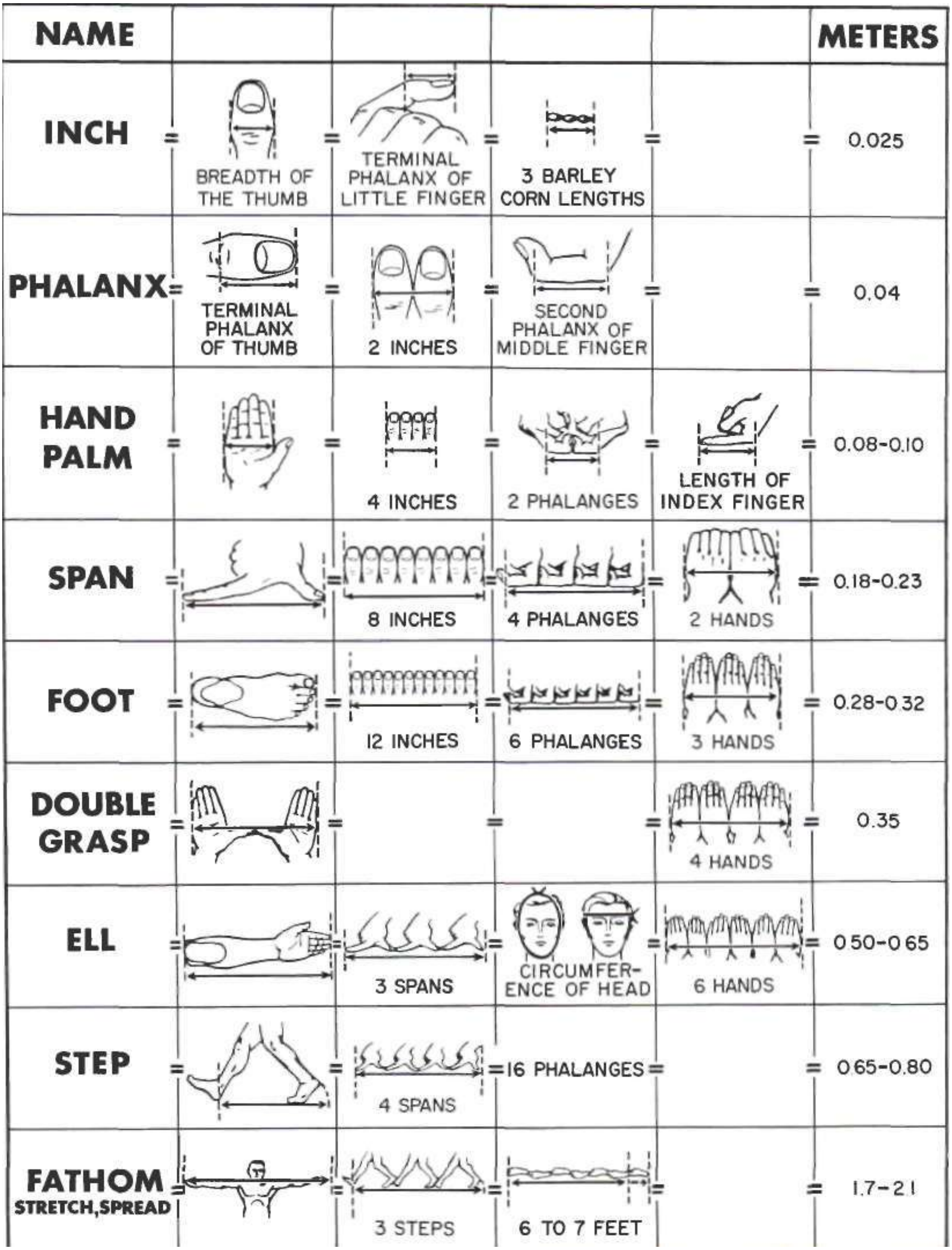

Fig. 8. Natural units of measure, still in use by Latvian and other European peasants. From Drillis *(9)*.

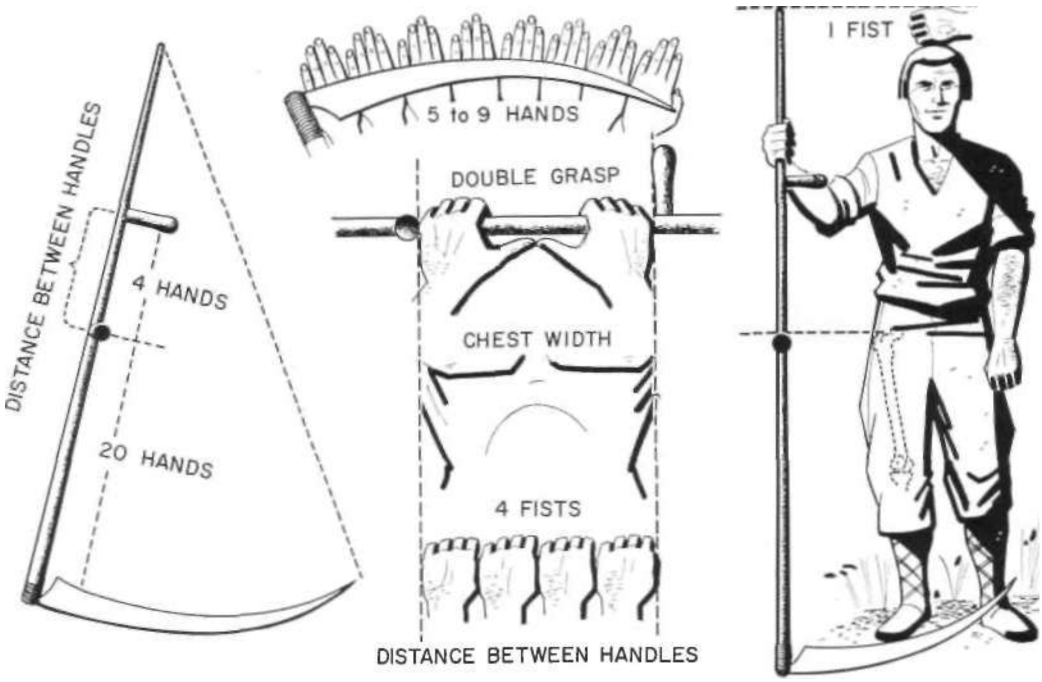

Fig. 9. The method, common among Latvian and other European peasants even today, of arriving at the proper dimensions for farm tools using the hand as the unit of measurement. From Drillis *(8).*

In ancient China, fingerprints were used to sign or to autograph paintings. They are doubly valuable as "signatures" because they cannot be altered or forged, and the intricate patterns of whorls, circular and folded loops, and arches differ from finger to finger and from individual to individual. As the person grows, his individual fingerprint patterns increase in size but do not change in geometric proportions. In 1882, Bertillon, a young French anthropologist, began to develop his famous system for identification of criminals by a physical description based upon eleven anthropometric measurements, deformities, and impressions of lines and markings of the finger tips. The Bertillon system of fingerprints has been used internationally and has proved valuable for physical identification.

SOME OTHER CONSIDERATIONS

OCCULTISM, SYMBOLISM, AND RITUALISM

In an anatomical sense, each hand is unique. Every hand betrays its possessor by characteristic mo/ement patterns, by peculiarities of gesture, or by occupational stigmata arising from physical and mechanical causes. From these characteristics, palmistry and a branch of occultism known as "chiromancy" have, for centuries, attempted to read the past, present, and future of individuals. Since early antiquity, numerous scholars of repute have concerned themselves with studies in palmistry. According to D'Arpentigny (7), Plato, Aristotle, Galen, Albertus Magnus, the Ptolemies, Avicenna, Averroes, Antiochus Tibertus, Tricasso (Fig. 10), Taisnier, Belot, and others have handed down lengthy treatises on the subject, and the observations of these early writers still prevail in our own modern times (Fig. 11). Palmists are interested chiefly in the surface of the hand—lines, stars, crosses, islands—and have divided the life line into seventy parts, each part symbolic of one of man's allotted seventy years of life. Chirognomists study the shape and form of the entire hand, in addition to surface characteristics *(20).*

But it is in the realm of quasi magic and symbolism that the hand reaches its highest cultural significance. For the great majority of mankind who think in concrete rather than in abstract terms, graphic representations of superhumanity are related to the human body. The Hindu of India symbolizes this superhumanity by the multiplication of the most important parts of the body, which, to him, are the head, the arms, and the hands. Since arms and hands are extremely useful, a twelve-armed god demonstrates the power and the strength denied a two-armed god. Such thinking may appear grotesque to the Westerner, but the Hindu, accustomed to symbolic thinking, knows that man is not so constructed, nor does he wish that he were. He simply recognizes that power and wisdom and strength may be expressed quantitatively *(23)*. The Moslem often wears a small image of the hand around his neck to ward off the evil eye.

Fig. 10. Principal lines and mounts of the hand as charted by Patritio Tricasso da Cerasari (Tricassus the Mantuan), a celebrated chiromancer of the sixteenth century. From Lenssen *(18)*, by permission of The Studio Publications, Inc., New York City.

Not only in the eastern world does the hand play an important part in the ritual usages but in western culture as well. The pentagram, the five-pointed star, is said to have been derived from an ancient custom of covering the face with the open fingers of the hand. That practice gradually was replaced by invoking the numeral "five," a convention that persists today in countries in central Europe. In Latvia, for example, the pentagram now appears on barns as a protective device.

Finally, the hand has become symbolic of human sentiment. We bless and we salute by raising the hand in various ways. The gentle laying on of hands is at once a symbol of benediction and, as among certain religious sects, the means of curing the sick and of drawing out the evil spirits that reside within the body. In legal practice, oaths are taken in court by the simultaneous use of both hands, right hand up and the left hand on the Bible. We close a bargain by shaking hands, we raise our hands in salutation, and a man takes a woman's hand in marriage. Contrariwise, the hand may express condemnation, malediction, and final judgment. In cursing we point the hand at the enemy. In ancient Rome, thumbs down ("pollice verso") sentenced the gladiator to death. Thus, the hand has become an expository of human sentiment. It can express love, hate, doubt, questioning, hospitality, judgment, rejection, or acceptance.

THE HAND AND GOOD HEALTH

The handshake may become an index to personality and representative of the *whole* person. The cold, limp hand, the strong, firm grasp, the moist palm, the dry palm, all help us to create a mental image of personality. To the trained hand of the physician, the cold, moist, flabby handshake often reveals clues relating to physical condition. Such a handshake often is a symbol of physical illness or an indication of an emotional disturbance. To the trained eye of the doctor the hand tells even more. The coloring, texture, lines, and creases sometimes reveal sickness or health. A trembling, warm, moist hand may mean overactivity of the thyroid, redness may indicate gout, a bluish appearance may indicate a certain kind of heart disease, and bad cases of malnutrition and diet deficiency frequently are reflected in the hand. There are many variations in the appearance of each hand, but the danger signals can be read only by the skilled hand and eye of a physician.

THE HAND IN EXPRESSION

The hand has also become associated with certain ethnic and nationality groups, for specific hand gestures have been associated with certain cultural types. Indeed, it has been said of the Italians that they never speak a language, that they caress it. Because movement of the hands serves to emphasize the spoken word, all of us find it difficult to speak while our hands remain perfectly still. A dramatic presentation of the use of the hand in conversation was portrayed through the medium of modern dance in a performance by a group at New York University involving an interpretation of an adolescent talking over the telephone No word was spoken, but the wide variety of gestures made clear to everyone what the performer was saying. The cult and the culture of the "teen-ager" in our country was delineated as sharply through the dance as it could have been through the medium of the written word.

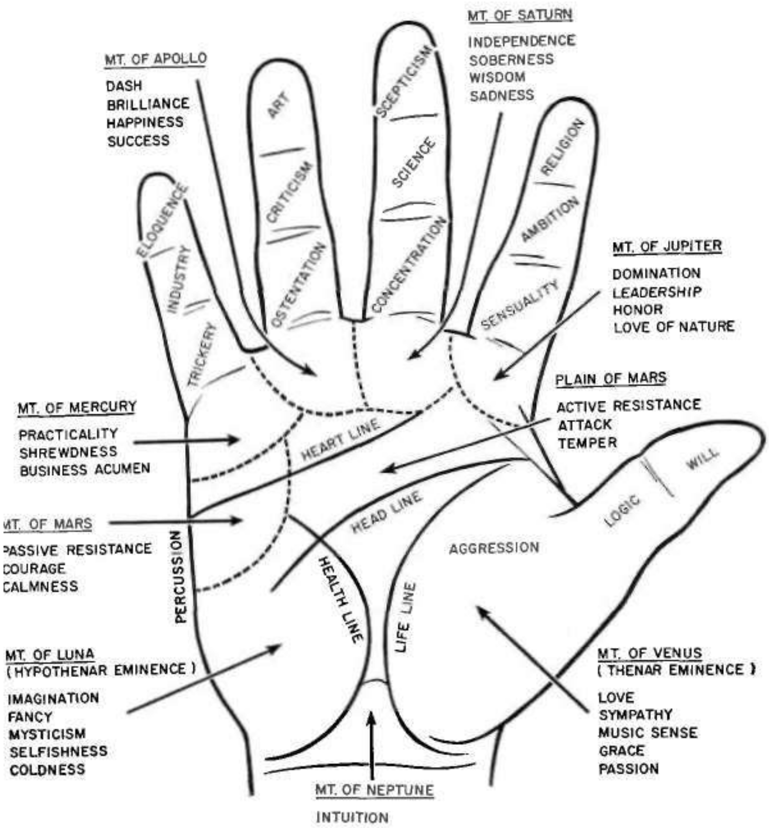

Fig. 11. The mounts and principal lines of the hand and the interpretative functions traditionally assigned to the several areas. Authorities differ in detail, but all follow the same general pattern. In palmistry, which dates from antiquity and which has been the subject of serious discussion by numerous scholars, including Aristotle, the relative development of the mounts and lines is considered to show the comparative ability of the subject to implement the talents and qualities associated with the individual features. Generally the mounts are seven in number, the eighth (Mount of Neptune) occurring in a comparatively small number of cases. Reference to the sun, moon, and planets relates, of course, to the influence which, in early philosophy, these celestial bodies were thought to exercise upon the course of an individual's life. Modern astrology calls upon similar relationships.

CONCLUSION

From its basic use, prehension, which grew out of anatomical development, the human hand gradually has evolved until it is now also an effective instrument for symbolic and aesthetic interpretation. Man's capable and sentient hand not only serves as a tool but it wields tools as well, and it has in addition the ability to take the place of other body organs. Because of its remarkable adaptability to functional requirements, as compared with the specialization in the forelimb of other animals, the hand is largely responsible for the creative manifestations that characterize the human species and that distinguish it from all other known forms of life. The hands are, as Kant is reported to have said, "man's outer brain."

ACKNOWLEDGMENT

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The Anatomy and Mechanics of the Human Hand

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It is obvious to all that the human hand represents a mechanism of the most intricate fashioning and one of great complexity and utility. But beyond this it is intimately correlated with the brain, both in the evolution of the species and in the development of the individual. Hence, to a degree we "think" and "feel" with our hands, and, in turn, our hands contribute to the mental processes of thought and feeling.

In any mechanism, animate or inanimate, functional capabilities relate both to structural characteristics and to the nature of the control system available for management of functions singly or in multiple combinations. Just so with the human hand. Analysis of normal hand characteristics therefore requires an understanding of both sensory and mechanical features. Of course whole volumes have been written on hand anatomy, and it is not possible in a short article to describe all elements in detail. It is helpful, however, to review the basic construction of bones and joints and of the neuromuscular apparatus for governing motions and forces. Twenty-four muscle groups, controlled by the various motor and sensory nerve pathways, with their rich potentialities for central connection, and acting upon a bone and joint system of great mechanical possibilities, give to the hand its capacity for innumerable patterns of action.

THE FUNCTIONAL STRUCTURE OF THE HAND

THE BONES

The bones of the hand, shown in Figure 1, naturally group themselves into the carpus, comprising eight bones which make up the wrist and root of the hand, and the digits, each composed of its metacarpal and phalangeal segments (Table 1). The carpal bones are

Table 1

BONES AND JOINTS OF THE HAND AND WRIST

Carpal bones	
GM,	Greater multangular
N,	Navicular
L,	Lunate
T,	Triquetrum
P,	Pisiform
LM,	Lesser multangular
C,	Capitate
H,	Hamate
Metacarpal bones	
M–I, II, III, IV, V	
First phalangeal series	
FP–I, II, III, IV, V	
Second phalangeal series	
SP–II, III, IV, V	
Third phalangeal series	
TP–I, II, III, IV, V	
Joints	
RC,	Radiocarpal
IC,	Intercarpal
CM,	Carpometacarpal
MP,	Metacarpophalangeal
PIP,	Proximal interphalangeal
DIP,	Distal interphalangeal

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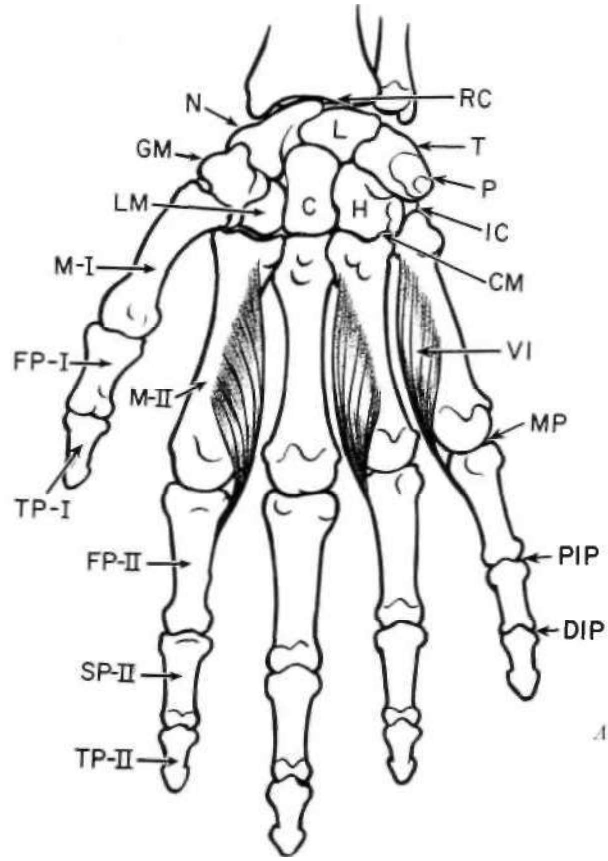


B

Fig. 1. Bones and articulations of the hand, including the interosseus muscles. *A*, volar view; *B*, dorsal view. For nomencla ture, see Tables 1 and 2.

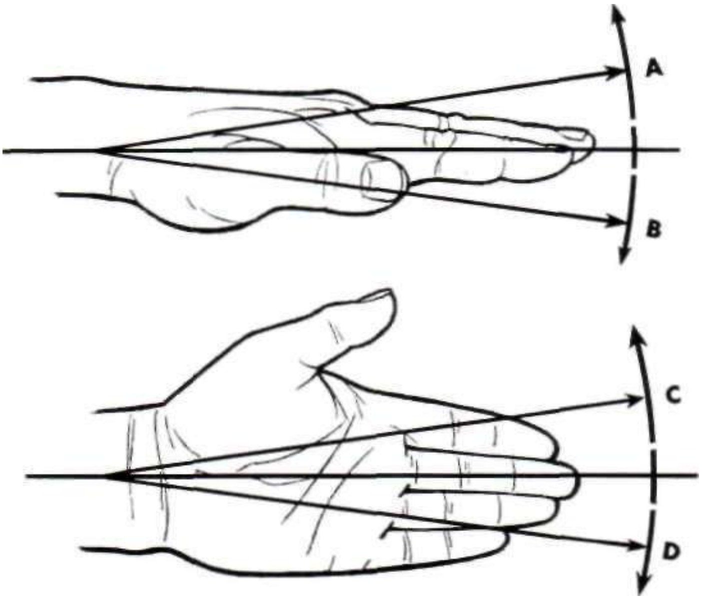


Fig. 2. Angles of rotation about the wrist. *A*, extension (or dorsiflexion); *B*, flexion (or volar flexion); C, radial flexion; *D*, ulnar flexion.

arranged in two rows, those in the more proximal row articulating with radius and ulna. Between the two is the intercarpal articulation. The bony conformation and ligamentous attachments are such as to prevent both lateral and dorsal-volar translations but to allow participation in the major wrist motions (Fig. 2).

In each of the digits, the anatomical design is essentially the same, with exceptions in the thumb. Metacarpals II through V articulate so closely with the adjacent carpal bones of the distal row that, although they are capable of some flexion and extension, independence of motion is very limited. The metacarpal shafts are arched to form the palm, and the distal ends are almost hemispherical to receive the concave curvature of the proximal ends of the first phalanges.

The metacarpophalangeal joint exhibits a pattern seen also in the interphalangeal joints. As shown schematically in Figure 3, the virtual center of rotation lies approximately at the center of curvature of the distal end of the proximal member. The lateral aspects of the joint surfaces are narrowed and closely bound with ligaments, so that lateral rotation is small in the metacarpophalangeal joints and lacking entirely in the phalangeal articulations. Hence, the latter are typical hinge joints. The thumb differs from the other digits first in that the second phalanx is missing and, second, in that there is greater mobility in the carpometacarpal articulation.

Table 2

Muscles of the Hand and Wrist

ADQ,	Abductor digiti quinti
AP,	Adductor pollicis
APB,	Abductor pollicis brevis
APL,	Abductor pollicis longus
APO,	Adductor pollicis obliquus
APT,	Adductor pollicis transversus
DI,	Dorsal interosseus
ECRB,	Extensor carpi radialis brevis
ECRL,	Extensor carpi radialis longus
ECU,	Extensor carpi ulnaris
EDC,	Extensor digitorum communis
EDQP,	Extensor digiti quinti proprius
EIP,	Extensor indicis proprius
EPB,	Extensor pollicis brevis
EPL,	Extensor pollicis longus
FCR,	Flexor carpi radialis
FCU,	Flexor carpi ulnaris
FDP,	Flexor digitorum profundus
FDQB,	Flexor digiti quinti brevis
FDS,	Flexor digitorum sublimis
FPB,	Flexor pollicis brevis
FPL,	Flexor pollicis longus
I,	Interosseus
L,	Lumbricalis
ODQ,	Opponens digiti quinti
OP,	Opponens pollicis
PL,	Palmaris longus
VI,	Volar interosseus

MUSCLES AND TENDONS

Most of the muscles of hand and wrist (Table 2) lie in the forearm and, narrowing into tendons, traverse the wrist to reach insertions in the bony or ligamentous components of the hand. Generally, the flexors (Fig. 4) arise from the medial epicondyle of the humerus, or from adjacent and volar aspects of the radius and ulna, and then course down the inside of the forearm. They are, therefore, in part supinators of the forearm (Fig.5).The extensors (Fig.6) of wrist and digits originate from the lateral epicondyle and parts of the ulna, pass down the dorsal side of the forearm, and thus assist in pronation. The thumb shares in the general flexor-extensor scheme, but its extensors and abductors originate from mid- and distal parts of radius and ulna.

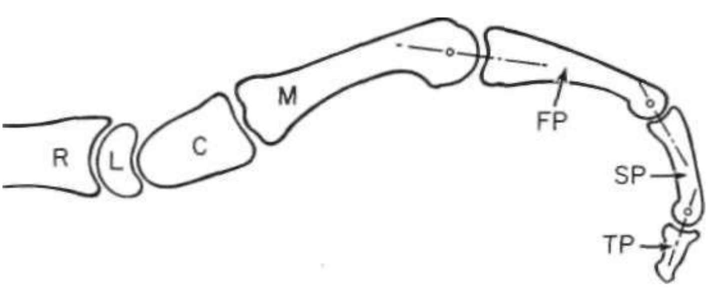


Fig. 3. Section through radius, lunate, capitate, and the bony structure of digit **III,** showing virtual centers of rotation of each segment upon the next more proximal one. When the fist is clenched, the prominence of the knuckles is formed by the head of the more proximal member of each articulation. For nomenclature, see Table 1.

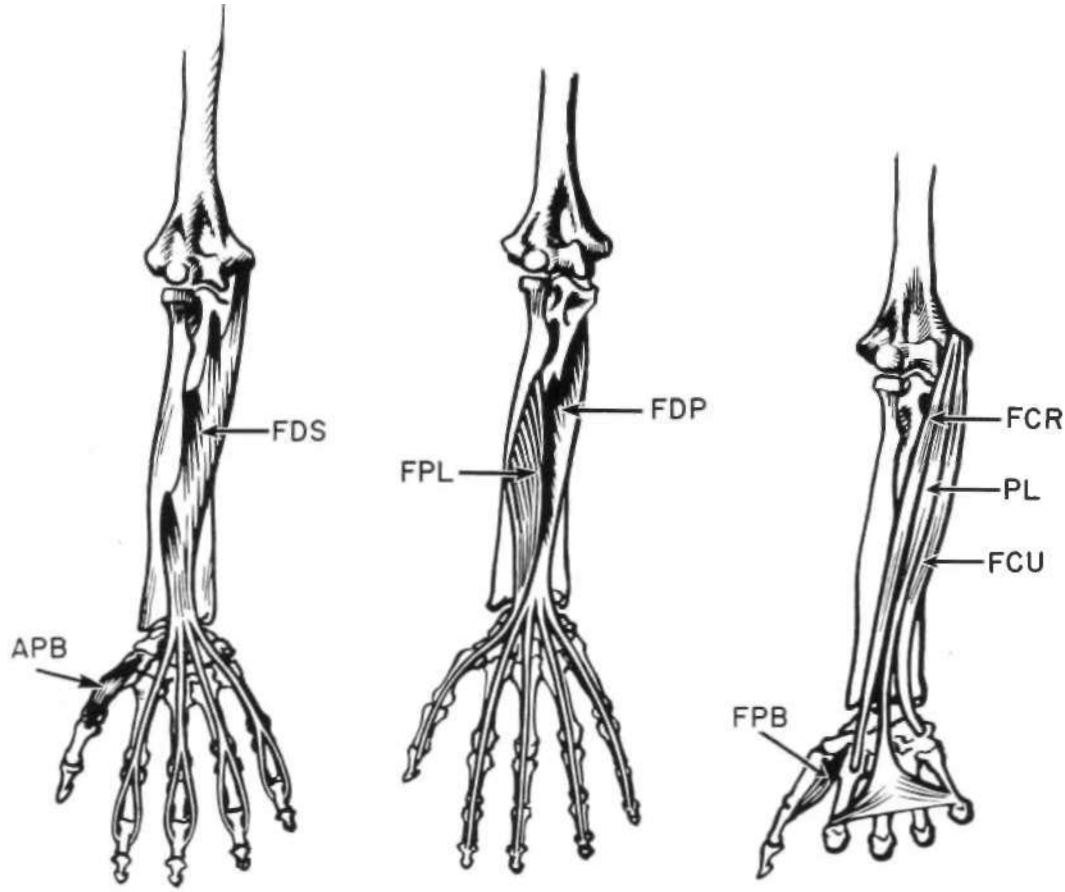


Fig. 4. Flexors of wrist and digits. For nomenclature, see Table 2.

The tendons of wrist and hand pass through bony and ligamentous guide systems, as shown schematically in Figure 7. Flexor tendons pass through a "tunnel" bounded dorsally by carpal bones, laterally by the greater multangular and the projection of the hamate, and volarly by the tough transverse carpal ligament. Similarly, the dorsal carpal ligament guides the extensor tendons, and a system of sheaths serves as a guide for flexor and extensor tendons through the metacarpal and phalangeal regions.

The intrinsic muscles of the hand, *i.e.*, those with both origin and insertion confined to wrist and hand (Fig. 8), are, with the exception of the abductors of thumb and little finger, specialized for the adduction of the digits and for opposition patterns such as making a fist, spherical grasp, and so on.

THE PALMAR AND DIGITAL PADS

The volar aspect of the palm and digits is covered with copious subcutaneous fat and a relatively thick skin so designed in a series of folds that it is capable of bending in prehension. The folds are disposed in such a way as to make for security of grasp, while the underlying fat furnishes padding for greater firmness in holding. Because, however, slipping of the skin over the subcutaneous fat would lead to insecure prehension, the folds are tightly bound down to the skeletal elements, much as mattresses and upholstered furniture are quilted or otherwise fastened to prevent slippage of the filler.

In the hand, the volar skin is tied down by white fibrillar tissue connecting the sheaths of the flexor tendons to the deep layer of the dermis along the lateral and lower edges of the palmar fascia. The folds therefore vary with the relative lengths of the metacarpal bones and with the mutual relations of the sheaths of the tendons and the edge of the palmar fascia.

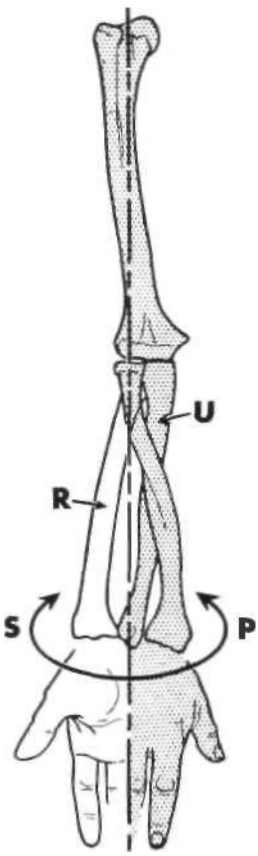


Fig. 5. Forearm design as related to hand mobility. By virtue of this arrangement, the hand can be rotated through 180 deg., palm up to palm down, with the elbow flexed. With the arm fully extended, participation of shoulder and elbow allows the hand to be rotated through almost 360 deg., palm up to palm up. *U,* ulna; *R,* radius; *P,* pronation; *S,* supination.

The sulci, or furrows, are emphasized because the subcutaneous fat in any given area is restricted to the interval between the lines along which the skin is tied down. Thus pressure upon any individual monticulus cannot displace the underlying soft tissue beyond the boundaries established by the fibrillar connections. The relative size of any particular eminence is an indication of the size of the muscle involved and of its relative development through usage, with the exception that the size of the hypothenar eminence depends in part upon the prominence of the pisiform.

THE DORSAL INTEGUMENT

Unlike the volar surface, the dorsal side of the hand is covered with thin, soft, pliable skin and equally mobile subcutaneous tissue, both capable of yielding easily under tension. Because in flexion of the fingers and in making a fist the covering on the back of the hand must be able to stretch from wrist to fingernails, the dorsal skin is arranged in numerous minute redundancies, which, in the fiat-of-hand, are manifest in the typical transverse wrinkles, particularly over the phalangeal articulations. Special adaptations in the dorsal skin of the thumb accommodate the distinctive rotational planes of that digit about its carpometacarpal articulation. In the normal, healthy hand, the degree of redundancy in any given area is just such that all wrinkles are dispatched when the fist is clenched. Swelling in any area, dorsal or volar, inhibits flexion-extension of the part affected.

NERVE AND BLOOD SUPPLY

Three principal nerves serve the muscles of the hand (Fig. 9). Nerve supply is indicated, except for minor variations and exceptions, in Table 3. Each of these major nerve trunks diverges into countless smaller branches ending in the papillae of the palmar pads and dorsal skin, and the whole neuromuscular system is so coordinated in the brain that motor response to stimuli is ordinarily subconscious and reflex. Thus an object slipping from the grasp is automatically gripped more firmly, but not so firmly as to damage the hand itself. Noxious stimuli are rejected automatically, as when

Table 3

PRINCIPAL NERVES SERVING HAND AND WRIST FUNCTIONS

Nerve	Muscles Served
Radial	Extensors of wrist, thumb, and fingers.
Median	Flexors of wrist and fingers; abductors, opponens, and flexors of thumb; lumbricals I and II.
Ulnar	All other intrinsic muscles of the hand, including all interossei; lumbricals III and IV.

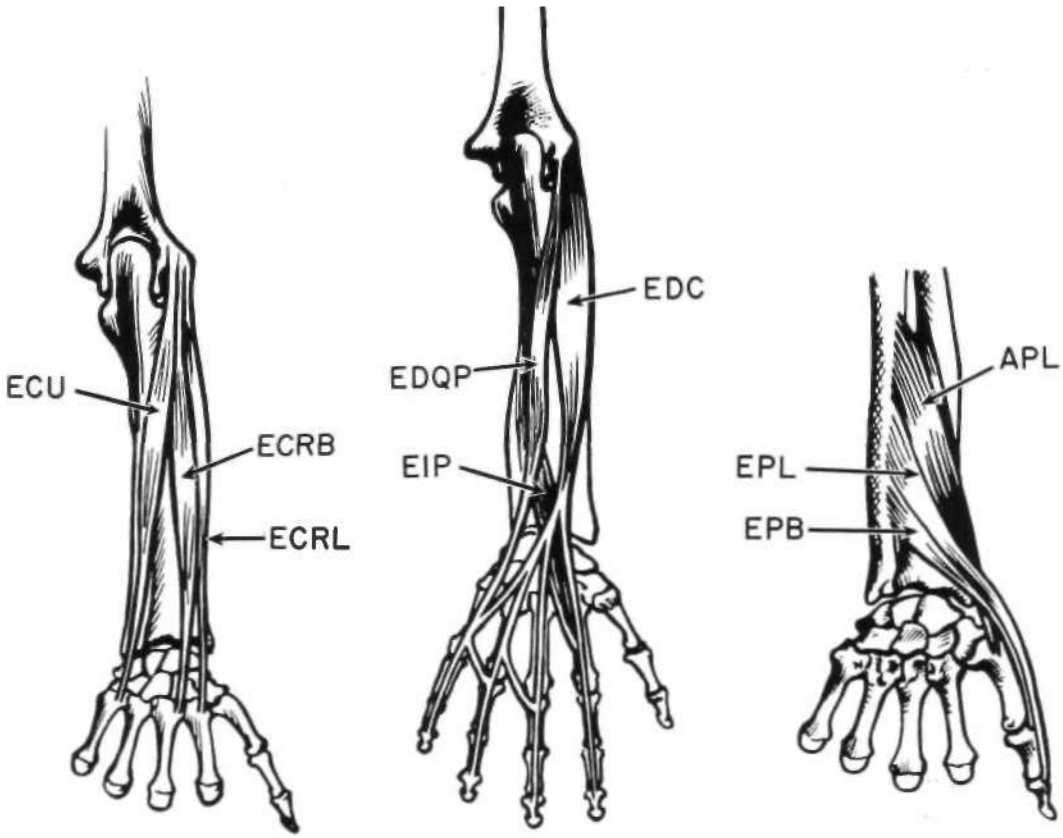


Fig. 6. Extensors of wrist and digits. For nomenclature, see Table 2.

the fingers are withdrawn from an object uncomfortably hot.

The wrist and hand receive their blood supply from the radial and ulnar arteries, which run parallel with the bones concerned, enter the hand through the flexor "tunnel," and then join through a double-arch system (Fig. 10). Small branches from the arches serve the digits. The major venous system comprises the basilic and cephalic veins superficially placed on the volar surface of the forearm.

THE RESTING HAND PATTERN

The resting hand assumes a characteristic posture, a feature easily seen when the hand hangs loosely at the side. The resting wrist takes a mid-position in which, with respect to the extended forearm axis, it is dorsiflexed 35 deg. (Fig. 11). It is worth noting that this is the position of greatest prehensile force (Fig. 12, bottom). The mid-position for radial or ulnar flexion appears to be such that the metacarpophalangeal joint center of digit III lies in the extended sagittal plane of the wrist (Fig. 11).

Typically, the conformation of fingers and thumb is similar to that shown for palmar prehension (Fig. 13), the fingers being more and more flexed from index to little finger. The relations between thumb, palm, and fingers are such as to permit grasp of a 1.75-in. cylinder crossing the palm at about 45 deg. to the radioulnar axis. Bunnell *(4)* considers this "an ancestral position ready for grasping limbs, weapons, or other creatures."

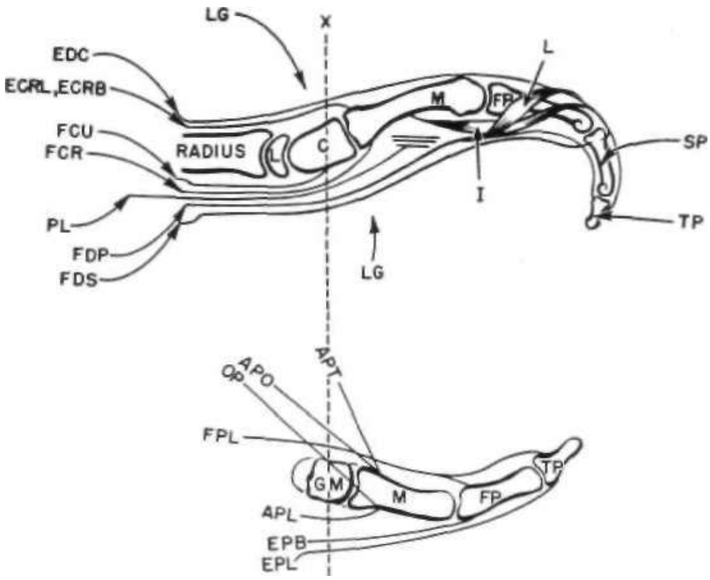


Fig. 7. The anatomy of prehension. Schematic sections through digits I and III show essential relations of muscles and bones. The letters *LG* indicate the presence of ligamentous guides which channel close to the wrist the tendons of muscles originating in the forearm. Guide line X—X indicates relative position of carpal bases of thumb and fingers. For rest of nomenclature, see Tables 1 and 2. From Taylor *(12)*.

FIXED HAND ADAPTATIONS

In thrusting or striking actions and the like, the hand may assume fixed and rigid postures while functioning with the arm in support. These represent nonspecialized functions in which the hand serves merely as an adapted "end of the arm." The various forms include the flat-of-hand, the clenched fist, the knuckle and digital support postures, and so on.

WRIST MECHANICS

The wrist joint, composed of the radiocarpal and intercarpal articulations (Fig. 1), has an elliptical rotation field with the major axis in the dorsal-volar excursion, the minor in the ulnar-radial. No significant torsion occurs. Bunnell *(4)* gives the angular excursions about the radiocarpal and intercarpal articulation as shown in Table 4.

The rotation within the carpal bones during these movements is too complicated for brief treatment. Not only do the rotations occur at several articulating surfaces, but the virtual axes of rotation lie distal to the contact surfaces owing to gliding motions in the convex-concave structure of the joints. Idealization of the motions into those of a simple lever, rotating about a fixed center, as implied in diagrams such as Figure 2, can be justified only as a convenient approximation.

The muscles traversing the wrist include those inserting into the carpus and metacarpus and those mediating flexion and extension of

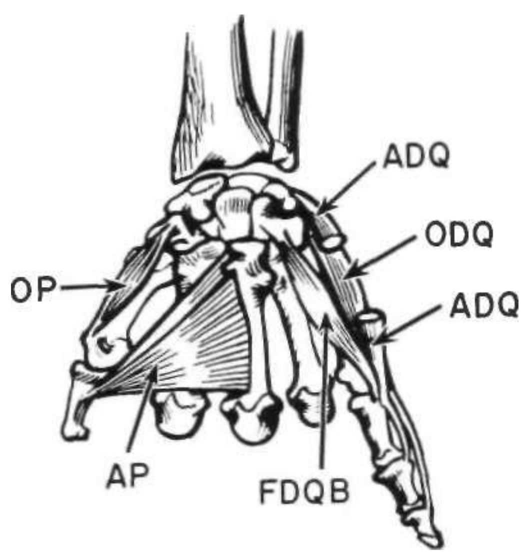


Fig. 8. Volar intrinsic muscles of the hand. For nomenclature, see Table 2.

the phalanges. The latter contribute to the wrist action, particularly under loads. In such cases, the finger muscles develop reaction against the object held (or within the hand itself if the fist is clenched) and add their forces to wrist action. The forces, action, and grouping of these muscles are given in Table 5.

PREHENSION PATTERNS

It is evident equally from a study of the muscle-bone-joint anatomy and from observation of the postures and motions of the hand that an infinite variety of prehension patterns is possible. For purposes of analysis, however, it suffices to describe the principal types. Seeking a logical basis for defining the major prehension patterns, Keller et al. (9) found that the object-contact pattern furnishes a satisfactory basis for classification. From photographic observation of the prehension patterns naturally assumed by individuals when (a) picking up and *(b)* holding for use

Table 4

ANGULAR EXTENT OF WRIST FLEXIONS[a]

Articulation	Dorsal Flexion (deg.)	Volar Flexion (deg.)	Total (deg.)	Ulnar Flexion (deg.)	Radial Flexion (deg.)	Total (deg.)
Capitate-radius	78	44	122	28	17	45
Capitate-lunate	34	22	56	15[b]	8[b]	23[b]
Lunate-radius	44	22	66	13[c]	9[c]	22[c]

[a] From Bunnell (4).
[b] Between capitate and proximal carpal row.
[c] By difference.

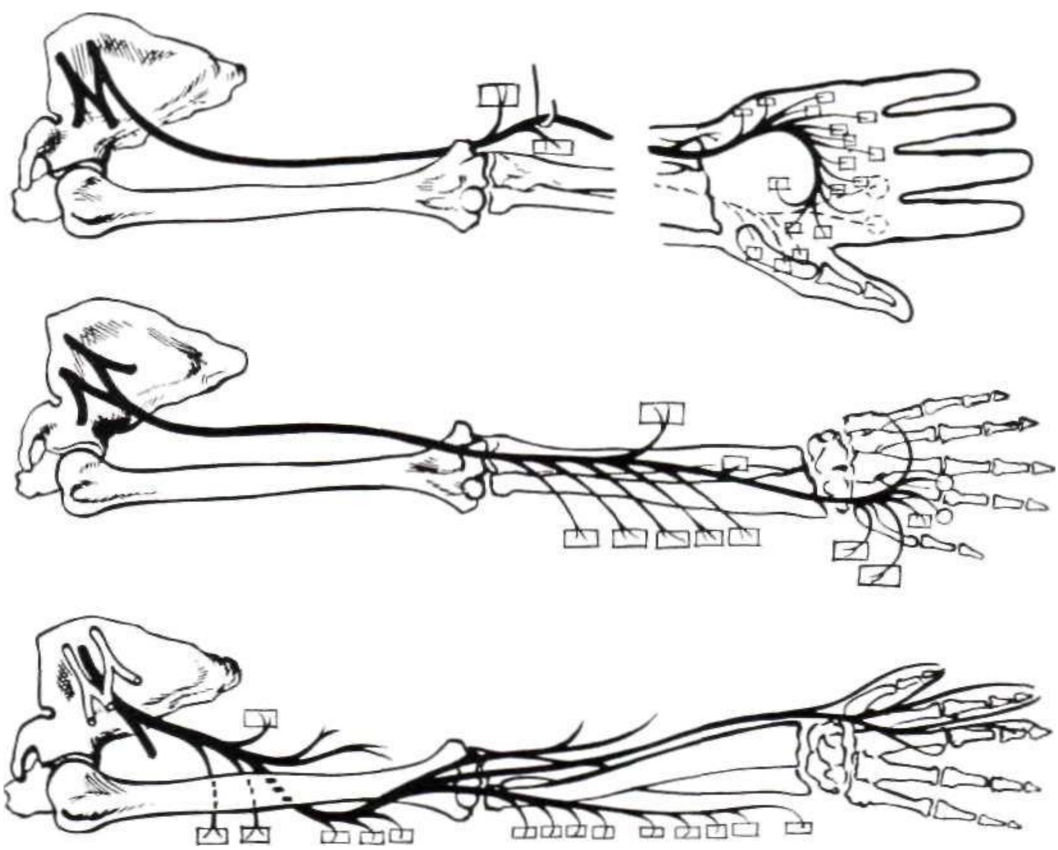
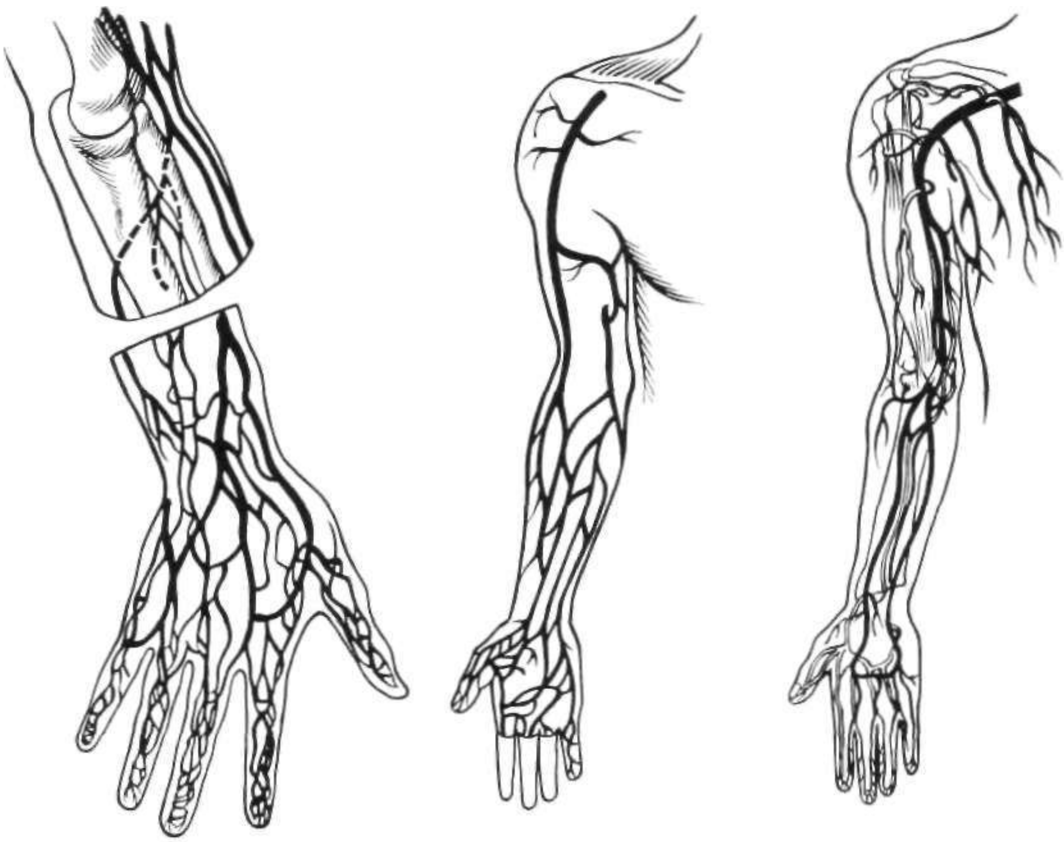


Fig. 9. Nerves supplying the hand. Top to bottom, ulnar nerve, median nerve, radial nerve. See Table 3.



A B C

Fig. 10. Blood supply to the upper extremity. *A,* above, medial view of the elbow. *A,* bottom, dorsal veins of the hand. *B,* superficial veins of the arm. C, arteries of the arm.

Table 5

HAND MUSCLE DYNAMICS

Action	Muscles	Total Fick Force[a] (lb.)	Measured Force (lb.)
Hand-on-wrist:			
Volar Flexion	FDS, FDP, FCU, FCR, FPL, APL, PL	730[b]	50.0[c]
Dorsal Flexion	EDC, ECU, ECRL, ECRB, EIP, EPL	367	30.0[c]
Radial Flexion	ECRL, APL, EIP, EPL, ECRB, FCR	244	38.0[c]
Ulnar Flexion	FCU, ECU	227	29.5[c]
Prehension:			
Palmar	FDS, FPL, FDP, L, FPB, OP		21.5
Tip	FDS, FPL, FDP, L, FPB, OP		21.0
Lateral	FPB, OP, FPL, I		23.0

[a] From Fick (7).

[b] The palmaris longus, absent in about 15 percent of cases, is omitted from the summed Fick forces of volar flexion.

[c] Averages from measurements of maximum forces normal to the hand, applied at the metacarpophalangeal joint, on 15 young males at the University of California at Los Angeles (unpublished data).

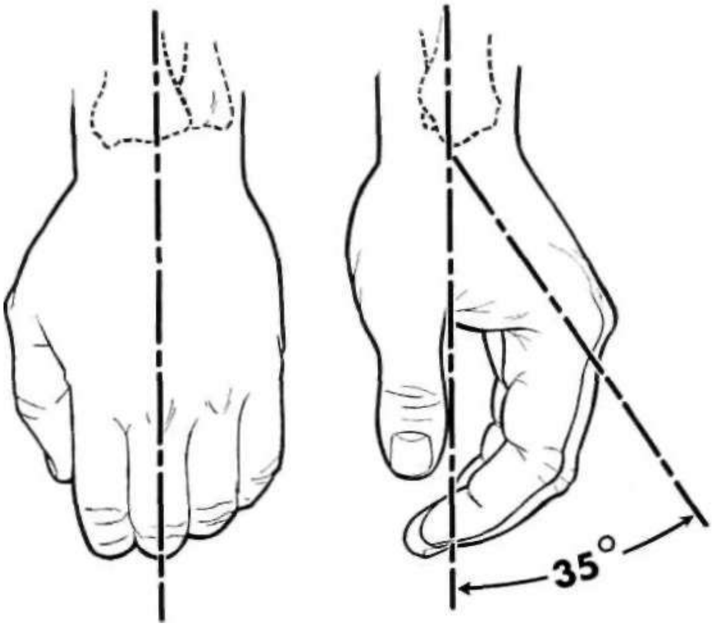


Fig. 11. The resting hand pattern.

common objects used in everyday life, three types were selected from among those originally classified by Schlesinger *(10)*. These, appearing in Figure 13, are palmar, tip, and lateral prehension, respectively. The frequency with which each of these types occurred in the investigation cited is given in Table 6. While the relative percentages differ in the two types of action, the order of frequency with which the prehension patterns occurred is the same.[3]

MECHANICAL-ANATOMICAL BASIS or PREHENSION PATTERNS

It is convenient to analyze digital mechanics in terms of flexion-extension variations in the digits, thumb postures, and variations in the radioulnar axis.

INDIVIDUATION OF DIGITAL FLEXION-EXTENSION

Insertion of flexor and extensor muscle systems into several major segments along the proximal-distal axis provides a variety of flexion-extension patterns in the digits. In Figure 7, the essential components are shown schematically for digits I and III. With these attachments, fixation of carpal and metacarpal segments by cocontraction of flexor and extensor carpi muscles provides a firm base for independent movements and fixations of the phalangeal segments. Individual flexions of the second and terminal phalanges stem from separate flexor muscle groups. Such flexor groups, inserted distally, can also cause complete cylindrical-grasp prehension by "rolling up" the hand (Fig. 13). The counterbalancing digital extensor inserts into the two most distal phalanges and, on contraction, rigidly extends the entire finger. Coordinated action between extensor and flexor groups, however, permits fixed intermediate positions of each segment of the system.

Two common postures of this system may be pictured. In palmar prehension (Fig. 13), the carpal and metacarpal segments commonly fix the wrist in moderate extension, while the digital configuration, mostly metacarpophalangeal flexion coupled with only slight phalangeal flexion, indicates action of the long flexors, strongly modified by the lumbricals and interossei, which are in position not only to contribute to the metacarpophalangeal flexion but also to maintain the phalangeal

Table 6
FREQUENCY OF PREHENSION PATTERNS

Series	Occurrence of Prehension Type		
	Palmar (%)	Tip (%)	Lateral (%)
Pick up	50	17	33
Hold for use	88	2	10

[3] Predominance of palmar prehension in both activities accounts for adoption of this pattern in the design of modern artificial hands (page 86).

extension. In tip prehension, the action of muscles upon carpal and metacarpal bones is similar, but distributed flexion in all phalangeal segments indicates predominant flexor activity.

THUMB VERSATILITY PATTERNS

The versatility of the thumb lies, first, in the variety of its flexion-extension patterns and, second, in the adjustable, rotatory plane in which flexion-extension can take place. The first of these is directly analogous to the digital system for the other four fingers, in that for any given metacarpal position there are numerous possible positions of the phalanges. The second effect is due to the relative mobility of the carpometacarpal joint, which allows the thumb to act in any plane necessary to oppose the digits. The principal oppositions are semidirect, as seen in palmar, tip, and spherical prehensions. Actually, in these cases the plane of the thumb action is inclined 45 to 60 deg. to the palmar plane. In lateral prehension, the plane is approximately parallel to the palmar plane.

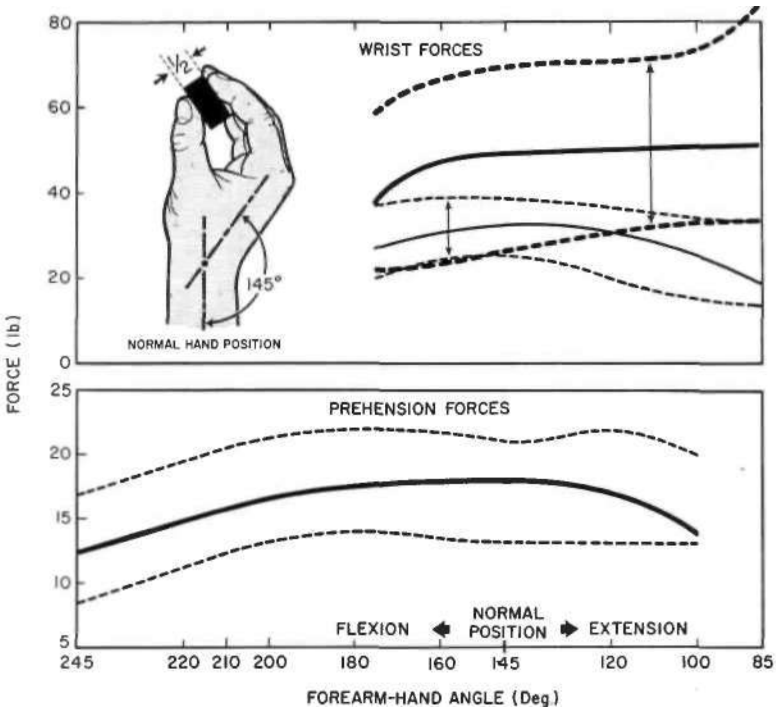


Fig. 12. Effect of forearm-hand angle upon wrist flexion and extension forces and upon prehension forces. Above, relationship between forearm-hand angle and maximum forces of wrist flexion and extension measured at the carpometacarpal joint. Heavy lines, flexion (volar flexion); light lines, extension (dorsal flexion). Solid lines, averages; dotted lines, standard deviations. Unpublished data, UCLA, 15 male subjects. Below, relationship between forearm-hand angle and maximum prehension force measured between thumb and opposing index and middle fingers grasping a 1/2-inch block. Right hand, eight normal male subjects. Solid line, average; dotted lines, standard deviations From a UC report *(14).*

VARIATIONS IN THE RADIOULNAR AXIS OF THE HAND

A third principal mode of variation concerns cross-hand alignments. Thus the metacarpophalangeal joints may be drawn into line, and with abducted thumb a flat-hand position is assumed. At the other extreme, the hand is cupped for spherical prehension (Fig. 13) as the opponens muscles of thumb and little finger, aided by other adductors and flexors, act to pull these digits toward each other. Similar alignment occurs when a fist is made.

HAND MOVEMENTS

The large number of muscles and joints of the hand obviously provides the equipment for numerous and varied patterns of movement. Not so evident, but equally important in determining complexity and dexterity of motion, are the large areas of the cerebral cortex given over to the coordination of motion and sensation in the hand. Thus, in the motor cortex the area devoted to the hands approximately

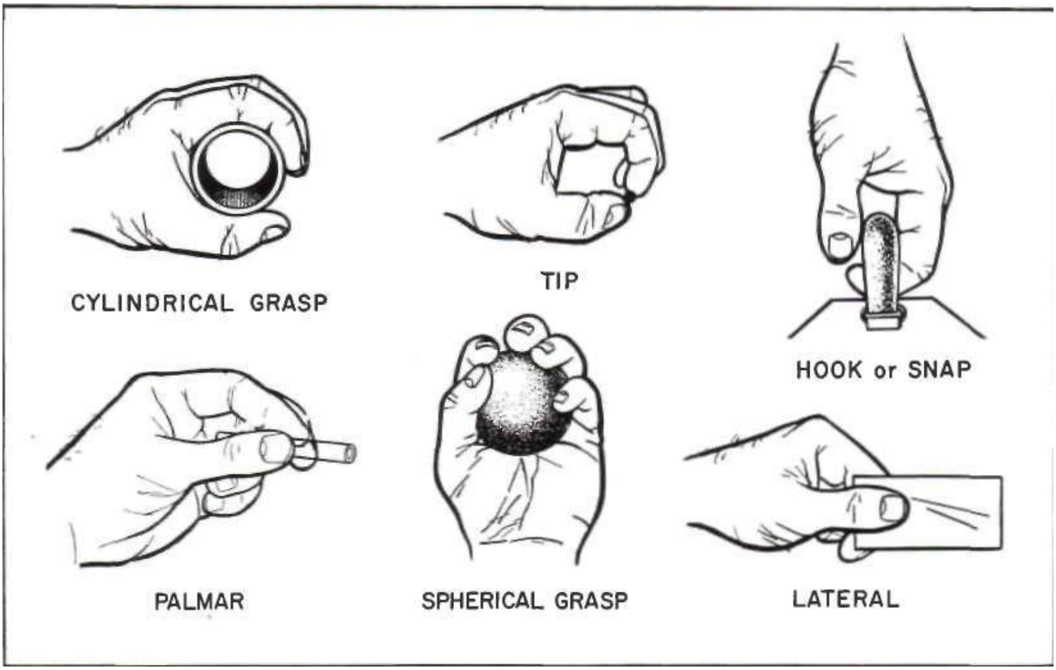


Fig. 13. Six basic types of prehension, as defined by Schlesinger *(10).*

equals the total area devoted to arms, trunk, and legs *(3).* This circumstance ensures great potentiality for coordinated movement and for learning new activities. Similarly, the sensory areas are large, so that they determine such advanced functions as stereognosis, the ability to recognize the shape of an object simply by holding it in the hand. The great tactile sensitivity of the hand is, of course, in large part due to the rich supply of sense organs in the hand surface itself. The threshold for touch in the finger tip, for example, is 2 gm. per sq. mm., as compared to *33* and 26 for the forearm and abdomen respectively *(2).*

The three major types of movement described by Stetson and McDill *(11)* are in part represented in the hand. They include fixation movements including cocontractions; movements ranging from slow to rapid with control of direction, intensity, and rate; and ballistic movements.

FIXATION MOVEMENTS

In all of the types of prehension described, the hand assumes a fixed position. If the prehended object is unyielding, reactions to the flexion forces are afforded by the object. If the object is fragile, or the hand empty, the hand is maintained in any required prehensile posture by cocontractions of the opposing muscle groups.[4]

The characteristics of balanced muscular action when supporting in the hand loads which produce moments at the wrist have been studied electromyographically by Dempster and Finerty *(6).* In general, when average potential amplitudes are used to characterize the electrical activity of the muscle, the curves of load-action potential are linear. Frequencies range from 35 to 65 per sec. but bear no clear-cut relationship to load. Typically, each of the muscles traversing the wrist was found to function as agonist, lateral stabilizer, or antagonist as the moment load was shifted from direct opposition at

[4] There are many other examples of fixation stales, such as the open-claw conformation of the fingers and the extended and rigid index finger for dialing a telephone.

zero deg. to the 90-deg. and then to the 180-deg. positions. The magnitude of the action potentials associated with each of these roles is approximately in the order 4:2:1.

SLOW AND RAPID MOVEMENTS

In movements ranging from slow to rapid, with control of direction, intensity, and rate, there is always some degree of cocontraction to ensure control and to permit changes in force and velocity. A net force in the muscles causes motion. In this category is a long list of activities, such as writing, sewing, tying knots, and pressing the keys of musical instruments. Included are most actions involving differential or integrated motions of the digits.

It is of interest to note that the full capacity for these motions is seldom developed by the average individual. With intensive practice, significant increases in the facility of manipulation, even with simple operations, may be achieved, although individuals differ markedly in the amount of training gain. The average individual has latent potential for development of skill, as shown by the feats of manipulation occasionally evidenced. Knot-tying, cigarette-rolling, and similar complex manipulations may be performed with one hand, as often demonstrated by accomplished unilateral arm amputees. According to Tiffin *(13)*, dexterity differences are correlated neither with mental ability nor with hand shape or dimensions, but Cox (5) points out that they have an important effect on the performance of industrial assembly operations.

BALLISTIC MOVEMENTS

Ballistic movements are rapid motions, usually repetitive, in which active muscular contractions begin the movement, giving momentum to the member, but cease or diminish their activity throughout the latter part of the motion. It is unlikely that, of themselves, the fingers utilize this type of motion to any marked degree. Barnes (/) reviews evidence that in repetitive work finger motions are more fatiguing, less accurate, and slower than are motions of the forearm. Consequently, in repetitive finger activities in which there is a ballistic element, such as piano-playing, typing, and operating a telegraph key, wrist and elbow motions predominate while the fingers merely position themselves to strike the proper key.

HAND DYNAMICS

The hand muscles, their actions, and contractile forces are given in Table 5 taken from Fick (7). The total Fick force equals the summated forces of the individual muscles participating in the action. For each muscle the force is equal to the physiological cross section *(i.e.,* the total cross section of the muscle taken normal to its fibers) multiplied by the force factor of 10 kg. per sq. cm., estimated by Fick to hold for human muscle. These forces are produced along the axis of the muscle and its tendon, but since the effective moment arm upon any of the wrist or hand joints is small, the *measured* isometric forces are only about 10 percent of the total force.

Among the wrist actions, total forces and measured isometric forces assume the same rank order. The variation,. with wrist angle, of both flexor-extensor forces in the wrist and of prehensile forces in the hand is of practical importance as well as theoretical interest. The prehensile force reaches a maximum at a wrist angle of about 145 deg. (Fig. 12, bottom). This is approximately the angle at which the maximum forces of wrist flexion and extension occur (Fig. 12, top). It is common experience that the wrist assumes this angle when very strong prehension is required. The lessened forces at wrist angles toward the extreme positions of flexion or extension are attributable to the well-known force reductions in the isometric length-tension curve as a muscle is markedly stretched or slackened *(8).* The exception to this rule, seen in the augmented force of flexion at wrist angle 85 deg., apparently means that this degree of wrist extension does not stretch the flexor muscles beyond their force maximum.

CONCLUSION

This, briefly, constitutes the anatomical basis of hand mechanics, from which it can be seen that normal hand function is the result not only of a highly complex and versatile structural arrangement but also of an equally elaborate and fully automatic system of controls. As will be seen later (page 78), such considerations lay down the principal requirements and limiting factors in the design of reasonably successful hand substitutes. When, in the normal hand, any functional feature, either mechanical or sensory-motor, is impaired, manipulative characteristics are reduced correspondingly. In the arm amputee, hand structural elements have been wholly lost, and the most delicate neuromuscular features, those in the hand itself, have been destroyed. Although the lost bone and joint mechanism can be simulated, adequate replacement of the control system defies present ingenuity. Lacking control comparable to that in the natural hand, present-day artificial hands are necessarily limited in the mechanical details that can be utilized, which accounts for the fact that the regain in function currently possible in hand prostheses falls far short of duplicating the natural mechanism.

ACKNOWLEDGMENT

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Some Problems in the Management of Upper-Extremity Amputees

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EXPERIENCE in the rehabilitation of upper-extremity amputees in recent years has highlighted the advantages of many concepts not previously considered or else heretofore noted only superficially. Not only has the development of prosthetic devices assured a greater degree of rehabilitation of many more amputees, but consideration of the amputee as a whole also has played a major role. It is now well recognized that, in times past, attention was too often directed only to the amputation stump. After the wound had healed, the patient was referred to a prosthetist without benefit of a physician's final evaluation. The development of the clinic-team approach (J) foreshadowed the end of such practices, and with the growth of the clinic team has come the all-important factor of considering the patient as a whole.

Implicit in such an approach is the concept that complete upper-extremity rehabilitation can rightly be expected only when the amputee has been afforded adequate training in efficient utilization of the prosthesis with which he has been fitted. Incomplete or unsystematic training is, at best, responsible for improper habits in prosthetic usage and hence for awkwardness and inefficiency. In the extreme case, it may lead to discard of the prosthesis entirely even though the components involved may themselves be of the greatest utility to an accomplished amputee wearer. The therapist has thus come to be looked upon as an important member of every prosthetics clinic team.

The importance of good health also has come to be realized. The patient who suffers from complicating injuries or diseases may not be able to cooperate fully, and when cooperation is limited, interest and motivation die rapidly. For example, the obese patient will profit by guided weight reduction and proper weight stabilization, and the anemic and allergic will benefit by proper corrective measures. Dermatological problems frequently are a serious complication for the amputee, especially when involvement of the stump is threatened or when harnessing excoriates areas of existing dermatitis. Here proper therapeutic measures may permit continued use of the prosthesis or ensure only a temporary suspension of its use. If, however, such conditions are allowed to continue unchecked, they may result in a prolonged period of inactivity.

Equal in importance to good physical condition is a healthy mental attitude. Unless rehabilitation therapy includes consideration of the patient's mental outlook, the entire process of recovery may result in complete failure. Accordingly, some cases may require the assistance of specialists in psychiatry and related fields.

With respect to the patient's mental condition, an important factor relates to vocational and avocational pursuits. Whether an amputee can engage successfully in work and recreation to his own liking, and whether he has a taste for such activities as are possible to him, may together spell the difference between success and failure in any given case. Proper attention by a qualified occupational therapist is therefore essential.

Functional loss aside, a number of other problems arise from hand loss. In addition to the functions of grasp and tactile sense, the hand is used in many symbolic patterns—in benediction, in supplication, in the salute,

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in the handshake. These are ancient and time-honored functions denied the person who has suffered loss of the hand. In the rehabilitation of the upper-extremity amputee, too much stress often is laid upon the restoration of functional losses relating to prehension, often forgetting the extraprehensile activities essential to the amputee's existence.

In addition to these matters are the problems associated with the importance of early fitting and those involved in the special cases of multiple amputation. And finally, mention deserves to be made of the largely faulty but widespread notion that people are inherently right-handed or left-handed. In the rehabilitation of the upper-extremity amputee, the popular concept of hand dominance leads to one of the most difficult problems to be overcome.

Since each of these individual problems is closely interrelated with all the others, the order in which they are considered by the clinic team is of no particular significance. Of greatest importance is that they all *be* considered and that over-all evaluation of the amputee's status take into account all the individual factors that, together, constitute total rehabilitation.

THE PROBLEM OF HAND DOMINANCE

Most people define handedness solely on the basis of whether the right or the left hand is used in writing, or in throwing a baseball, or the like. The less specific definition of a medical dictionary, which describes handedness as the preferential use of one hand over the other, is perhaps more acceptable, for handedness does not appear to be a flat case of one "necessary" and one "nice-to-have" hand but rather a case of two cooperating members either one of which could be trained as the leader. Nevertheless, the concept of dominance is so widely established that loss of the writing hand is considered by most compensation authorities to constitute severe disability, whereas loss of the other often is viewed lightly. Similarly, loss of one hand in the ambidexterous generally is considered to present no great rehabilitation problem.

How do we determine whether an individual is right- or left-handed? When the average person is asked which is his dominant hand, he usually selects the writing hand. In the upper-extremity amputee, we seemingly are presented with a case of "dominance" or "subdominance." Simply to ask the patient whether he is, or was, right- or left-handed is, in most cases, a wholly inadequate method of determining the degree of dominant handedness. It produces premature evaluations of disability and of future rehabilitation problems, both of which may need complete revision before the patient is discharged from the care of the clinic team. The problem of handedness is of primary interest to those directly responsible for all phases of training the upper-extremity amputee. It is during the preprosthetic stage that the real aspects of dominance present themselves, for during this period the patient is a one-handed individual.

THE DICTATES OF CONVENTION

Judging from the design of many of the articles we use daily, it appears that society already has dictated that ours shall be a colony of right-handed individuals. From the position of the knife and fork at the table to the placement of the gearshift lever on the modern automobile, we are reminded constantly that we are expected to use our right hand much more than our left. This decision of engineers and of authorities in etiquette causes no small concern to the parents of children who seem to use the left hand more than the right. Parents recall other left-handed individuals—individuals who always find themselves crowded when seated at the dinner table (Fig. 1), or whose bodies assume the position of an animated corkscrew when attempting to write at a desk. For these and other reasons, parents try subtly to encourage the use of the right hand in the young child, despite some of the beliefs of medical science. Even the garmentmakers have conspired against the man who uses his left hand for some tasks. Commonly, a button is placed over the left hip pocket, where it seems understood the wallet will be placed, while the right hip pocket is free for easy withdrawal of the handkerchief. The man who uses the left hip pocket for the handkerchief has no protection for the wallet when it is kept on the right.

Fig. 1. The southpaw at dinner. Convention dictates the norm; habits in conflict with the established pattern usually lead to trouble.

THE POPULAR FALLACY

These elementary observations indicate that hand usage is dictated by habit patterns, possibly as a means of conforming to the norms of the society in which we live (page 9). It is important, however, to consider whether or not truly right- or left-handed individuals exist and, if so, to consider what is meant by the terms. As has been noted, when the arm amputee first is questioned about handedness, writing is apt to be the first thing considered, and the answer is likely to be made on that basis. Additional questioning usually reveals that, although the patient may have used the right hand for writing, many other tasks requiring delicate, coordinated movements might have been done with the left hand, or vice versa.

Too many persons believe that the writing hand also is the only hand capable of performing all other smoothly coordinated tasks. As more probing questions are asked of the patient, it may be evident that the opposite hand also performs many functions. If the keys or small change are carried in the pocket opposite from the hand used in writing, bilaterality rather than simple dominance may well be indicated. Information in this connection can be elicited more readily with male patients by asking which pocket carries the handkerchief, which pocket holds the wallet, which hand holds the pipe or cigarette, and which hand is used to strike a match.

It often is surprising to find that, with the exception of writing, almost all daily activities involve equal participation of both hands, one serving as a helper to the other with interchangeable ease. When loss of the use of a hand occurs, either temporarily or permanently, the most frequent problem stems not from the inability to write but rather from the inability to perform the tasks requiring use of both hands—tying shoes, buttoning clothes, cutting food, and so on. Hence, it is important that a prosthesis be designed to restore bilateral activity rather than dominance or the ability to write. When a patient loses a so-called "subdominant" hand, he soon expresses some degree of surprise at the number of jobs formerly done by the missing member. He also notes, with as much surprise, that many tasks are quite difficult for the remaining hand alone, even though it be the dominant or leading hand. But the amount of time required to relearn all these tasks, including writing, with some degree of agility is quite short. Except in bilateral cases, the patient soon becomes reasonably independent. If allowed to continue as a one-handed individual, the unilateral arm amputee soon learns short cuts that permit him to be more independent and ultimately to feel that he has no need for a functional replacement of the missing hand.

Such a patient gives the greatest cause for concern. Perhaps the inability of some to recognize the absence of a true dominance or to understand the rapidity with which a one-handed individual can adjust and become reasonably independent may, in some measure, account for a number of failures in upper-extremity rehabilitation. Certainly there are other causes—inadequate surgery, poor prosthetic replacement, inadequate training—contributing to these failures. But only when all of these factors are considered and eliminated can full utilization of the prosthesis be expected.

The patient who has learned to do reasonably well with one hand is the very patient most likely to be a failure when fitted with a prosthesis. His training will be most difficult and frustrating for all concerned simply because he cannot recognize the need for a prosthesis. Training for such a patient comprises largely a program of unlearning all of the grotesque contortions to which he has become accustomed. Because here the individual, having been pleased with his one-handed accomplishments, must learn to be a two-handed person again somewhat against his "better judgment," frustration becomes an important consideration. The more complicated the prosthesis, the lower is the frustration tolerance of the patient because he cannot accept the need for a device which seems to complicate rather than to simplify his life.

A TWO-HANDED WORLD

One might now properly ask why so much concern should be shown for such a patient. Would it not be easier to permit his unilateral activities to continue and thereby eliminate all problems of fitting, training, and further care? Unfortunately, the solution is not so simple. We live in a two-handed world. To maintain our place in society, two hands are needed, or at least substitutes for them. One need only consider the obvious difficulties encountered by the one-handed individual when carrying a loaded cafeteria tray, serving himself at the table, or attempting to tie up a parcel (Fig. 2). In the effort to prevent similarly embarrassing situations, the one-handed person may gradually seek less and less public contact, social and vocational, and with this self-inflicted isolationism ultimate loss of his own security may develop. Despite all short cuts and self-helps, the amputee who remains without a prosthesis must still require a degree of additional assistance for many tasks. A functional prosthesis offers independence. An unfitted stump usually leads only to a gradual but ultimate deterioration of self-pride in all tasks, public or private.

PSYCHOLOGICAL PROBLEMS

When it appears that a patient has emotional complications that are not responding to treatment, he should be referred to other medical specialists. Such emotional problems may occur at any phase of the patient's course, and the use of proper specialists will, in many instances, permit the rehabilitation team to continue its work while the patient receives the indicated treatment. Prompt recognition and treatment of such unfortunate situations often will salvage the patient, where otherwise he might drift aimlessly through prosthetic fitting and training until the symptoms are so pronounced as to be recognized by everyone on the street.

Initial interviews rarely, if ever, disclose an amputee's underlying feelings about his loss. As he advances through the rehabilitation processes, the amputee may feel that it is too late to open questions of fear and misgiving, in which case his feelings of insecurity are only perpetuated. Hence, it is wise for the physician to suggest possible questions and answers when the amputee is first interviewed. To focus attention upon likely questions may offer an opportunity for the patient to talk about his family's acceptance of his amputation, to discuss social problems resulting from his physical and mental condition, and to air any other problems peculiar to the individual. Unfortunately, no hard and fast rule can be applied; for no two amputees are alike, either in physical or mental make-up or in social and economic status. In any given case, each question should be answered as frankly as possible, and, if the answer is not known, every effort should be made to provide one as quickly as possible. Although left to themselves most amputees ultimately find the answers to their own questions, the answers thus obtained usually come only after many frustrations and sometimes after severe emotional stress *(1)*.

MEDICAL PROBLEMS

The problems of pain, real and phantom, and of phantom sensation, sometimes are so difficult as to postpone actual fitting and training or even to suspend use of the prosthesis after it has been fitted. Recently, phantom pain and phantom sensation have been explored at length *(5,6,9)*, and more complete concepts of etiology and treatment now are evident. When it is caused by thin or densely adherent scar tissue, neuromata, or bony spurs, stump pain is one of the most common causes for delayed initial fitting or for abandonment of the fitted prosthesis.

Fig. 2. The empty sleeve versus the upper-extremity prosthesis—some examples. Although the unilateral arm amputee may learn to perform well with the remaining sound hand many activities formerly conducted with the amputated member, and although the stump and other parts of the anatomy may be called upon to substitute in "two-handed" activities, a great many essential functions are carried out awkwardly, if at all, by the arm amputee who remains unfitted.

In such cases it is futile to delay treatment in the hope that actual fitting, continued use of the prosthesis, exercise, or physical therapy may render a neuroma painless or reduce a spur so that it no longer is troublesome. As time passes and the pain or tenderness persists, the patient is entirely justified in questioning whether or not he ever will be able to wear a prosthesis. Specific difficulties that do not respond to conservative measures should be corrected surgically and with the least possible delay. When it seems wise to attempt a conservative approach to minor stump difficulties, an explanation will ensure the patient's continued confidence in the physician. During such a period, the patient's progress must be evaluated regularly. When and if the conservative treatment fails, more radical measures are in order.

VOCATIONAL PROBLEMS

All amputees—those, like the housewife, engaged in the home as well as those employed in business and industry—have vocational problems at one time or another. Again, the patient requires much honest and factual reassurance. Although the trend in employment of the physically handicapped is much more gratifying now than it has been in previous years, rose-colored pictures of industries seeking amputees for all types of employment lead only to false comfort and to eventual disillusionment of the patient. Although true vocational counseling has become a specialty in itself, the physician must never lose sight of the fact that the job of restoring the patient to useful function is his, the physician's, personal responsibility. Even though the patient may at some time be evaluated by a vocational counselor, the physician must regard the evaluation as a type of referral with continued follow-up to ascertain the progress being made.

Proper use of the social worker may prove invaluable in maintaining close liaison with the employer and the rehabilitation team *(2,3).* The employer should be encouraged not to discharge the amputee patient until the possibilities of further employment have been fully explored. To the new amputee still in the hospital, nothing can be more devastating than a notice to the effect that he has lost his employment as a result of his newly acquired handicap (Fig. 3). Assurance that there is a reasonable chance of continued employment, or that efforts are being made to place the patient in some similar position, will do much to speed his total recovery and to provide motivation, the one factor without which there can be no genuine rehabilitation.

It is fortunate that current trends in aiding the physically handicapped are toward providing vocational training and placement rather than monetary compensation and the subsequent opportunity to sit in the park and collect the pitying, sideward glances of the passers-by. The amputee who formerly held a job requiring bilateral hand use very early recognizes the need for

Fig. 3. The pink slip versus the helpful proprietor. In total amputee rehabilitation, morale is important. Full cooperation of the employer is essential to the success of the prosthetics clinic team.

a prosthesis, accepts it readily, and receives training as quickly as possible. With the younger, inexperienced person, who perhaps has drifted aimlessly through several more or less unproductive jobs, the problem of prosthetic acceptance and use is more complicated. Such a person has yet to learn the true value of two hands.

Unfortunately, some of the veterans of World War II and of the Korean conflict have been victims of such an experience. These men, many coming directly from high school or from odd jobs, had no opportunity to learn vocations or skills requiring use of two hands. Consequently, many of them accept a prosthesis, cooperate halfheartedly in training and follow-up, and then discard the prosthesis to look the country over for a job they can do with one hand and sympathy. When an effort is made to offer these people vocational guidance, many indicate they are "going to school," apparently in the belief that one can get through school with one hand. But as a matter of fact the process of education more often than not demands bilaterality, and the inability to recognize the value of a prosthesis constitutes the principal reason why many amputees eventually withdraw from schools.

TRAINING PROBLEMS

Although there can now be no doubt of the value of prosthetics training, it is interesting to note that many amputees, usually those who have worn a prosthetic device for many years, indicate that they see no need for training. The patient and prosthesis become one, and little tricks of operation and short cuts, all of which lead to increased efficiency, become second nature. From such a peak of efficiency it is difficult to remember the basic training required to perfect every motion, In the past, moreover, training rarely was conducted as intensively as it is today. Simple instruction in the use of the terminal device, usually by the prosthetist, was about all the patient could expect, and he depended on trial and error and the passage of time for the remainder of his training.

A patient who has gone through such a procedure may scoff at the prolonged period of time now thought necessary to assure adequate training in prosthetic control. But the time thus spent really is immeasurably short because it saves the patient much false motion and wasted effort and prepares him to resume his place in society more quickly than the patient with no training. Of course, training must not be confined to the period of prosthetic wear; rather, it must start as soon as the condition of the stump permits *(7,8).* Preprosthetic training includes maintenance of joint mobility and muscle strength as well as maintenance of cerebral patterns of motion.

THE PROBLEMS OF MULTIPLE AMPUTATION

The bilateral hand amputee presents both to the patient and to the medical staff a problem of the greatest difficulty. The patient who has lost both hands still possesses two stumps which afford some means of gross prehension. A pencil can be grasped for crude writing, an eating utensil can be held between the stumps for clumsy eating, and the stumps fill out the sleeves. But all delicate prehension, all discrete tactile senses, are lost. Initially, the bilateral amputee is apt to be deeply depressed, and he therefore usually responds poorly to the first rehabilitation contacts. He requires as rapid a fitting as possible, because otherwise he remains almost completely dependent for all necessities, not only economically but, more important, socially and in the home. The latter situation is the one usually most devastating and the one which unfortunately most often is brushed over when the patient first is met. He must have assistance not only in eating but in all toilet activities as well and finds himself relegated to a crude and almost infantile existence.

Prosthetic training is much more detailed and prolonged for the bilateral amputee than for the unilateral because the patient has no remaining natural hand for a prosthesis to assist. All acts of dexterity must be accomplished by one or the other terminal device. The therapist cannot consider training complete when the patient meets the requirements of the unilateral amputee but must, in addition, cover use of the prostheses in all acts of everyday life—feeding, toilet care, and dressing. It is fortunate that such activities are well within the realm of accomplishment for the bilateral hand amputee, especially when the stumps are comparatively long and the natural elbows are intact.

An additional complication, usually resulting from trauma, involves amputation of part of a leg in addition to loss of an arm. In the light of present experience, neither amputation truly can be said to take priority over the other, and each case must be considered on an individual basis. In every case, body mechanics and sense of balance are impaired seriously. Gait training becomes more difficult when a part of an arm has been lost. Similarly, upper-extremity training is made more difficult without the use of both normal lower extremities. The patient is necessarily confined to bed or uses a wheel chair or crutches for support. If one of the arms is artificial, crutches are used only with difficulty and often in a manner potentially dangerous. The patient may find his arm prosthesis so attached to the crutch that, in the event of a fall, he is unable to free himself rapidly and to discard the crutch. There is thus always the possibility of damage to the stumps or other parts of the body. Considering these potentials, it would seem best to undertake gait training first. When it can be instituted safely, this practice seems to present fewer problems to all concerned.

THE PROBLEMS OF EARLY FITTING

Early fitting of the prosthesis has come to occupy a major place in present-day concepts of amputee management. To postpone fitting until maximum stump shrinkage has occurred often gives the patient those few extra weeks of one-handed experience that lead him to believe he does not need a prosthesis. Although there is no known criteria for determining exactly when a stump has stopped shrinking, it now appears that the greatest incentive to maximum shrinkage is actual wear and use of a prosthesis. Once the patient is shown that early fitting and constant practice are the shortest roads to recovery, he usually cooperates willingly.

With early fitting naturally comes the problem of continued stump shrinkage, which usually results in a loose socket. It is entirely possible that fabrication of a second socket may be necessary before complete adjustment has taken place. The patient should be made aware of this possible complication, and, when it appears that a second socket may be required, the added cost might be included in the price of the prosthesis. In a patient's decision to abandon a device, repeated expenditures for prosthetic adjustments often play as important a role as does a loose socket. But if initially the patient is told the reasons for possible additional expenditures, more than likely he will accept the conditions without protest and without discouragement.

SOME SOLUTIONS

What can be done to solve some of the problems that are potential sources of failure in the proper utilization of an arm prosthesis? First, it must be realized by all concerned with the management of upper-extremity amputees that the present concept of dominance is a relative one. The person who loses the so-called subdominant hand is just as seriously disabled as is the one who loses the dominant hand, and he stands just as much chance of becoming a nonwearer. The remaining member often can be taught to perform many of the functions of the missing hand. If this situation is allowed to persist for long, the amputee begins to feel that prosthetic replacement is unnecessary.

THE EDUCATION OF THE PHYSICLAN

To the end that all upper-extremity amputees shall be properly fitted and trained, it is imperative that the education of all physicians and ancillary medical personnel be continued and expanded. Current knowledge and new techniques must be passed on not only to those physicians and technicians who, because they are specialists, see amputees regularly but also to all general practitioners, especially to the family doctors who usually are first to see the amputee. The general practitioner must be brought to realize that new skills and devices are available to help his patients, and he also must be made aware of the fact that the longer assistance is delayed the more unlikely is the amputee to wear and use a prosthesis. Education must be carried to every level, ideally down to the county medical society, which in many instances is the only group in which the general practitioner can participate regularly. Information relating to amputee management should appear in *all* medical literature, for technical assistants also are responsible for extending any educational program devoted to the amputee. If complete success in total rehabilitation is to be expected, an amputee must be presented to the various specialized centers or clinics with the least possible delay after amputation.

THE EDUCATION OF THE AMPUTEE

Equal stress must be placed upon educating the amputee. If, for example, he has a short stump or some other problem requiring that he be fitted with a more complicated and hence less efficient device, the limitations of the prosthesis must be explained in detail. Too many patients are given the benefit of excellent surgery and fit but are not prepared for the shock that comes when they discover that the prosthesis is, at best, only a device to assist the remaining hand. Such a disappointment often produces discouraging results and sometimes complete failure. Many specialists and technicians are prone to be overenthusiastic about a particular prosthesis. What to them appears to be an excellent prosthesis well may be to the patient a hideous collection of bolts and ropes. As a result of some specialists' enthusiasm, many amputees envision a prosthetic device far more functional than actually is possible.

When a patient is counseled for the first time, therefore, every effort should be made to point out all the factors involved in total rehabilitation. The limitations of the prosthesis should be explained at once, so that no false concepts or hopes are allowed to exist or to be perpetuated. Even if nothing more than a photograph is available, the patient should be shown a prosthesis similar to the one he eventually will use, and the necessity for training must be outlined so that the patient realizes that wearing the prosthesis and using it efficiently are two distinct functions. Many patients are astonished to find that training is necessary, and many look upon it as just one more stumbling block in an already confused amputee existence. Each step in the program must be explained fully, and the possible complications also must be outlined. Only in this way can the amputee be spared the bitter disappointments that often attend rehabilitation.

TRAINING AND CHECKOUT

Adequate checkout procedures should assure efficient mechanical function as well as correct fit *(4).* An inefficient cable system may, for example, render an otherwise satisfactory prosthesis so difficult or clumsy to operate that even the patient with a great desire to learn may find it impossible to use the device. The disinterested patient who does not appreciate the true value of prosthetic replacement may seize upon such a situation as the final excuse to give up training completely.

Prosthetic training and final checkout complete the patient's initial steps toward rehabilitation, but unfortunately training can be responsible for failure. Therapists must be sympathetic with the patient's initial efforts, but they also must be firm in developing adequate control before actual use of the prosthesis is attempted. The patient's first desire after receiving the prosthesis is "to do something with it," and time spent in learning control techniques may seem worthless to him. Here again explanation of the reasons for the training steps is essential.

If the patient is unable to demonstrate adequate control skill in a reasonable time, it often is wise to postpone or slow the training process rather than to provoke marked frustration in both patient and therapist. In such instances it is important that the therapist keep the prosthesis until sufficient basic skills are developed by the patient. If the amputee is permitted to wear the device immediately, he is likely to develop inefficient and sometimes weird methods of operation, thus negating all of the valuable time expended in fabrication and fitting. It is essential, however, that the patient understand the reasons for his sometimes difficult and slow progress in training and why it is necessary for the therapist to retain the prosthesis until basic skills are achieved.

In some clinics there are to be found a standard below-elbow and a standard above-elbow prosthesis with split and laced sockets to permit adaptation to many different kinds of stumps. These so-called "standard" prostheses are used in early training to prepare the patient for efficient operation of his prescribed prosthesis. When used with proper care and reasonable patient selection, they serve a valuable purpose, but such a procedure may be unwise if the training arm cannot be adjusted readily to the individual patient or if it contains undesirable components. Attempts to use an ill-fitting training arm may be so difficult that the patient becomes discouraged and anticipates the permanent prosthesis with misgivings. Accordingly, training arms should be used only on the advice of the clinic team.

Too much training can be as harmful as too little. The higher the level of amputation the less functional usefulness can be derived even from the best prosthesis. Realization of this circumstance can prevent the hypertensive episodes that occur in patient and therapist alike when too much is demanded of the amputee-prosthesis combination. There is no personal defeat when, as is often the case, it must be admitted that the prosthesis can serve only as a "helper" hand. Under such circumstances, training, to be effective, must be guided appropriately. Overtraining only discourages the patient whose level of amputation is a basic factor in determining the degree of prosthetic function. Achievement tests should be used to measure and record the patient's progress and final skills, but such tests vary from level to level and from patient to patient and can serve only as a crude measuring stick, not as the final criterion as to whether or not a patient has achieved the maximum benefit of training. The answer to that broad question can come only with careful observation of the patient during activities of daily living and of vocational pursuits.

CONCLUSION

From these considerations, it is possible to formulate certain basic rules for the management of the upper-extremity amputee. It is important first to know as much as possible about the patient besides the fact that he is missing a hand. It is necessary to understand him and to understand his disability. Too much faith must not be placed in the absence of either a so-called "dominant" or "subdominant" hand as the sole measure of disability. In addition, the patient must be made to understand what is in store for him. Above all, no questions about any phase of his problem should be left unanswered. In some instances the amputee is reluctant to discuss problems not relating directly to his amputation, and the physician should be certain that, aside from the amputation, there are no other physical or mental problems that may affect total rehabilitation.

For psychological as well as physical reasons, the patient should be fitted as rapidly as possible. Early fitting allows the amputee to realize the advantages and limitations of his prosthesis. Moreover, early fitting often eliminates the danger of the patient's coming to think that he can get along with one hand—a situation which can complicate and prolong total rehabilitation. Finally, because overtraining can be just as harmful as are all the other "don'ts" of amputee management, no attempt should be made to train the patient to do more things than the level of his amputation and the nature of his prosthesis permit.

When all of these individual problems are considered systematically by the respective members of the clinic team, over-all management of the upper-extremity amputee becomes a synthesis of cooperative effort. In no other way can so much success and satisfaction be afforded both the patient and those charged with his care.

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The Noticeability of the Cosmetic Glove

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A HAND prosthesis can be useful in more than one way. It can be helpful in dealing with objects, and it can be helpful in interpersonal relations. The latter aspect is the one with which we are here concerned. The usefulness of a prosthesis in human relations is termed "social usefulness." To a wearer who considers his hand amputation a private matter, for example, and to one who does not wish to be recognized as an amputee, a prosthesis is socially useful if it cannot be recognized as an artificial device. Moreover, the amputee may be concerned that another person looking at the prosthesis should feel comfortable. In such a case, that prosthesis is most useful which does not repulse or embarrass another person but is "good to look at."[4]

In 1949 a cosmetic glove, produced at the Army Prosthetics Research Laboratory, was sent for testing to the Research Division of the College of Engineering, New York University. Investigation of the cosmetic glove led to formulation of the problem of the social usefulness of prosthetic devices in general. The methods developed during the study of the glove are, furthermore, generally applicable to the investigation of the social usefulness of other prostheses. This article deals only with the problem of the noticeability of the cosmetic glove. The question of its appearance, *i.e.*, the desirable and undesirable characteristics of the sight of the cosmetic hand, is not discussed.

EXPERIMENTS AND RESULTS

On cursory examination, the experimental prosthesis looked like a normal hand, but on closer scrutiny it could easily be recognized as a cosmetic device. Further, it did not match the normal hand of the particular wearer, although it was, at that time, the best match among several available cosmetic gloves (Figs. 1, 2, 3, and 4). Moreover, the glove simply was filled with vinyl foam, and the hand was thus nonfunctional except insofar as the amputee might wedge light objects between the springy fingers.[5]

The problem was to determine whether such a glove is realistic enough not to be noticed as a prosthesis, or, rather, how frequently the wearer of such a glove goes unrecognized as an amputee. Four different experiments were conducted.

'Based on Report 115.07, Research Division, College of Engineering, New York University, to the Advisory Committee on Artificial Limbs, National Research Council, prepared by Elizabeth Cattell, Tamara Dembo, Sylvia Koppel, Esther Tane-Baskin, and Solomon Weinstock. Some of the experiments were conducted at the New School for Social Research, New York City.

[2] Associate Professor in Psychology, Clark University, Worcester, Massachusetts.

[3] Psychologist, South Hadley, Massachusetts.

[4] Independent of the appearance of a prosthesis to other persons is the importance of its appearance to the wearer himself. This subject involves such complex problems as the feelings a person has about his injured body, a matter much too detailed to be discussed here.

[5] In extensive work with arm amputees at the Army Prosthetics Research Laboratory, it has since been demonstrated that proper motion characteristics are as essential to hand realism as is the appearance of the glove itself. Among the most revealing features of the present APRL hand are its robotlike action in prehension and its obvious rigidity when not in use. A future goal in artificial-hand design is to build into the mechanism some reflex "cosmetic" movement in prehensile activities and some "natural" motion of the digits when the prosthesis is not in active use, such as when it is carried empty at the side during walking. See page 93. —ED.

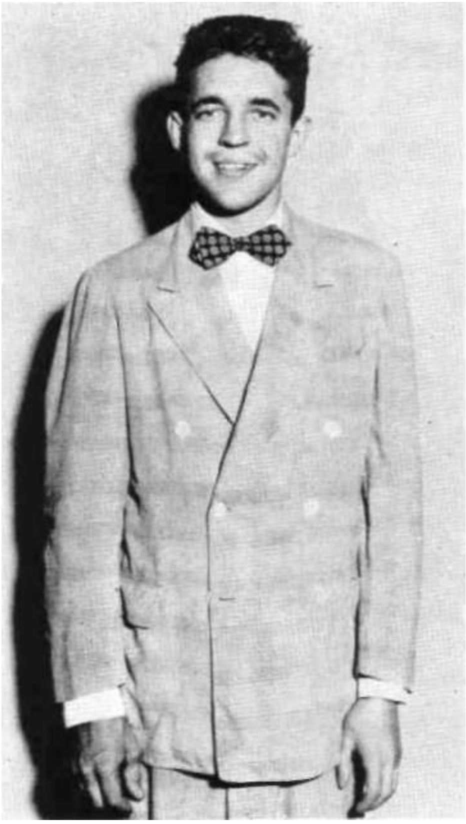

Fig. 1. Winthrop Sullivan wearing the cosmetic glove on his left (to the reader's right).

EXPERIMENT I

In the first experiment, 30 separate tests were performed. Each required a wearer,[6] an experimenter, an observer, and a stranger. The stranger was the "subject" because his reaction, *i.e.*, whether he did or did not recognize the cosmetic hand as a prosthesis, was of prime importance. The wearer went, as a customer, to various stores and shops in New York

[6] No account of the study would be complete without mentioning the unstinting help of the wearers. Winthrop Sullivan and Brennan C. Wood. Whenever necessary, they volunteered to participate at odd hours and on weekends in addition to their regular time. More important, they made many observations which contributed to a clearer understanding of the experimental situation Mr Wood incurred a right above-elbow amputation in 1943. Mr. Sullivan underwent a left below-elbow amputation in 1937 Both wearers have been connected with the NYU Research Division since 1948. They started to wear the cosmetic hand at the beginning of these experiments. Considering themselves hook wearers, they were at tirst somewhat critical of the hand. During the investigation, however, they became aware of some advantages of a cosmetic hand prosthesis.

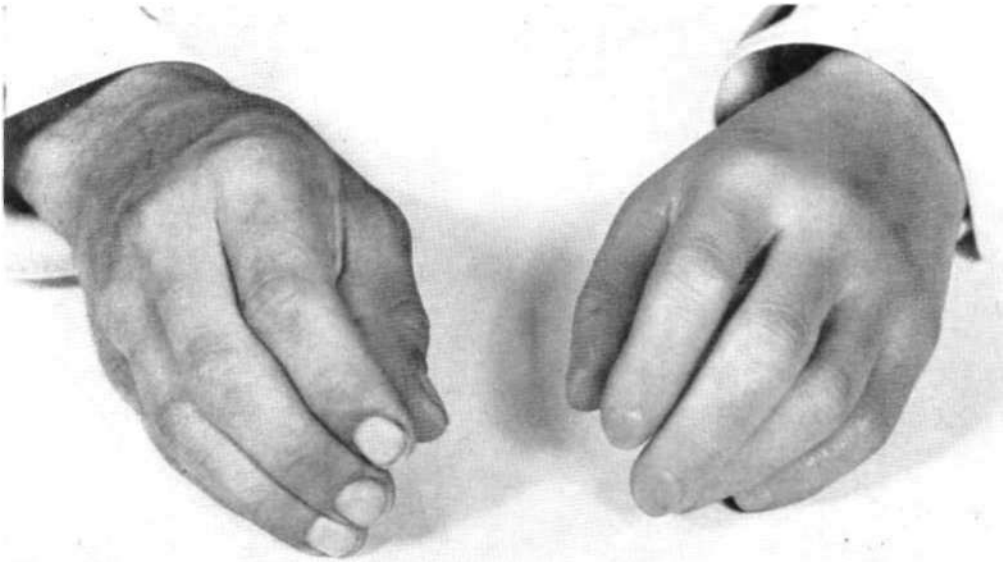

Fig. 2. Mr. Sullivan's hands.

City and engaged salemen (subjects) in conversation. In each instance, he put his arms on the counter and, to make sure that the cosmetic glove was in sight of the salesman, gestured, pointed, scratched his hand or face, indicated size or shape of objects, held a newspaper, smoked, soiled the cosmetic hand and wiped it off, or supported objects *(e.g.,* held a wallet against his body with the artificial hand), all the while acting in a leisurely manner in order to prolong the contact, usually for from five to twenty minutes. Experimenter and observer entered the store with the wearer but as a separate party. While the wearer talked to the subject, experimenter and observer stood aside as if engaged in conversation, the observer pretending to listen to the experimenter but actually taking notes on the behavior of the wearer and the salesman. The latter, of course, did not know that he was the "subject" of a psychological experiment.

When the wearer left the store, the experimenter approached the salesman and asked some questions about the man who had just left. The observer continued to stand aside and recorded the discussion (interview) between the experimenter and the subject. An example of an interview follows:

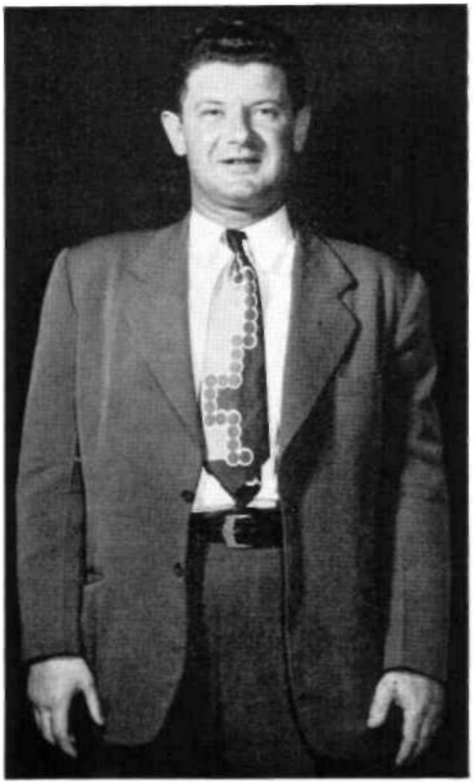

Fig. 3. Brennan C. Wood wearing the cosmetic glove on his right (to the reader's left).

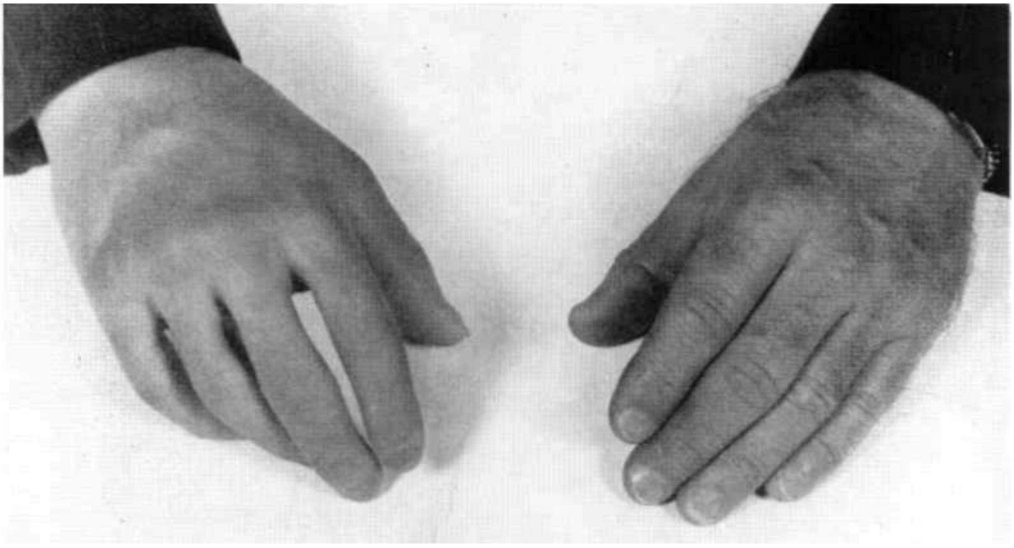

Fig. 4. Mr. Wood's hands.

Experimenter: Did you notice anything **about the** man who was just in here?
Salesman: In what respect?
Experimenter: Well, did you notice anything unusual about him?
Salesman: About his hand.
Experimenter: What was there about it you noticed?
Salesman: There was no action in it.
Experimenter: When did you notice it?
Salesman: When he had his hand at his side. When he lighted a cigarette. He held his hand like this [shows stiff position].
Experimenter: Do you think it could have been an artificial hand?
Salesman: No, it was not an artificial hand. It was his hand. He held it close to his side. Maybe he had no action in the shoulder. He did not use that hand. Used one hand at mirror. Held it. Just turned it.

After being informed that the hand was a prosthesis, the salesman said he had not recognized it as such.

EXPERIMENT II

In the second experiment, three or four people (college students and their friends) were asked to take part as subjects of a psychological group experiment on "impressions of personality." On their arrival, the subjects found the wearer, who was introduced as one of the group members. Everyone was asked to sit around a table and to wait for another group member supposedly delayed and, in the meantime, to get acquainted with each other. The wearer, holding his hands in plain view on the table, conversed with the group members. After about 10 minutes he left the room, ostensibly to make a phone call. Then each member of the group was asked to accompany an experimenter to another room, where the participant was asked to give his impression about the person who went to make the phone call. If, during the interview, it became clear to the experimenter that the subject had not noticed the hand, the subject was given another opportunity to observe the wearer, and then a second interview took place. Sometimes the procedure was repeated a third time. In all, 29 subjects were used.

An example of an interview performed in Experiment II follows:

Experimenter: As you know, we are studying quick impressions of personality. Mr. X is part of the experiment. Could you give your first impressions of him? What struck you about him, mainly?
Subject: He seemed intelligent, friendly, sociable. It seemed as though he could talk on other than his major field of interest.
Experimenter: How would you describe him physically?
Subject: Physical impressions are a pretty personal matter, I think. Would say he was more positive than negative, from the point of view of attractiveness. Genial.
Experimenter: Could you give the outstanding characteristics of his face?
Subject: He had a fairly easy smile, seemingly accompanying a sense of humor and a desire to please.
Experimenter: Could you describe his hands?
Subject: Yes, I noticed his hands. I usually do notice hands.
Experimenter: Could I interrupt to ask why you always notice hands?
Subject: I just always have. It dates from the fact that when I was young I thought I couldn't be beautiful, but I could have nice hands and fingernails, so I always notice other people's. I guess I can visualize the hands of every friend I have ever had. I think his were in-between, no particular character.
Experimenter: Anything else?
Subject: He had nice hair, a little wavy. A kind of flushed face, more healthy than not.
Experimenter: Were there any gestures on Mr. X's part that you remember?
Subject: No. He had his hands out on the table most of the time, but I don't remember his gestures particularly.

The subject who stated that she usually notices hands did not notice the cosmetic hand or any signs of difference about the hand.

The experimenter and the subject returned to the group. After about ten minutes more the wearer left, and the second interview took place:

Experimenter: Now can you give some further impressions of Mr. X?
Subject: I noticed his eyes more this time, a little different than most people's but difficult to describe, noticeable. I noticed his nose tips up a little, like Sonja Henie's. I noticed his hands more because you called them to my attention, but I don't think these physical impressions mean too much.
Experimenter: Was there anything outstanding about his hands?
Subject: His nails were not particularly graceful, they were a little short, but clean looking. I confirmed the fact that his hair was curly and his face ruddy. He seemed very well balanced, not neurotic, in that he seemed willing to go along on other people's fun. He certainly didn't show any compulsion to take the spotlight or to resent it when somebody else took it.
Experimenter: We'll all go back together again, and then

there will be a third interview. I want you to notice his hands again particularly, and in detail. Notice the movement or lack of it.

The subject was interviewed again after she saw the wearer for the third time:

Subject: I did notice his hands, the shape, and the rather short fingernails. They looked clean and healthy, but I like tapering fingernails.

Even during the third period of contact with the wearer, the subject did not notice any difference between the wearer's two hands, although she was able to describe them.

The results of Experiments I and II are given in Table 1.

Table 1

NOTICEABILITY OF THE COSMETIC GLOVE

Experiment	Seen as Prosthesis		Seen as Own Hand of the Wearer					
			Injured hand		Different hand		No difference seen	
	No. of Ss	%	No. of Ss	%	No. of Ss	%	No. of Ss	%
I 30 Subjects (Ss)	0	0	6	20	0	0	24	80
II 29 Subjects (Ss)	3	10	0	0	3	10	23	80

Of 30 subjects in Experiment I, 24 (80%) did not recognize the cosmetic hand as a prosthesis. In fact, they did not even notice any difference between the two hands of the wearer.[7] The remaining 6 subjects (20%) commented that the arm or hand was in some way injured, but they too did not notice that the hand was artificial.[8] Thus, in an everyday situation of a salesman dealing with a customer, *not one* salesman in Experiment I noticed the cosmetic glove *as a prosthesis.*

The question arises as to why the prosthesis was not noticed by the salesmen. One could ask whether the unnoticeability may not be accounted for by the "fact" that the busy New York salesman does not have enough time to pay attention to the appearance of his customers. This, however, was not borne out by the data. When asked to describe the customer (the wearer), the salesman was well able to describe how the wearer looked, what he did, and what he said. Yet the saleman had not noticed the cosmetic glove.

In Experiment II, 29 subjects took part.[9] Within the framework of "description of personality," 23 (80%) did not notice any difference between the two hands, 3 (10%) noticed that one hand looked different from the other but did not recognize it to be an artificial hand, and 3 (10%) noticed that it was a prosthesis.

That the cosmetic hand was not recognized by any of the salesmen as a prosthesis and rarely as such by the students and their friends, one may argue, is due to the "fact" that people do not pay attention to the properties of another person's hands. To test this "hypothesis," Experiment III was carried out.

EXPERIMENT III

In Experiment III, with a setup essentially the same as in Experiment II, the wearer used a hook instead of the cosmetic hand. Here, 11 out of 12 people (92%) noticed that the amputee was wearing a prosthesis. It appears, then, that the cosmetic hand goes unnoticed not because people are negligent in their observations but rather because it does not deviate sufficiently from the appearance of the natural hand. The hook, however, which de-

[7] A person examining a cosmetic hand may be surprised that it is so frequently unnoticed. The incidence of unnoticeability came as a surprise to the wearers themselves. After the first few contacts, the wearer encouraged the experimenters to make doubly sure that the cosmetic hand *really* had not been noticed. The experimenters did this by explaining to the salesmen the purpose of the experiment and asking this time directly whether the subjects had noticed the cosmetic hand.

[8] It might be noted that in 5 out of 6 cases the hand was noticed as injured when attempts to do something with it failed. For example, the wearer took ice cream, started to put it in the cosmetic hand, then put it down and picked it up again with the other hand. Another time a wearer held his wallet against his body with the cosmetic hand. As the salesman brought the change near the wearer's wallet, the wearer rapidly put out the normal hand to take the change.

[9] Although 32 subjects engaged in Experiment II, three of them had to be excluded. One was married to an arm amputee. The two others tried to shake hands with the amputees. These three subjects recognized the hand as a prosthesis. But our experiments were confined to visual contacts onlv,

viates radically in appearance from the normal, is noticed readily (Table 2).

Table 2

NOTICEABILITY OF THE HOOK AS COMPARED WITH THAT OF THE COSMETIC GLOVE

Experiment	Seen as Prosthesis		Seen as Own Hand of the Wearer					
			Injured hand		Different hand		No difference seen	
	No. of Ss	%	No. of Ss	%	No. of Ss	%	No. of Ss	%
II (Hand) 29 Subjects (Ss)	3	10	0	0	3	10	23	80
III (Hook) 12 Subjects (Ss)	11	92	0	0	0	0	1	8

EXPERIMENT IV

In the first three experiments, untrained observers were used. The question arose as to whether different results would be obtained in experiments with people especially trained to notice bodily characteristics. One could expect that art students, for example, would be especially apt to notice the cosmetic hand. Accordingly, in Experiment IV, six art students participated as subjects, all members of a drawing class for which the wearer served as a model. Six to eight feet separated the wearer from the students. They were told that, after having made the drawing, they would be asked how the model impressed them as a person.

During the first part of the experiment, the wearer posed with his cosmetic left hand supporting his chin (Fig. 5). Ten minutes were allotted for the drawing. Then the wearer left, and the art students were questioned individually, the interviews being conducted in terms of what impression the art student had of the model's personality. Results showed that not one of the six art students was aware that he had been drawing an artificial hand, although some reference was made to the difference between the two hands, or it was felt that the hand somehow did not fit the person.

The second part of the experiment offered even greater opportunity for direct comparison

Fig. 5. Mr. Sullivan as sketched by an art student. The hand held to the face is the cosmetic one. While drawing this picture, the art student did not notice a difference between the two hands (Experiment IV, Part 1).

of the two hands. Here, the subjects were told that the model (wearer) would return for a second pose and that later the subjects would be asked "how his *hands* expressed personality." During the second drawing period, the wearer sat with his two hands covering his face (Fig. 6). But even under these conditions,

Fig. 6. Second drawing of Mr. Sullivan by the same art student who drew the picture shown in Figure 5. The notation listing the differences between the two hands is that made by the student at the time of the drawing (Experiment IV, Part 2).

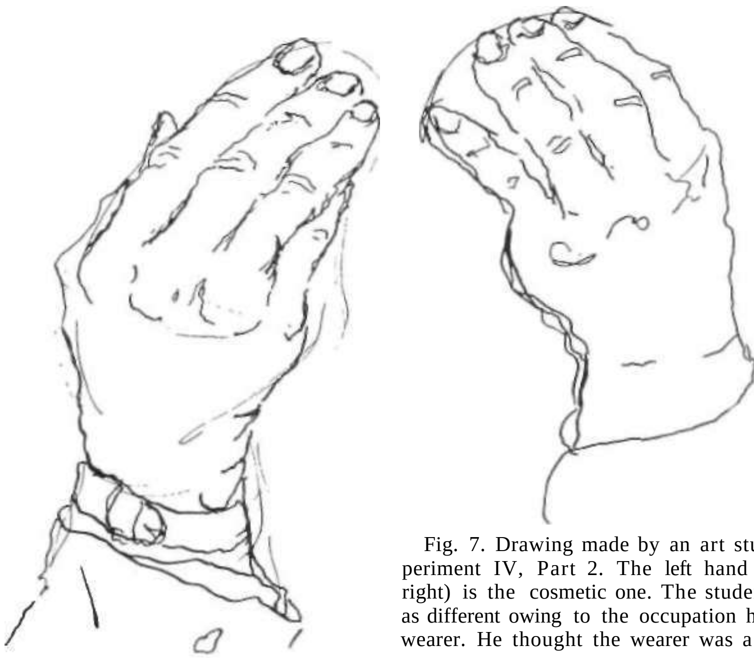

Fig. 7. Drawing made by an art student during Experiment IV, Part 2. The left hand (on the reader's right) is the cosmetic one. The student saw the hands as different owing to the occupation he ascribed to the wearer. He thought the wearer was a violinist.

only two of the six subjects noticed that one of the hands was artificial. The remaining four did not realize that they were drawing a cosmetic hand.

To illustrate how, in spite of differences noticed between the two hands in Experiment IV, it did not occur to the subjects that one hand was artificial, excerpts from two interviews conducted after the second drawing (Fig. 7) follow:

Experimenter: What gives now?

Subject: Interesting things, real interesting. Makes a difference when you know you're supposed to look at hands. About his hands, there is a basic difference in his two hands. The right hand is more used, I would say [left hand is the cosmetic one]. There are several interesting things about them. First of all, the fingernails were fairly short. Gives me an idea that he may play a stringed instrument. The button of his cuff was open, couldn't tell if broken off. I thought of a violinist who would open his cuff so he could handle it. I think he is right-handed because that would be the bow hand, and all the movement would have opened the cuff. I don't think this particularly jibes with the feeling that the hand that would do the fingering would be the most wrinkled, worn hand. For this was not the case. Yet had the feeling that he does do something special that involves th specialized use of one of his hands.

Experimenter: Why do you think this?

Subject: Well, there is a basic difference in structure. 1 couldn't see the right hand before when he was posing [subject refers to Figure 5], I drew the right hand first. It was thinner. I felt there was more structure visible, it was more wrinkled, I could think of some special occupation. Another interesting thing, the watch was worn inside the wrist on the right hand, which made me think it indicates a little about the personality.

Another interview in Experiment IV went as follows:

Experimenter: And what did the hands express?

Subject: Well, it looked to me as if [the hands express] the character of a person in very serious thought. Some trouble, wrestling with some problem, rather unhappy.

Experimenter: Was this because of the hands, or the pose, or both?

Subject: Both together. The hands were very tense and tight, not relaxed. Indicated that there was a conflict.

Experimenter: This was the physical appearance?

Subject: Yes, the tense position of the hand and fingers, the fingers close together and tight, not relaxed and easy. They show what's inside the person. He unconsciously clenched his fist and \ou noticed something,

DISCUSSION

In the first experiment in which the cosmetic glove was worn, not once was the cosmetic hand recognized as a prosthesis. In Experiment II, the glove was seen as a prosthesis by only three (10%) of the subjects. In both experiments, a difference between the two hands was noticed only rarely. In Experiment III, the hook was recognized as a prosthesis in all cases save one. If one wishes to "explain" the unnoticeability of the cosmetic hand during relatively short contacts, one may say that the appearance of the cosmetic hand is similar enough to that of the normal to remain unnoticed. We know, however, that the differences between the glove and the normal hand are pronounced enough to be seen by almost anyone. What, then, are the conditions under which the *similarity,* rather than the *dissimilarity,* is decisive? To understand what is involved requires a brief discussion of a few general problems of visual perception.

It is a well-known fact that objects on which we focus are seen much more clearly than are those seen within the area of our peripheral vision. Distinguished from these two areas in the visual field should be two others, namely, "area of concern" and "area of mere presence." An object is in the "area of concern" if we inspect it, that is, if we concern ourselves with it. If, however, we perceive an object "as just being there," if it is not being examined by us and we do not concern ourselves with it, it is in the "area of mere presence."

The area of presence and the area of concern of a visual field do not necessarily coincide with the central (focal) and peripheral parts of the field of vision. Each of the areas, that of concern or that of mere presence, can be either central or peripheral. We can, for example, stare at an object, focus on it, and yet not be concerned with it but with something going on elsewhere in our field of vision. Such is the case, for example, when one is looking at an object but wishes to watch another person unobtrusively. Here, the object focused upon is central and at the same time is in the area of mere presence. The person being watched is in the peripheral field of vision but at the same time is in the area of concern. Centrality and peripherality thus are distinguished by whether we do or do not look at an object directly, areas of presence or concern by whether or not we attend to (examine) the object.[10]

Often there is a tendency on the part of an observer to make the area of concern coincide with the center of his field of vision, while objects that do not concern him are shifted to the periphery. The separation of the field of vision into central and peripheral areas is, however, essentially different from the separation into areas of concern and of mere presence. With regard to the noticeability of the cosmetic hand, the most important fact is that objects in the area of concern differ in appearance from those in the area of presence. Some differences in details perceived when two objects are in the area of concern are not perceived when two objects are in the area of mere presence. Thus, two objects in the area of concern may look different, whereas the same two objects may look alike when in the area of mere presence.

In meeting people, we usually do not concern ourselves with their hands, *i.e.,* hands are in the area of mere presence. Because the observer perceives fewer details in this area, hands which on examination look different can appear alike to the stranger and thus may not provoke attention during casual contacts. This would account for the infrequency with which the cosmetic hand was recognized in Experiments I and II. Since looking directly at or focusing on an object does not necessarily mean that the object is examined, glancing and looking at the hands directly, as did some of our subjects, failed to result in observation of significant differences.

When something unusual happens, the hands shift from the area of mere presence to that of concern or, to put it in another way, the observer changes the position of the hand from the area of mere presence to that of concern. If, for instance, the subject expects the wearer to use a given hand, and if this hand is not

[10] It appears that a distinction related to the one formulated here has been advanced within the framework of "sensory-tonic field theory." Werner and Wapner have made a distinction between "extraneous" and "object" stimulation. See Psychological Review, Vol. 59, No. 4, 1952, p. 332.

used as expected, or if the action is interrupted (Experiment I), the observer becomes concerned with the hand, examines it, and becomes aware of its deviation from an ordinary hand. Again, if examination of the hands is suggested to a subject, the area in which they are seen becomes one of concern. Moreover, if the subject is told that the hand is artificial, an incentive is provided to examine it. In this case, too, the hand is perceived in the area of concern.

The physical properties of the cosmetic hand are such that, on examination, they are seen not to match those of an ordinary hand. Yet the handlike prosthesis is sufficiently similar to a normal hand that, in the area of mere presence, it may be seen as an ordinary hand. A hook, however, differs to such an extent in physical properties that, even in the area of mere presence, it can hardly be mistaken for a hand. This accounts for the results of Experiment III, in which the hook was noticed by all but one subject.

In comparatively few instances (Experiments I and II), the cosmetic hand was seen as "different" from the other hand but was not recognized as artificial. The existence of cases in which differences are recognized, but in which the hand is not recognized as a prosthesis, may be due to the fact that, as a rule, people are not aware that a realistic hand prosthesis exists. Were that fact commonly known, the 20 percent who noticed the hand as "injured" in the first experiment, and the 10 percent who noticed it as "different" in the second experiment, might have seen it as a prosthesis. But knowledge of the existence of such a prosthesis would not affect the proportion of those who saw *no* difference (80 percent in both the first and second experiments). Since they did not notice any difference, these subjects would not even begin to concern themselves with the hand. As long as the hands match in the area of presence, knowledge that artificial hands exist would not in itself lead to an examination of hands.

FUTURE WORK

Briefly stated, the results show that strangers in everyday contacts with the wearer rarely notice a difference between the two hands. Yet noticeability is only one aspect of the larger problem of social usefulness of the cosmetic hand. Recognition of the cosmetic hand as a prosthesis is bound to occur in repeated contacts with the wearer. Furthermore, friends and relatives know that a wearer is an amputee. When the hand is recognized as artificial, a new problem arises. The appearance of the hand in the area of concern becomes important. Preliminary investigations indicate that, when the cosmetic glove is recognized as such, its appearance evokes in some people very unpleasant feelings. The study of the appearance of the cosmetic glove thus is necessary in order to determine the emotional impact relative to that of other prostheses and to ascertain which properties of the hand provoke negative feelings.

Some people perceive a cosmetic hand as having a yellowish-greenish shade. This circumstance might evoke toward the prosthesis feelings as toward a dead hand. Such feelings might be alleviated if the color of the cosmetic hand approached more closely that of an ordinary hand (page 57). It might even be shown that, to appear as real as possible, the cosmetic hand should have a definitely less yellowish tinge than does an ordinary hand. For such determinations, the subjects chosen should have strong negative feelings toward the hand available now, and observations should be made when the hand is worn.

In conclusion, it should be stressed again that the problem of noticeability is only one aspect of the larger problem of the social usefulness of prostheses. Further studies are required to uncover those psychological properties of the observer which have to be taken into account in order to develop not only "functionally" but also "socially" (or rather "sociopsychologically") useful prostheses.

Color Realism in the Cosmetic Glove

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M. G. DEFRIES, M.Ch.E,[2] AND
FRED LEONARD, Ph.D.[3]

IN ANY list of the attributes comprising that quality of the human hand described as "lifelike," color must occupy an important position. It therefore seems reasonable that, in the design of cosmetic gloves, provision should be made for obtaining a duplication of the color of normal human hands that is as realistic as possible. Failure to do so may lead to a finished product having a "wax-museum" look, a "dead" look, or a "sick" look *(15).*

The problem of representation of human skin engaged the attention of the artist first. Just how representation was achieved is difficult to determine because the artistic expression of attaining the effects of flesh varies so greatly. Many procedures were followed, and the use of several pigments became established. Very often the flesh tones in a painting are not dictated solely by the desire of the artist to duplicate realism but are modified to harmonize with the scheme of over-all color composition. In the development of portraiture, however, there was evolved during the fifteenth century a technique whereby the flesh areas were first undercoated with green or silvery tones of gray. Over this imprimatura were superimposed very thin layers of red, yellow, and white, so as to cause a fusion of the different and delicate colors of the skin. Although it cannot be said that early artists knew about the three-dimensional structure of skin, it seems they realized fully the unique nature of the problem of duplicating skin tone.

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FACTORS IN SKIN COLOR

THE EFFECTS OF LIGHT

Before the color of human skin can be reproduced faithfully and with some degree of realism in a plastic medium such as a cosmetic glove, it is necessary first to inquire into the physical phenomena giving rise to color and to study skin pigmentation and structure. Visually, the color of an opaque or transparent object is dependent upon the character of the light used to illuminate it and upon the ability of the object to absorb selectively various portions of the illuminating energy. If white light, for example ICI Illuminant C (Fig. 1), is used to illuminate an object and the unabsorbed portion is transmitted, the object is colored and transparent. If, on the contrary, the unabsorbed light is reflected and no light is transmitted, the object is colored and opaque. In both cases, the color results from the unabsorbed constituents of the white light which reach the eye. Objects which reflect or transmit all spectral colors equally are white, those which reflect or transmit none are black.

Between these two limits are infinite tints that vary according to the degree to which objects reflect or transmit some colors and absorb others. An object appears red, for example, because it absorbs substantially all frequencies except those in the red portion of the visible spectrum. Hence, objects actually have no color of their own; to the observer the color changes with changes in incident light.

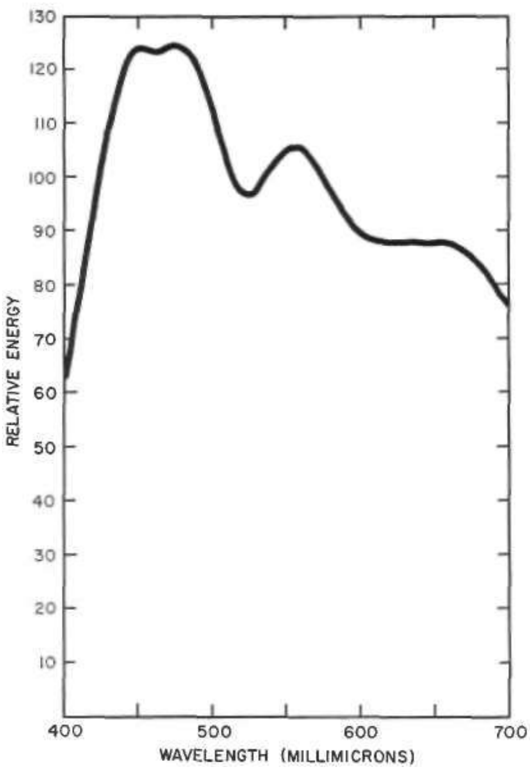

Fig. 1. Relative spectral distribution of the energy radiated per unit time by ICI Illuminant C. From Hardy *(11)*, by permission of The Technology Press, Cambridge, Mass.

If a white object is illuminated in a dark room by each of the colors of the spectrum successively, it has no fixed color but may appear to be red, orange, green, and so on, depending upon the light used to illuminate it.

Although white, or actually "off-white," light (for example, daylight) is our most frequent source of light for normal visual comparisons of color, it is monochromatic light[4] that is most useful in the scientific analysis of color. Two objects that match under noonday light need not necessarily match under incandescent light. If, however, a wavelength-by-wavelength analysis of the energy reflection is made, and if it is found that two objects reflect equal amounts of light at all wavelengths of the spectrum, then the color of the two will match under all viewing conditions. Such an analysis can be made with an instrument called a "spectrophotometer," a graph of the percentage of the incident energy reflected (or transmitted) versus the wavelength of the incident light being called a "spectrograph." Not only are spectrographs useful for determining the match of two colors under all illuminating conditions, but they also can be used as an analytical tool for determining the constituents of a material. Because colored materials usually have unique and characteristic spectrographs, it is possible to determine quantitatively and qualitatively the components of mixtures contributing to the over-all shape of the color curve. Historically, it was only after instrumentation had progressed sufficiently for the rapid, automatic determination of spectrographs that it was possible to make a comprehensive study of skin pigmentation.

STRUCTURE AND PIGMENTATION

The History

Over a century ago, the anatomical structure of the human skin was revealed by microscopic sections. It was reported in 1837 in Berres' *Anatotnia Microscopica Corporis Humani (2).* Histological observations concerned with the pigments of the skin were carried out by Breul *(4)* in 1896 and by Adachi *(1)* in 1903. To Haecker (P) is attributed the discovery that black and bluish tinges are caused by heavy melanin concentrations beneath turbid skin layers. The distribution and quality of the peripheral blood supply was studied by Spalteholz *(17)* in 1893 and, in 1926, by Wetzel and Zotterman *(18)*, who used the technique of capillary microscopy. With the advent of spectrophotometry, analysis of the skin has been effected by Dorno (5), by Bode (J), and by Sheard and Brunsting *(16).* Edwards and Duntley (7) were the first to employ a Hardy spectrophotometer *(10)*, and the subsequent discussion of skin pigmentation is derived largely from their work.

The Layers

Human skin is composed of a series of translucent layers—the epidermis, the dermis, and

[4] Colored light which has its total energy contained in vibrations at a single wavelength.

the subcutaneous tissue—all containing pigments contributing to over-all skin color (Fig. 2). When skin is illuminated, a small portion of the incident light is reflected from the surface unchanged, as though it were reflected from a mirror. The amount of light so reflected contributes to that quality of a surface called "gloss." Remaining light enters the epidermis where, selectively, it is either absorbed, transmitted, or reflected diffusely, according to the color characteristics of the pigments present in that layer. The reflected portion contributes to the visual stimulus, while the transmitted portion enters the dermis. In the dermis, as well as in the subcutaneous tissue, the process is repeated, so that over-all skin color is the result of a complicated process of absorption, reflectance, and transmission, depending upon the relative position and abundance of the color-producing pigments in the skin and upon the turbidity of each layer.

The Pigments

According to Edwards and Duntley (7), five pigments—melanin, melanoid, oxyhemoglobin, reduced hemoglobin, and carotene—play an important role in the production of skin color. Melanin, shown to be responsible for the difference in skin color among races, is found in the epidermis (Fig. 2). It is present in small amounts in certain cells in brunet whites, to a greater extent in the yellow races, and most abundantly in Negroes. Depending upon its concentration, melanin is responsible for yellow and brown effects in the skin and contributes to the bluish tinge sometimes seen in such shaven areas as the male cheek (7). After skin has been exposed to ultraviolet light, the melanin concentration increases, so that the total melanin content may be considered to consist of "primary" melanin and "secondary" melanin, the latter being that produced by ultraviolet exposure. Melanoid, also found in the epidermis, is a derivative of melanin. Its color characteristics are similar to those of melanin except in the violet portion of the spectrum, but it occurs as a soluble material rather than as discrete granules of insoluble pigment, as is the case with melanin.

The most important pigment of the blood, hemoglobin, is present as a mixture

Fig. 2. Cross-section of human skin showing the three main layers and representative distribution of pigments. *M*, melanin (and melanoid), occurring chiefly in the basal layers of the epidermis; *O, R*, oxy- and reduced hemoglobin, occurring in varying proportions at capillary tips beneath the epidermis and in the subcutaneous tissue; C, carotene, occurring in subcutaneous tissue and in limited amounts in the stratum corneum; *S*, light scattering, which occurs in all turbid regions.

of oxy- and reduced hemoglobin, and as such it contributes to the red or pink tone of the skin. Oxyhemoglobin has twin absorption peaks at 542 and 576 millimicrons, and the influence of these peaks can be seen in the normal Caucasian skin curves of Figure 3. Reduced hemoglobin has less absorption in the blue region of the spectrum and has only one absorption peak at 556 millimicrons. The initial reddening effects of exposure of the skin to sunlight is caused by hyperemia *(6),* a condition that brings greater quantities of hemoglobin to the surface. Subsequent "tanning" is due to enhanced production of melanin and melanoid. The fifth pigment, carotene, found in the stratum corneum of the epidermis, absorbs blue light, thereby contributing to the yellow and red characteristics of the skin.

Light Scattering

In addition to the five pigments, light scattering also is partly responsible for skin coloring. As light strikes turbid regions such as the epidermis, there is transmitted a greater proportion of the longer wavelengths *(i.e.,* red) than is present in the incident light. By the same token, the reflected light contains a greater proportion of shorter wavelengths *(i.e.,* blue). The bluish cast produced in skin is dependent on the degree of turbidity in the various layers. Turbidity increases with age, so that the skin of older people tends to be bluish, that of children relatively pink. It is light scattering that tends to give both the sky and the skin a bluish cast when viewed by reflected light. When skin is viewed with transmitted light, it appears quite red, as can be seen by holding a strong light behind such translucent regions as the lobe of the ear.

OTHER FACTORS

Because the five skin pigments are present in different concentrations from person to person, the color characteristics of the human skin vary considerably. Other factors, such as the state of health and even the state of mind of the individual, the activity of the body, prior exposure to ultraviolet rays, ambient temperature, the effect of gravity upon blood flow, all contribute to the color of the hand at any given moment.

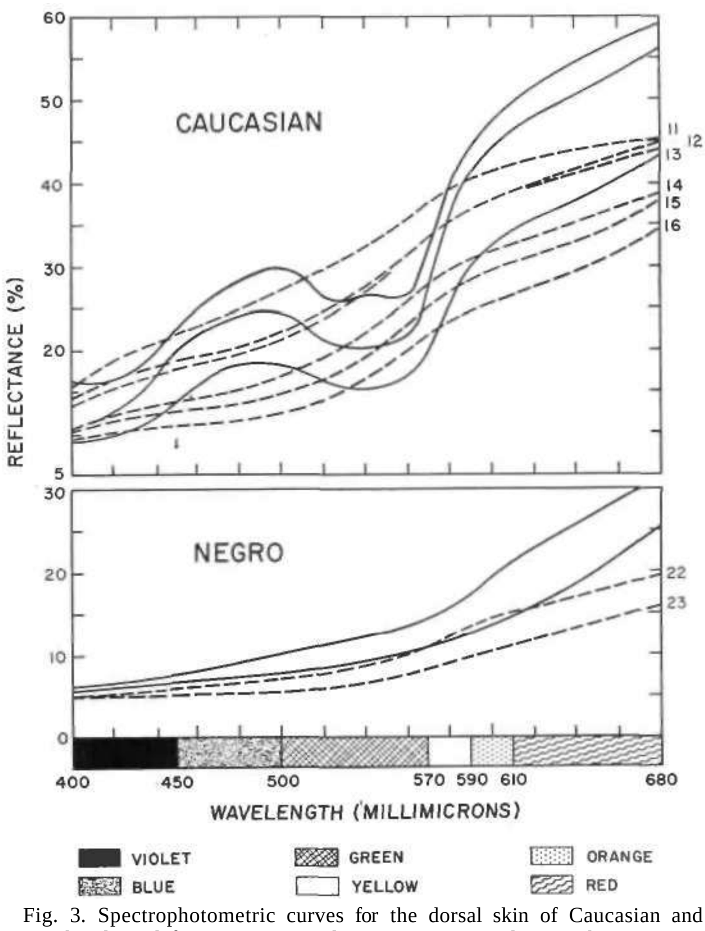

Fig. 3. Spectrophotometric curves for the dorsal skin of Caucasian and Negro hands and for Caucasian and Negro cosmetic gloves. Above, curves for Caucasian hands (solid lines, three subjects) and for cosmetic gloves, shades 11 through 16 (dashed lines). Below, curves for Negro hands (solid lines, two subjects) and for shades 22 and 23 of the Negro glove (dashed lines).

THE PROBLEM OF COLOR

That it would be impossible to provide a continuing match for a normal hand under all viewing conditions was a fact recognized at the start of the program established to provide a suitable cosmetic glove. With this circumstance, the problem became twofold—to provide a limited number of gloves which are statistically a "best fit" in color, and to provide hands which, above all, are colored realistically, especially if true matches cannot be realized in all cases. It is this second factor which is of primary importance in fulfilling the purpose of a cosmetic hand. No matter how favorable an impression is made on the viewer, the success or failure of an attempt to restore a missing hand (as a cosmesis) can be judged only by the absence of notice rather than by the occurrence of notice. The challenge, then, is to produce a hand that, on superficial examination, *could* be a human hand. To attain this end, the hand must be of a color that does not jar the observer's memory of the thousands of normal hands he has seen, thus taking advantage of the tendency of the human mind to accept as real that which it has no reason to believe is synthetic (page 55).

The match, or mismatch, between a normal hand and a cosmetic one is, of course, important. Primarily, it is important because an unaccustomed, extreme difference in coloration triggers the mind, causing it to search after the reason for the disturbing situation. Fortunately, two factors allow for latitude in pairing a normal and a cosmetic hand. First, color mismatch may occur even in normal pairs of hands. Differences in hand color may be produced, for example, by holding one hand above the head and the other at the side. Yet when the two hands are brought together the mind accepts them both as real despite the color difference. Second, the amputee does not often position his normal and cosmetic hands in such a way that direct comparison is invited. In fitting a cosmetic hand to a unilateral amputee, the closest match possible is of course desirable, but considering the changeability of the normal hand and the latitude afforded by the toleration limits of the observer's mind the concept of a limited number of colors is justifiable.

One cannot consider realistic coloring of a glove as a problem divorced from such contributing factors as the shape and form of the hand to which it is applied, the texture of the surface, or even the realism of the movements of a mechanical hand. For instance, in the compounding of colors for duplication of a particular skin tone, it has been observed that it is difficult to achieve a feeling of lifelike color on flat surfaces. If, however, the color is applied to a plastic model of the correct hand shape and texture, the feeling of realism is increased.

Use of such articles as rings and watches also may affect the degree of realism the glove achieves. One odd effect noticed, even in people who are quite familiar with the cosmetic glove, was the reaction to a glove on which a *Band-Aid* was used to cover a tear in one of the fingers, the *Band-Aid* creating a still greater realism. Perhaps even a more realistic effect could be achieved by painting in a cut or scar. Seemingly, the problem of cosmetic restoration involves building into the glove realistic situations and removing those factors unacceptable to the mind's concept of "normality."

THE COLOR SURVEY

To select hand colors that would satisfy the greatest number of amputees, the dorsal surfaces of the hands of 175 Caucasian and 175 Negro subjects were examined with a Hunter Color-Difference Meter *(8,13),* a tristimulus color comparator. The device gives a uniform measure of the visual perceptibility of color differences and describes color in terms of three numbers that can be converted to the standard ICI specifications *(11)* by a series of linear equations *(8).*

On the basis of the results of these measurements, a statistical analysis of the data was made. Considering the proportion of amputees to be fitted by a specific shade, the economic feasibility of supplying cosmetic gloves in a number of shades, and the required closeness of color match, it was decided that six shades for Caucasians and six for Negroes would be satisfactory. The calculated colorimetric values are shown in Table 1, where the color characteristics represent the average integrated color taken from a circular area, totalling 1.5 sq. in., in the middle of the dorsal surface, this particular area being selected because it is thought to be of prime visual importance with regard to color.

As one progresses visually from shade 11, the lightest of the Caucasian colors, to shade 16, the darkest, the appearance of the hand changes from that of a pale, light skin to that of a dark, ruddy skin (Fig. 3). Similarly, shades 21 through 26 vary in appearance from what usually is considered light Negro skin to dark Negro skin. Interestingly enough, the hue, represented by dominant wavelength values, overlaps considerably in Negroes and Caucasians, and the data thus seem to be in agreement with the conclusions of Edwards and Duntley (7) to the effect that the skin pigments responsible for pigmentation in the dark races also are responsible for pigmentation in the white. The calculated values shown in Table 1 also agree essentially with measurements made on Negro and Caucasian hands by Heer and White *(12)*, who used a General Electric recording spectrophotometer.

Table 1

COLORIMETRIC VALUES FOR CAUCASIAN AND NEGRO SHADES

Race	Shade No.	Brightness[a] (Value)	Dominant Wavelength[a] (Hue)	Purity[a] (Chroma)
Caucasian	11	31.8	587.3	23.7
	12	28.3	587.3	26.0
	13	25.8	587.3	26.8
	14	23.3	588.6	29.0
	15	20.8	588.6	29.3
	16	17.8	590.0	31.7
Negro	21	14.5	586.9	45.2
	22	12.4	587.3	43.2
	23	10.4	587.3	41.7
	24	8.6	589.6	38.0
	25	7.2	590.0	37.0
	26	5.8	594.3	32.4

* The terms "brightness," "dominant wavelength," and "purity" represent colorimetric values describing appearance in diffuse daylight *(11)*. They correspond roughly to value, hue, and chroma, respectively, found in the Munsell system of color nomenclature *(14)*.

Of course, cosmetic gloves would not appear lifelike if they were simply painted homogeneously with pigments having the required color characteristics. It is necessary for the artist to reproduce the required shade as convincingly as possible. For example, it appears advantageous to tint the glove on the inner surface, so that colors are seen through a layer of material, thereby giving the illusion of depth. Furthermore, the pigments should be applied in a heterogeneous manner to emulate that found in the human skin. The local color of knuckles and veins must be placed in the respective areas, half-moons and fingernails must be painted, and, where necessary, freckles and other fine details must be incorporated.

LIGHT AND COLOR

Caucasian and Negro cosmetic gloves carefully tinted by a competent artist to the color specifications recorded in Table 1 appear realistic in daylight. But as the kind of lighting changes *(i.e.,* from daylight to artificial) glove color, especially in the Caucasian shades, varies in a manner different from that seen in human skin. Indeed, under some kinds of artificial light the cosmetic glove may appear unrealistic or even "dead." Hence it is not enough to provide a color match that appears real under one kind of lighting only. The cosmetic glove must be so tinted that it appears to change color in the same manner as does the human hand. Thus, colorwise, a lifelike cosmetic glove could be defined as one that has a distribution of pigments equivalent to that of human skin and whose over-all color appears to change precisely as does that of the natural skin under all types of illumination.

To achieve such a result, it is necessary first to examine the spectral reflectance curves of human skin and to compare these curves with those of the tinted cosmetic gloves currently available. The curves in Figure 3, obtained from measurements made with a General Electric recording spectrophotometer, are profiles of the amount of light reflected by the hand or glove at each wavelength in the visible range, *i.e.,* from 400 millimicrons (violet) to 680 millimicrons (red). It is apparent that the reflectance curves for the three Caucasian subjects are markedly different in shape from those for the present Caucasian cosmetic gloves. None of the absorption characteristics of reduced and oxyhemoglobin in the region of from 520 to 540 millimicrons are observable in the tinted gloves, and none of the gloves show the sharp increase in reflectance in the blue and red regions. Notwithstanding the fact that the present Caucasian gloves may match human skin in brightness, dominant wavelength, and purity when viewed under ICI Illuminant C *(i.e.,* diffuse daylight), it is clear why they may not match at all under other viewing conditions, such as when illuminated by incandescent or fluorescent lights.

The spectrophotometric curves for two Negro hands and for two Negro gloves also are shown in Figure 3. In this instance, because of the high concentration of melanin in Negro hands (7), the absorption bands due to oxy- and reduced hemoglobin are obscured, and the curves show a steady rise in the amount of reflected light from the violet to the red regions. The curves for the Negro gloves have essentially the required shape and should be a fairly good match for the human counterparts over the whole wavelength range, a fact that has been borne out by experience.

The question now arises as to what can be done to make the spectrophotometric curves for the Caucasian gloves coincide in shape with the curves for the normal skin. The problem could, of course, be solved simply if the skin pigments were available in sufficient quantities and if they were sufficiently stable in the plastic medium for use in tinting the cosmetic glove. But such is not the case. The solution to this aspect of the problem lies in combining specific pigments in such a manner that the shape of the skin curve is duplicated precisely. To date, a large number of commercially available pigments have been examined for their spectrophotometric properties. Exact spectrophotometric duplicates of the skin pigments have not been found, but, by making judicious combinations of several pigments, representative curves duplicating that of living skin have been achieved to a reasonable degree. Such a curve is shown in Figure 4. It remains, however, for this or similar pigment mixtures to be applied to gloves in order to produce a number of shade guides that will satisfy the amputee population.

COLOR AND GLOVE MATERIAL

It appears that in the not-too-distant future synthetic pigment mixtures will be available for achieving color realism in cosmetic gloves. Unfortunately, the pigments themselves represent only one aspect of the materials problem associated with color realism. Another important factor is the permanence of the plastic

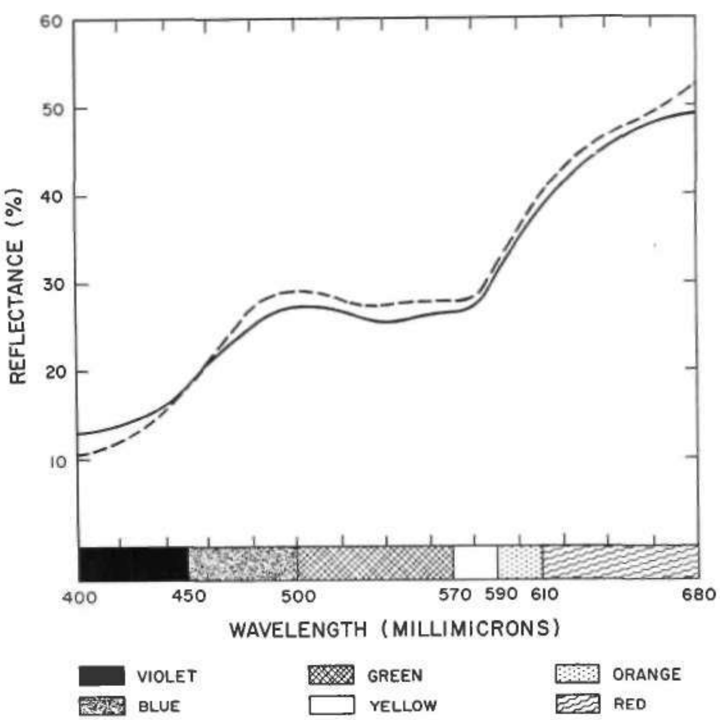

Fig. 4. Actual reflectance curve of the dorsal skin of a Caucasian hand (solid line) and of an experimental synthetic pigment mixture (dashed line).

material. Even if it were possible to fabricate a precise skin duplicate in the form of a cosmetic glove, unless the glove retained its proper color for a reasonable period of wear it would not merit serious consideration. A satisfactory glove must therefore be made from a material that remains stable colorwise when exposed to conditions of amputee use.

Such an application requires, in effect, a super skin. Human skin itself is far from permanent. Its apparent permanence stems from its ability to regenerate itself continuously. Thus living skin may be stained, burned, scarred, torn, cut, or otherwise generally maltreated. If the damage is not too severe, the whole skin is, after a lapse of time, once again renewed, and substantially the original appearance is restored. No such regenerative process characterizes inanimate materials. Artificial skin must have intrinsic resistance to staining, outdoor exposure, tearing, and so on. Stains that cannot be removed, and degradation evidenced by yellowing, reddening, and gradual over-all darkening and graying, obviously affect glove realism adversely. Fortunately, laboratory methods are available for determining the rate of degradation of plastic materials, one such method of evaluation being shown in Figure 5.

With respect to color, the materials problem involved is one of major importance, and it is therefore necessary to inquire into the factors producing irremovable stains, degradation, and yellowing. As for stains, it is to be noted that the commercially available plasticized polyvinyl chloride glove contains approximately 50 percent of a solvent-type liquid plasticizer, included to impart the necessary flexibility. Because of the presence of the plasticizer, staining agents are adsorbed at the surface and then diffuse into the glove material. Thus, to enhance the stain resistance of a cosmetic glove, it would be desirable to eliminate plasticizer—if not completely then at least on the surface subject to staining.

Two factors may contribute to the phenomenon of gradual discoloring. For one, inadvertent rubbing against objects may result in plasticizer (and perhaps stabilizer) extraction from the glove and/or absorption of colors from the objects. For another, oxidative degradation also probably plays a part in discoloration. Plastic materials that are chemically unsaturated, or those having labile chemical groups, are most susceptible to oxidative degradation. Thus, a material should be chosen that is chemically saturated and free from labile chemical groups.

THE FUTURE IN COSMETIC GLOVES

Once realistic pigment mixtures and a stable, stain- and discoloration-resistant plastic medium can be specified, the manner in which these materials are to be mixed and molded to achieve optimum effect becomes important. This phase of glove development still is largely a matter for conjecture. At present, the glove is cast, reversed, and pigmented on the inner

Fig. 5. Apparatus, consisting of ultraviolet lamp and turntable, for determining color fastness of pigments and degradation of plastic materials under exposure to simulated sunlight. *Courtesy Army Prosthetics Research Laboratory.*

surface to give the illusion of depth. Perhaps a more realistic effect could be obtained by using a compounded dispersion of pigment in a diversified multiple laminate to provide a compatible filter medium consistent with the reflectance characteristics of the individual color, thus emulating the character of the living skin. Or perhaps certain of the pigments could be dispersed in the plastic medium itself, the glove reversed, and the inner surface pigmented by the present technique. Research to produce gloves of increased realism colorwise continues therefore along three major lines—application of pigment mixtures that will reproduce the spectrophotometric curves of skin more closely than do the present colors, development of a material exhibiting a high degree of resistance to staining and discoloration, and, finally, development of techniques for combining these materials in such a way as to give optimum realism.

Whatever the final materials and techniques selected, assurance must be had that the cost of the glove will be such that it can be purchased by most of the amputee population. As opposed to the idea of custom-made gloves, commercial production of gloves at a reasonable price poses a challenge for those involved in achieving glove realism. Although there must be no sacrifice of ultimate realism to economic necessity, unit cost is an unavoidable consideration. The ultimate goal is a product of first-rate quality at a reasonable price.

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The Choice of Terminal Devices

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SINCE the chief purpose of all other components of the upper-extremity prosthesis is to make it possible for the terminal device to be operated effectively, the hook or artificial hand is considered to be the most important component of any artificial arm. The terminal device (or devices, since they can quickly be interchanged for a given individual) plays the decisive role in determining the functional and cosmetic value of the prosthesis to the wearer. Of considerable importance, therefore, is a knowledge of the process by which the terminal device is chosen from among the many types available commercially *(19).* But the criteria for selection and prescription of hooks and hands present a confusing picture and often are difficult to isolate. Some amputees, because of long-standing habit, resist change and retain the hook or hand with which they were first fitted. Others rely on the advice of well-intentioned friends, who also may be amputees, and make frequent changes in the attempt to find what does not exist—the *completely* satisfactory device. Perhaps the largest group depend upon the prosthetist for guidance *(14).*

With the recent development of prosthetics clinic teams, usually consisting of a physician, a prosthetist, and a therapist *(3),* the tendency is for more and more amputees to have their terminal devices prescribed for them. Although the prescription of terminal devices by the clinic team is clearly the most desirable method, certain aspects of this process are confusing too because different clinic teams pursue different lines of thought in making decisions. Some clinics concentrate on occupational factors and attempt to prescribe in terms of success on the job. Other groups rely heavily on the amputee's personal preferences, while still others make their choices largely with regard to site of amputation, believing, for example, that a long-below-elbow amputee should be prescribed one terminal device, a medium-above-elbow amputee another.

Finally, many clinic teams have developed, through experience or persuasion, other relatively fixed preconceptions with regard to terminal devices and prescribe within the framework of established biases. Among these are a preference for canted hook fingers as opposed to straight fingers (or vice versa), a preference for either steel or aluminum construction, a preference for voluntary-opening as opposed to voluntary-closing (or vice versa), a distaste for artificial hands as being functionally of little or no value (rarely the reverse), a preoccupation with the desire to prescribe low-cost items (also rarely the reverse), and preferences or dislikes based on other specific features.

This discussion is not intended to be all-inclusive, nor is it meant in a critical vein. Its purpose is simply to illustrate the difficulty of reaching a valid decision in the prescription of a terminal device and to highlight the divergent opinions extant today. An attempt is made to explore the factors involved in the proper choice of a particular terminal device for a particular amputee.

To arrive at the best choice of a terminal device for a particular amputee involves a number of considerations. First, perhaps, are the psychological needs of the individual. These arise from a complex of the intangible judgments, desires, motivations, and preju-

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dices which lead an amputee to prefer certain characteristics of one terminal device over those of another. Then there is the nature of the environment in which the prosthesis is to be used, including the vocational and avocational considerations as well as the various requirements of daily living. And finally biomechanical (anatomical and physiological) characteristics may help to determine an amputee's capacity to use a particular terminal device. What bodily functions remain, and the degree to which these functions are useable, may both influence the selection of terminal devices. Such considerations, taken as a whole, compose the basic knowledge upon which a system of differential prescriptions may be developed.[3]

PSYCHOLOGICAL CONSIDERATIONS

On the basis of personal or psychological considerations, individual amputees express varied individual attitudes toward the function, appearance, and durability of terminal devices. Not infrequently these feelings are outgrowths of the experience of amputation itself and are related to problems of later psychological adjustment.

ATTITUDES RELATED TO APPEARANCE

Appearance probably is one of the first things that a patient thinks about after amputation. He questions what he will look like, what he will be able to do, and what people will think of him. Thus the appearance of a given terminal device can be a critical factor in its acceptance or rejection. Several studies have dealt specifically with the all-important role of cosmesis in prosthetic replacement, including the psychological dynamics of the process *(11).* Because these matters are discussed ably by Dembo and Tane-Baskin (page 47), they need not be elaborated upon here. But several other aspects of the problem may be considered.

[3] Throughout this paper the discussion applies primarily to the unilateral, upper-extremity, adult amputee. Several of the points made cannot, and should not, be considered as having validity for the special prosthetic problems of children, bilaterals, or cineplasty amputees.

The only means of satisfying the need for acceptable appearance by the upper-extremity amputee is to use the so-called "cosmetic hand," that is, a hand that approaches the configuration, texture, and color of the norma] hand. But to produce from inanimate materials a satisfactory mate for the normal hand involves a series of compromises. To the requirements of form and appearance add the need for adequate prehensile function and the necessity of manufacturing the device at a reasonable cost (which requires mass-production techniques, thereby making true custom-matching impractical), and any idealized prosthetic replacement becomes an impossibility *{5,10).* The problem, therefore, is to provide a relatively inexpensive terminal device having the general appearance of the remaining hand and possessing as much prehensile function as possible without too much sacrifice of cosmetic properties. The APRL No. 4C hand (Fig. 1) approximates these requirements *{5,10),* and improvements may be expected with the years. In terms of appearance, however, such artificial hands can never hope to be more than an approximate match for the normal hand. At best, an artificial hand can serve to disguise the fact of amputation from passers-by and casual contacts with whom intimate association is not intended.

In view of these circumstances, each amputee is faced with a psychological adjustment process when he first wears a prosthetic hand. The adequacy of his adjustment depends on his personal concept of how well the cosmetic hand matches the normal and on the extent to which he feels any differences are noticeable to others. Depending on the strength of these feelings, so-called "acceptance" will or will not be achieved. Moreover, each amputee must choose what is, for him, the best combination of functional replacement and cosmetic appearance. Because each terminal device is, by design, a compromise between these two factors, some devices emphasize cosmetic appearance at the expense of function, and vice versa. The final selection by the amputee reflects his intuitive weighting of these two features.

Although the problem of hand cosmesis has received considerable attention, and although the functional implications of hook-finger

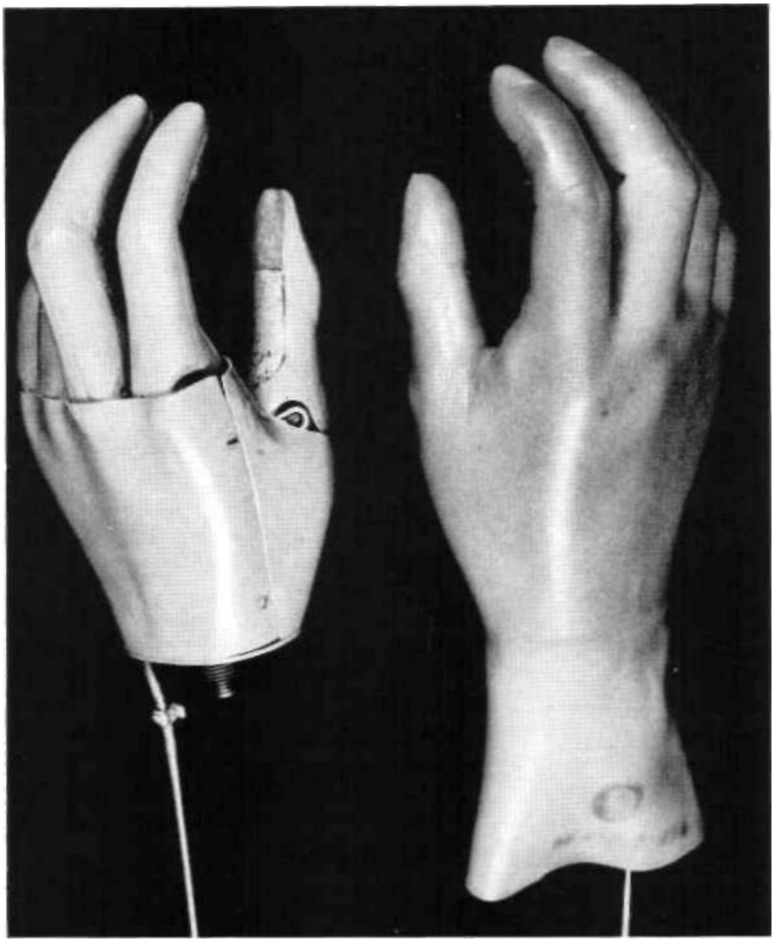

Fig. 1 The APRL No. 4C voluntary-closing artificial hand, with and without cosmetic glove. *Courtesy Armed Forces Institute of Pathology.*

either to amputees or to the public, the finish of hook fingers and case, as regards both color and texture, might very well undergo serious investigation.

That color and texture might be important considerations has been highlighted by the excellent reception accorded the child's prehension device in which the metallic core of the hook fingers has been covered with a flesh-colored plastic (Fig. 2). Some additional support for such procedures may be drawn from the field of dentistry, where, if the prosthetic restorations are to be visible, increasingly greater use is made of acrylics rather than of metals. Some preliminary studies of this matter are being started by the Prosthetic Devices Study, New York University.

If careful attention is being directed to the appearance of the terminal device, it seems equally important that care also be exercised in the choice of descriptive terms used to identify it. The prosthetic replacement for a missing hand generally is termed a "hand" or a "hook." Whatever this second device may be in fact, it is described by a word that, to many, raises questionable if not negative feelings. The word "hook" brings to mind such ideas as stevedoring, Captain Hook, catching fish, gang warfare, and unsuccessful vaudevillians. As a matter of fact, Merriam-Webster defines "hook" by using the following words: "snare," "trap," "catch," "seize," "hold," "gore," "pierce," "steal," or "lop off," as with a sickle.

shape have been studied extensively both within the Artificial Limb Program and by others, little has been done thus far with reference to alteration of hooks for cosmetic purposes. Co-workers in the engineering sciences advise that the fundamental geometry of hook fingers cannot be altered very radically without sacrificing some of the fundamental functions of holding, pushing, pulling, and hooking *(17)*. But to date there has been no inquiry into the matter of external coloring, texture, and finish of hook case and fingers. While there is no experimental evidence to the effect that the metallic finish in current use is objectionable,

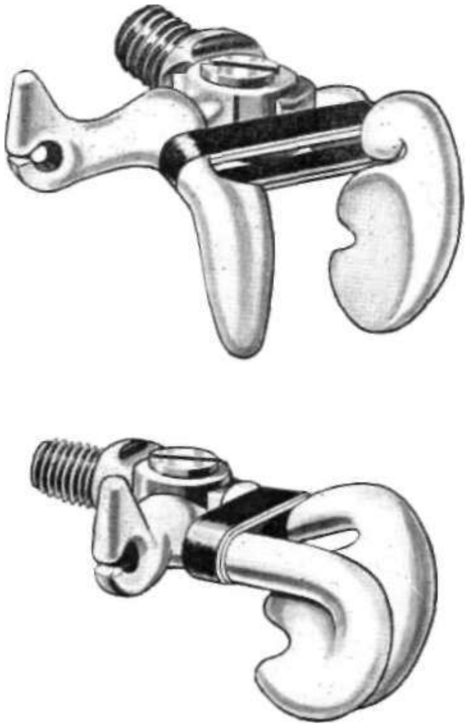

Fig. 2. The child's wafer hook, a Dorrance voluntary-opening device as modified at the Army Prosthetics Research Laboratory. The hook fingers are covered with a flesh-colored plastic molded in a special configuration. The plastic helps to protect both wearer and associates and provides more acceptable appearance as well.

Of course none of these synonyms are very pleasant. Viewed in the context of an individual who has the anxieties and other problems concomitant with amputation, the meanings of words take on a particular significance. In such a situation, the words used in communicating with the patient are most important to his welfare. It does not seem likely that most amputees look forward expectantly to being provided with a "hook," and therefore whatever can be done to provide this device with a more satisfactory identification would seem to be in order. Unfortunately, no concise, euphonious name comes immediately to mind. The somewhat longer, generic term "prehension device" has been suggested.

ATTITUDES RELATED TO FUNCTION

One of the most important requirements of a terminal device is reliability, so that the wearer may consistently perform specific activities successfully *(8,10)*. As use of the device can approach the level of automatic behavior, as performance becomes more subconscious and can be accomplished with less awareness, the amputee approaches an important goal of personal readjustment. The extent to which an amputee is motivated to apply himself toward achieving this goal is a second determining factor in his use of a terminal device.

Just as the human hand reflects personality by the way in which it is used, so the use of a terminal device depends upon the personality of the wearer. Although the manner in which the terminal device is used is by no means as sensitive an indicator of the individual personality as is the human hand, nevertheless, in a gross sense, patterns of use of the terminal device reflect the personal needs of the wearer. One amputee, for example, may use his device in a restricted and limited way, perhaps as a paperweight, while depending chiefly on his normal extremity for general function. Such behavior may be motivated by the fact that he is rejecting himself as an amputee and does not wish to give further thought or effort to the problem of readjusting to his amputee status. Or perhaps he may not desire better prehensile function because he has shifted his performance patterns to the normal extremity and has become accustomed to the awkwardness and inefficiency of one-handedness.[4] In a similar situation, another amputee may be determined to master his prosthesis because he has become aware of his problem and of the advantages of two-handedness; he works to achieve a more normal type of prehension pattern. Once having been shown the advantages of the added utility and grace concomitant with expert prosthetic usage, addi-

[4] This is, in effect, the same type of behavior pattern found in the two-handed person who prefers to continue with the inefficient hunt-and-peck system of typing rather than expend the effort necessary to learn touch typing.

tional function is developed through continued use of the device.

In both instances, particular personality traits come into play—concentration, patience, vanity, drives of all sorts, reactions to pressures and frustrations, and so on. And although it would be desirable to be able to relate these personality traits precisely to specific types of terminal devices *(e.g.,* the more functional devices with careful, neat, orderly people and the less functional, simpler devices with less demanding, more easygoing people), it is, at present, impossible to do so. Nonetheless, as studies proceed, the relationship between terminal-device usage and the psychological needs of the wearer will become increasingly clear *(2,4).*

PSYCHOLOGICAL INFLUENCES ON DURABILITY

At the present stage of development of terminal devices, one of the major determinations necessary in prescription relates to durability in various occupational or avocational activities. It must be remembered that people differ in the care they give material things. Hammers, chisels, saws, automobiles, and prostheses, all of which are extensions of an individual's capacity for work, are handled very differently by different people. One person performs the duties of a steel puddler with greater gentility and care than another man uses when he repairs fine watches, and this difference is reflected in the use of their tools. Although the comparison is perhaps overdrawn for purposes of emphasis, the point is nevertheless true over a wide range of activities.

Similar considerations hold for terminal devices. Hence, reinforced steel terminal devices are destroyed quickly by some amputees; lighter, less durable terminal devices afford the careful amputee adequate usage over a long period of time. In an attempt to determine the causes of malfunction and breakage, the common approach is to look into *what* a man does. The important factor may instead be *how* he performs various activities. Although the importance of the first consideration should not be discounted, the second factor may be of even greater significance.

The way in which a task is done is clearly related to the performer's attitudes. With specific reference to amputee attitudes, it should, of course, be borne in mind that considerable aggression may be displaced toward prostheses and in turn referred toward terminal devices *(8,16,20).* In an effort to release some of the anger generated by amputation, the wearer may impose considerable maltreatment upon a terminal device. Actually a certain amount of secondary gain also is involved in the attention received when it is necessary to have the device serviced (*1*). Consequently, a second motivation exists for maltreatment of terminal devices. Until improved understanding as well as better prognostic measures of psychological mechanisms are available, prescription will have to depend partly, as it does today, upon the type of occupation and avocation in which an individual is engaged *(9).* Even when these limited criteria are used, however, it is important to know something more of the precise activities to be performed than is ordinarily the case.

ENVIRONMENTAL CONSIDERATIONS

The major day-to-day activities of amputees, just as is the case with normals, involve relations with other people, vocational pursuits, dressing and eating, personal hygiene, and recreational activities or hobbies. In the matter of interpersonal relationships, the cosmetic features of the terminal device probably have the major influence on the reaction of other people to the amputee. This is certainly true of the general public *(11),* though perhaps less true of an amputee's family and intimate friends.

HAND OR HOOK

Because cosmetic appearance is important, it seems reasonable to ask why, up to the present, most amputees have been hook wearers rather than hand wearers. One reason for this situation seems to lie in the personal preferences of some amputees who express distaste for the deceit they feel is involved in disguising an amputation with a cosmetic hand. This is true of a relatively small group, but a much more important reason lies in the widely held belief that, although a hand has cosmetic advantages, it has little or no functional value.

It is doubtless true that a hook can do finer, more delicate work with its tip prehension, can hold some objects more securely, and can work in tight corners where a hand, by virtue of its bulk, cannot operate. In addition, the hook does not obscure vision as much as does the hand, an important consideration because of the absence of proprioception in the fingers of a terminal device. Despite these advantages of hook function, however, it must be pointed out that, since the advent of the APRL No. 4C hand *(5,6)*, many tasks can be performed more easily with a hand than with a hook *(13)*. Round objects, for example, such as a water glass or a soda bottle; long-handled tools such as a broom, shovel, or rake; and such items as paper, pencils, and telephones, to mention a few, can be grasped more securely with a hand than with a hook. The widespread notion that considers the hand as almost completely nonutilitarian is based on the fact that not until recently have artificial hands combined reasonable weight, reasonable ease of operation, good appearance, and satisfactory prehension characteristics. In raising the functional adaptability of the hand to the standard attained in the hook, the development of the APRL hand has gone much further than is generally realized. Future hand developments may very well complete the evolutionary process (5).

Even though the APRL No. 4C hand is the hand of choice, it can in no way be considered the ultimate. Among its shortcomings are the fact that it is available in one size only, that there is a serious tendency for the glove to tear and soil, and that maintenance requirements are greater than they should be. In spite of these disadvantages, the rate of amputee acceptance has been gratifying. In the field test of the APRL hand, 97 percent of the hand wearers and 84 percent of the hook wearers, or an average of 89 percent of both groups, found the device useful and acceptable. These general findings have been clearly verified by the upper-extremity field studies currently being conducted by New York University.

If such acceptance is possible under adverse circumstances, a truly superior hand should clearly be accepted and used by well over 90 percent of all arm amputees. As a matter of fact, if these data may be relied upon, it would seem that upper-extremity prescriptions of the future should properly include an artificial hand in every case except those isolated instances where peculiar psychological or environmental conditions contraindicate. Yet in all probability there will always be a need for the hook for specific occupational or avocational situations, as well as to satisfy the personal preferences of a limited sample of the amputee population. More and more, however, the hook will be thought of as a specialized tool to be used in specific situations, while the functional hand will be of sufficient versatility to be the device that is worn most generally.

Present information does not, for the most part, allow specific occupations to be related to particular hooks *(12,15)*, for, as already noted, the manner in which an activity is performed may be more significant than the nature of the activity itself. It is known, for example, that some amputees use their hooks as a pounding instrument, as a hammer, or as a prying lever. If these habits are well established, the physical characteristics of the terminal device must be such that it can withstand this kind of use. It is necessary, then, to determine whether the individual uses his hook as a tool or whether he uses it to hold tools. If the hook is to be used as a tool, simple steel hooks, such as some of those offered by Dorrance (7), should be prescribed. If it is to be used as the normal hand is used, the aluminum Dorrance hooks with rubber-lined fingers, the Northrop-Sierra voluntary-opening two-load hook *(5,18)*, or the APRL hook are, because of their more versatile grasping abilities, the devices of choice (Fig. 3).

HOOK MECHANISMS

From the standpoint of vocational usage, then, a primary distinction must be made in terms of durability, so that the device selected will withstand the use to which it is put. In making this distinction, the type of mechanism as well as the materials employed in the manu-

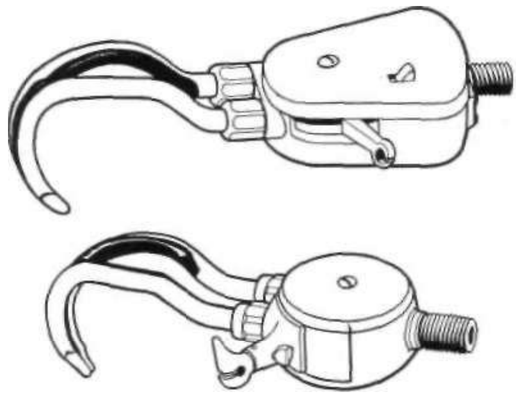

Fig. 3. The APRL voluntary-closing hook (above) and (below) the Norlhrop-Sierra voluntary-opening two-load hook. Both use rubber-lined, lyre-shaped hook lingers.

facture of the hooks are determining factors. Obviously, a hook having more complex mechanism and therefore more working parts (Fig. *4A)* will not stand up well under exposure to chemical action, extreme heat, or habitual use as a pounding or prying tool, whereas the simpler pincer type of design (Fig. *4B)* is relatively unharmed under any of these conditions. Once this major differentiation in terms of durability is established, a particular device can be prescribed with respect to the other features of the various devices available.

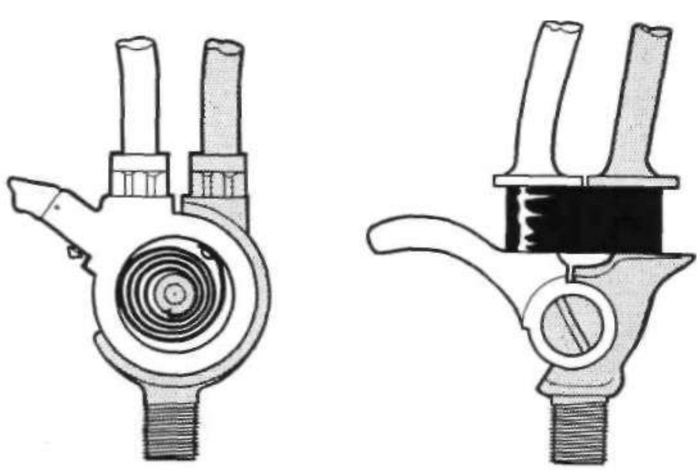

Fig. 4. Comparison of two types of voluntary-opening hooks. *A,* Northrop-Sierra two-load hook, with springs enclosed in housing; *B,* Dorrance hook, with exposed but easily replaceable rubber bands.

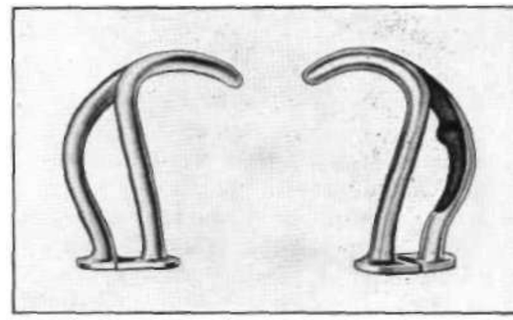

Fig. 5. Hook fingers of Dorrance design, with and without rubber linings.

RUBBER LININGS FOR HOOK FINGERS

Another feature which distinguishes between particular devices is whether or not they have rubber-lined hook fingers or metal contact surfaces, usually either ridged or corrugated (Fig. 5). Rubber linings were designed to provide improved frictional qualities. They do, in fact, afford a more secure grasp of such items as paper, glass, and other slick-surfaced objects. In addition, they permit grasp of some objects without danger of scratching or marring. Grasping abrasive or very hot objects, however, such as those a welder might handle, has a deleterious effect on the rubber. With the exception, then, of a few specialized occupations, the rubber linings are advantageous for the majority of amputees *(12).* It seems clear that consideration should be given to the development of a more durable material for finger lining so that its inherent advantages may be even more widely applicable.

SHAPE OF HOOK FINGERS

Finger shape is another general feature of terminal devices requiring consideration. Three kinds of hook lingers can be distinguished. They include the straight-approach, lyre-shaped fingers, such as those of the

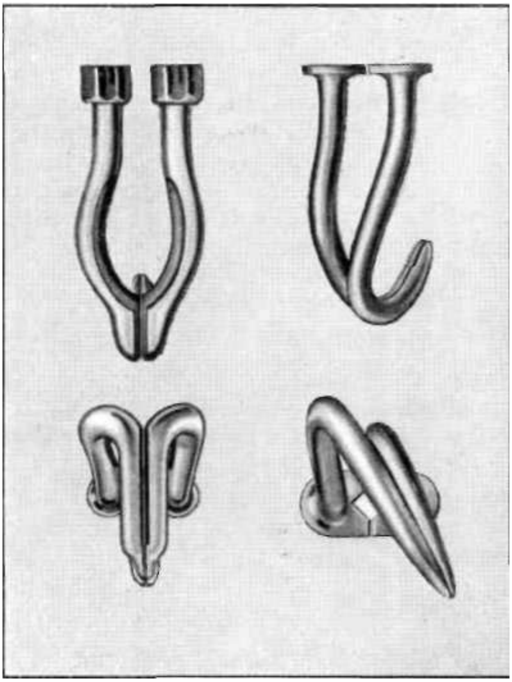

Fig. 6. Two views of straight-approach and of canted hook fingers. The straight fingers are exemplified in the APRL voluntary-closing hook and in the Northrop two-load voluntary-opening hook (5,6). The canted fingers are of Dorrance design

APRL hook (Fig. 3); the canted fingers, exemplified by the Dorrance No. 5 (Fig. 6), among others; and the specialized shapes, such as those found in the Trautman Locktite hook, for example, or in the Dorrance No. 3 (Fig. 7). Many amputees express a strong preference for either the lyre or the canted type. But these preferences are about equally divided between the two. Claims of advantages of one design over another appear to be based mostly on individual amputee experience. Present knowledge indicates that either type of finger can be used for most activities and that, in selecting a device, finger shape is not as important as are other factors.

With respect to specialized finger shapes, however, the situation is quite different. Knobs, projections, and finger geometry are designed so that these special hooks can be used with particular tools and for heavy manual labor. Farming and carpentry, for example, usually are considered to be occupations requiring such hooks as the Trautman or the Dorrance No. 3, No. 6, or No. 7. Although some amputees find these devices more satisfactory than others for individual needs, advantage in some particular function is achieved at the expense of ability to perform routine activities of daily living as effectively as with the other types of hooks. Hence, specialized designs should be prescribed only when vocational needs clearly warrant it.

VOLUNTARY-OPENING OR VOLUNTARY-CLOSING

Voluntary-opening and voluntary-closing systems comprise the last major distinguishing feature of hooks. Voluntary-closing terminal devices offer finer control of the grasping functions because, at the discretion of the amputee, the finger pressure applied to an object may range from extremely light to quite heavy, firm grasps. Combined with the self-locking feature, graded prehension makes voluntary-closing terminal devices valuable for many activities. But the versatility of voluntary-closing devices is achieved at the cost of a more complicated system of operation. In contrast, most voluntary-opening devices, though comparatively simple to operate, cannot lock on an object and do not offer positive control of finger pressure (page 88).

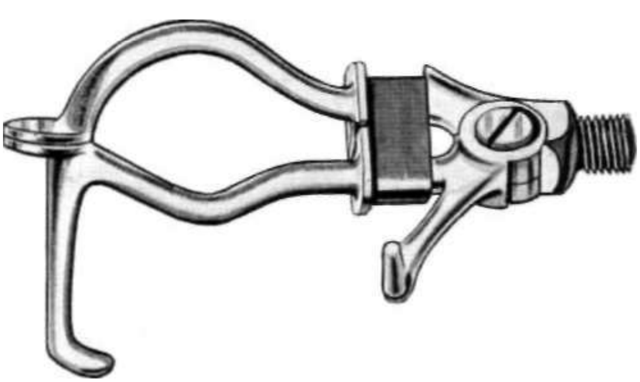

Fig. 7. The Dorrance No. 3 hook, a voluntary-opening terminal device of highly specialized design sometimes used by farmers, laborers, mechanics, and others engaged in various kinds of manual work.

Two points should be made regarding the voluntary-closing device. First, proper training is essential to effective utilization of the unique features offered. Second, amputees being fitted for the first time generally make excellent use of a voluntary-closing device because training is not complicated by habits acquired with a voluntary-opening device. Even considering the matter of durability, voluntary-closing devices, by virtue of their unique grasp features, are preferred to voluntary-opening models except where ingrained habit patterns and personal preferences contraindicate *(12).* But the present voluntary-closing hook has several disadvantages also. They include higher cost, excessive backlash on locking, frequent malfunction, and the cosmetic factors of bulk and length. Continued development may, however, eliminate these negative features and thus enhance the inherent advantages.

AVOCATION AND DAILY LIVING

Avocational pursuits and the routine chores of daily living also need to be considered under the broad heading of environmental influences. With respect to avocations, the situation is somewhat analogous to that of occupational considerations, in that the range of activities covered is extremely wide. In his leisure time the amputee may read books, hunt or fish, do carpentry work or gardening, play golf or bowl, or sit and watch television. The considerations already discussed apply equally to the vocational and avocational life of the amputee. All of which highlights the danger of selecting a terminal device without considering all of the patient's activities. It may be that the amputee's job requires one device, whereas a different device might best suit his recreational activities. These requirements can sometimes be met by the use of more than one type of terminal device.

In contrast to the requirements of vocational and avocational pursuits, the routine of daily living involves certain activities common to all amputees—dressing, eating, personal hygiene, reading and writing, and so on—generally light tasks requiring no great strength or exertion. Cutting meat with a knife and fork, for example, buttoning and unbuttoning clothing, handling a telephone and billfold, tying a tie and shoelaces, and handling and lighting cigarettes are tasks requiring, instead of strength and exertion, sensitive manipulation and a secure grasp. Although many amputees use voluntary-opening devices effectively, any or all of these activities usually can be performed better with the more versatile voluntary-closing type, either hand or hook.

BIOMECHANICAL CONSIDERATIONS

SITE OF AMPUTATION

Some attempt has been made to use site of amputation as the criterion for deciding between voluntary-opening and voluntary-closing devices. It is argued that the voluntary-closing hook or hand requires more control motions for performance of a given activity and that the higher the site of amputation the greater is the effort involved in making a control motion, particularly when the site is considerably above the elbow. The conclusion is drawn that, since operation of voluntary-closing devices requires additional control motions on the part of above-elbow and shoulder-disarticulation amputees, such devices should be prescribed chiefly for below-elbow cases. Although generally the premise is true, the validity of the conclusion depends on the answers to two questions. The first concerns how much extra effort is involved in the additional control motions, and the second relates to how much more effort is required for a given control motion by an amputee with a short above-elbow stump. In a word, the problem revolves around the effort tolerance of the individual and around the importance to the amputee of any increments in control effort. Present evidence does not answer these questions, and the factor of site of amputation has been, up to now, of limited value as a guide to prescription of a terminal device.[5] Perhaps further study will lead to the development of

[5] The one exception is the wrist disarticulation or the very long below-elbow stump, where for cosmetic reasons the site of amputation limits the choice of terminal device. In these cases, the device selected must be short enough so that the length of the prosthetic arm approximates that of the sound arm.

criteria for terminal devices specially designed for use with specific levels of amputation.

STUMP STRENGTH

Where lack of strength in the stump cannot be remedied by therapeutic measures, the weight of the terminal device becomes a matter of serious concern. When, in such cases, a hook is the device of choice, the lighter aluminum hooks should be selected in preference to the heavier steel hooks *(7,18).* With regard to hands, it may be noted that, although the lightest functional hand now weighs more than any one of the hooks, a hand is not necessarily contraindicated, since it may be of the greatest psychological importance in individual cases. If, however, arm amputees are to be provided with the most suitable hand, a lighter model is clearly required.

Of additional concern is the fact that strength must be considered in relation to the length of the stump. If the stump is very short, its resistance to the moment produced by the weight of some terminal devices may be marginal or inadequate. In that case, the weight of the terminal device again may be an important consideration even if good muscular strength is present. Parenthetically it should be mentioned that the voluntary-closing hook often is not prescribed because the one model available is heavier than most other hooks. It appears that consideration should be given to providing voluntary-closing operation in more than one hook size.

RANGE OF MOTION

Considered alone, range of motion may have no bearing on the selection of the terminal device because the excursion required for operation is approximately of the same magnitude for any hook or hand. Furthermore, in the case of most terminal devices, a reduced range of control motion, whether of the humerus or of the scapulae, usually can be compensated for (provided sufficient force is available) by modifying the lever ratio of hook or hand.

SUMMARY

Because, then, so many factors influence the prescription of a terminal device, the one chosen usually represents a compromise based upon consideration of the psychological, environmental, and biomechanical circumstances. Among the major psychological considerations is the fact that selection and use of a terminal device is obviously related to the particular personality needs of the individual amputee. But determination of the precise pattern of this relationship requires further research. Since a prosthetic hand is the only means of providing amputees with a "cosmetically satisfactory" appearance, such devices will be preferred by the large majority of amputees, especially as further improvements are made in design.

The cosmetic aspects of hook design have received insufficient attention, especially with reference to color, texture, and finish. Further, the matter of terminology deserves consideration. Because of its negative connotations, the word "hook" probably ought to be dropped from the vocabulary of prosthetics.

As far as function is concerned, reliable, automatic performance of the terminal device is of first importance to amputees. In any case, wearers of upper-extremity prostheses must necessarily accept a compromise between appearance and function, for there is no such thing as "ideal" replacement. The extent to which amputees can effect this compromise determines the degree of their acceptance or rejection of the terminal device. Finally, the durability of terminal devices is dependent more upon the psychological attitudes and adjustment patterns of the amputee than upon his occupational and avocational pursuits.

As for the major environmental considerations, it may be said that the APRL hand, despite limitations imposed by cost and maintenance, is considered a useful device which approaches, and even surpasses in some ways, the utility of a hook. The artificial hand should therefore not be thought of solely as a cosmetic, nonutilitarian device. But at present hooks are still of major utility and importance. In choosing a hook, the manner in which it is to be used, as well as the possibility of exposure to heat or chemical action, are the determinants in the selection of either a rugged, steel device with no working mechanism or a lighter aluminum one. When relatively careful use can be anticipated, so that durability is not a major factor, hooks with working mechanisms should be used because of their more diversified prehensile function.

Hook fingers with rubber linings are considered generally advantageous except when contact with objects prone to damage the rubber is anticipated. Consideration should therefore be given to improving the wear characteristics of finger linings. The distinction between canted fingers and straight-approach, lyre-shaped fingers is not especially important, since many amputees are proficient with both types. But finger shapes of odd or unconventional design should be selected with great care, since they are highly specialized and are not considered applicable to a variety of vocational, avocational, and daily-living activities. Although there are definite disadvantages in the present voluntary-closing hook, and consequent limitations to its prescription, this type of operation offers the amputee more versatile prehensile function than does any other hook. Accordingly, efforts should be directed toward providing voluntary-closing operation in several styles of hooks and toward eliminating troublesome maintenance problems with this type of mechanism.

Among the major biomechanical considerations are stump length and strength. Short or weak stumps usually require prescription of lightweight, aluminum hooks and hands. The importance of the weight factor indicates the desirability of developing lighter terminal devices, with particular reference to the functional hand. While biomechanical considerations play a major role in prescription of other prosthetic components, they appear to have no further influence on choice of terminal device.

In conclusion, it should be noted that the major factor restricting the search for knowledge and understanding of the principles involved in prescription and use of terminal devices is the limited number of independent design features that are built into any one terminal device. Since each variation in design is not available independently, neither freedom of prescription nor a complete analysis of the relative value of each feature is possible. Until this problem is resolved, systematic studies of the relationships between various terminal devices and the needs of individual amputees are seriously limited.

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The Principles of Artificial-Hand Design

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To REPLACE with a fully adequate substitute any living organ as complicated and as finely fashioned as the human hand is long apt to remain a virtually impossible task. The designer of hand prostheses must therefore accept at once the pre-established circumstance that, in any model he is likely to produce, he will be faced with the simulation of the infinite mobility of the natural hand but at the same time will be lacking the power sources, nervous sensitivity and subconscious reflexes evidenced in the natural mechanism. Since "hand replacements," even if possessing some anthropomorphic features, can scarcely be viewed as replacements in fact, they are inherently destined to have only the characteristics of tools designed to extend the usefulness of an arm stump.

Because in the present state of the art it is quite impossible to incorporate into a hand prosthesis more than a very limited number of the attributes of the normal (page 22), limb designers have always been called upon to select, from among all normal hand characteristics, those features whose loss is most seriously felt by the arm amputee. Among these, of course, are prehensile function, sensory and perceptual ability, and the cosmetic appearance of the hand itself, generally in that order of importance even in the unilateral below-elbow case and usually in the female as well as in the male. In almost all cases of upper-extremity amputation, the inability to grasp objects is the deficiency most keenly felt, and in bilateral cases the patient is thus rendered virtually helpless except insofar as other parts of the anatomy—particularly the stumps, the teeth, and the lower limbs—may adapt to some of the former functions of the hands.

Except in unusual cases, it is a comparatively easy matter to provide substitute prehension, for the several patterns of normal grasp (page 33) are all seemingly variations of a basic pincer action. This accounts for the more or less obvious development of the split hook, in a great variety of designs (page 72), to be powered by scapular abduction, arm flexion, cineplastic muscle motor, or other sources of force and excursion working in opposition to springs or rubber bands *(6,7,15,19)*. By virtue of its adaptability as a tool for a great many different kinds of activity, and with no serious limitations in form and appearance, the hook prosthesis has had a long period of yeomanship in the service of thousands of arm amputees.

Just as replacement of a basic, if crude, prehensile function offers the engineer no real problem, so also is it comparatively simple to fabricate a nonfunctional but realistic artificial hand. Thus reasonably faithful, passive hand replicas have been available for some time past. But to provide both hand form and hand function in one and the same hand substitute is an infinitely more difficult task. For reasons of limitations of power sources, of space for mechanisms, of available materials, of finger design, and of other matters, cosmetic appearance usually has been obtained only at the expense of functional adequacy, and vice versa. This circumstance accounts in part for the past popularity, still widely persisting, of hooks among arm amputees generally. Because such

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artificial hands as existed heretofore were either functionally deficient or cosmetically poor or both, a great many arm amputees found them more bother than benefit.

Although sensory perception may be considered by many arm amputees to be next in importance to prehensile function, it is unquestionably the one feature most difficult to provide in a hand substitute. If, to prehension and hand form, there be added the requirement of sensory perception at a reasonably satisfactory level, then the design of successful hand substitutes is again obviously complicated manyfold. That this is so is reflected in the fact that, for sensory control, the upper-extremity amputee even at the present time has still to rely on a combination of visual reception, audible clicks of various kinds purposely built into operating mechanisms, and a set of secondary neuromuscular cues to be obtained from shoulder harness, cineplastic muscle tunnels, pressure of the socket on the stump, and so on.

The normal hand has the inherent ability to relay, with no external assistance from the other senses, information about the shape, form, texture, and general physical condition of objects grasped. It can sense when contact has been made and what gripping force is in effect, and it has in addition an elaborate control mechanism with the ability to modify the force of grasp automatically as required to adjust for slipping or crushing. Besides this, the natural hand can report unassisted its own orientation in space. Present hand substitutes have no such self-contained attributes. Direct sensory control in either hook or artificial hand remains as a major challenge for the future in upper-extremity prosthetics.

Despite these recognized limitations, some very sound reasons can be set forth as to why hand design, as contrasted with hook design, deserves increasing emphasis. In comparatively recent studies with an improved functional hand *(12)*, it has been shown that a great many more arm amputees prefer a hand over a hook when the two are of reasonably comparable usefulness. Although it seems unlikely that the manipulative characteristics of artificial hands will any time soon attain the functional level possible in hooks, and although many amputees will no doubt continue to prefer hooks for many activities, there is a growing body of evidence that numerous patients would, for a number of reasons, prefer a functional hand for many occasions and, indeed, for a steadily increasing number of occupational pursuits. The data clearly suggest that the more realistic *and* functional a hand substitute can be made the more and the more often do amputees, and the general public as well, prefer artificial hands over the most pleasant-appearing hooks *(12)*. In these circumstances, earlier work in the Artificial Limb Program aimed at improved terminal devices *(7,19)* has been continued with increasing attention to the requirements of successful artificial hands. Out of this work has now come a set of design criteria based on fundamental investigations conducted largely at the University of California at Los Angeles and at the Army Prosthetics Research Laboratory.

THE REQUIREMENTS OF HAND DESIGN

The first and very obvious requirement placed upon the designer of a satisfactory artificial hand is that the exterior configuration must be such that the device cannot readily be distinguished from the natural hand. This limitation involves not only size and shape but external surface characteristics as well. Thus the second matter to consider is the method to be employed in arriving at lifelike appearance.

Within the limitations imposed by these two requirements, and considering the available sources of power and control, a choice must be made of the functions to be provided. How these functions had best be performed then requires adoption of a plan of digital mechanics that is operable within the limitations already established.

Finally, because so few sources of power are available for operation of upper-extremity prostheses, it is generally agreed that not more than one source should be diverted to hand operation. Because muscles are capable of producing tension only, the designer is faced with the fact that power from any single body source can be applied in one direction only. Thus, in the present state of development, power may be applied either to opening or to closing, but not to both.[3]

THE PROBLEM OF HAND SIZE

Careful observation reveals that the human hand varies greatly in size and shape from person to person and even within the same person. Hence it is clear that, if the hand requirements of the amputee population are to be satisfied, a spectrum of sizes of artificial hands has to be provided. How extensive the size range needs to be depends upon a number of factors. Since the custom design of individual hands for individual amputees, though possible, leads to high costs, and since in any case it has been shown *(13)* by Dembo *et al.* (page 47) that casual observers rarely detect small differences when objects approximate the appearance expected, it is first necessary to determine the minimum number of hand sizes that will provide an acceptable match for the natural hand of most unilateral arm amputees and that in the bilateral case will furnish a hand somehow "compatible" with body size.

But the problem of hand sizing is a subject that has generated more heat than light and one that is replete with pet theories. One reason for this situation is that the matter of hand sizing is extremely complex and subjective and that the factors contributing to size and appearance appreciation are elusive and undefined. It has been observed, for example, that two plastic hand models having precisely the same dimensions may, by varying the hand attitudes, be made to appear different in size. Furthermore, in a sequence of hand models of decreasing size, relocation of a model in the sequence, or changing its distance from its nearest neighbors, may seem to cause a change in its apparent size. Other factors, such as shape, skin detail, texture, knuckle and vein characteristics, and color, may contribute to over-all apparent size and appearance.

Various combinations of these factors lead to such generic terms for describing hands as "masculine" and "feminine" and to such specific adjectives as "large," "small," "stubby," "smooth," "gnarled," "bony," "graceful," "awkward," and so on.[4] The problem of hand sizing is therefore twofold—one relating to actual sizing, which may be described by numbers, and the other to appearance attributes, which may affect the apparent size but which presently are not amenable to quantitative description. In any case, the number of hand sizes to be provided is dictated by the distribution of sizes in the hand universe, by the closeness of the match desired, and by the commercial feasibility of supplying a given number of hand sizes.

Surveys of Hand Sizes

The first survey to size the prosthetic hand for male adults was made by Birdsell *(4)* of the University of California at Los Angeles. Undertaken from the viewpoint of the anthropologist, it was detailed and complete, some 26 hand dimensions of approximately 100 adults being reported. But the results indicated that the major dimensions (Fig. 1) showed a low degree of correlation. For example, a correlation coefficient r — 0.50 was obtained for hand length vs. hand breadth. This being the case, a single, basic hand dimension—hand breadth—was chosen, and all other measurements were regressed against hand breadth regardless of the size of the correlation coefficient obtained. By use of these methods, a systematic sizing schema was set up for the male adult hand.

From the adult mean values for hand

[3] Springs have generally been employed to provide the return action. Cineplastic muscle tunnels have been provided in the flexor and extensor muscles of the forearm in an effort to furnish powered operation in both directions, but these muscles inherently are lacking in sufficient force and excursion to provide adequate prehension *(3).* Furthermore, such an expedient would solve the problem in the wrist-disarticulation and long-below-elbow cases only The prospects now seem good that unidirectional power soon may be applied successfully both to opening and to closing. For a discussion of the so-called "reflex hand," see page 90.

[4] In the popular concept, perhaps the distinguishing differences between feminine and masculine hands relate to size, shape, and, possibly, to fingernail length. But as a matter of fact women's hands may be large or small, long or short, gnarled or smooth, graceful or awkward, and generally may have as prominent skin detail and knuckle and vein characteristics as those usually ascribed to men's hands.

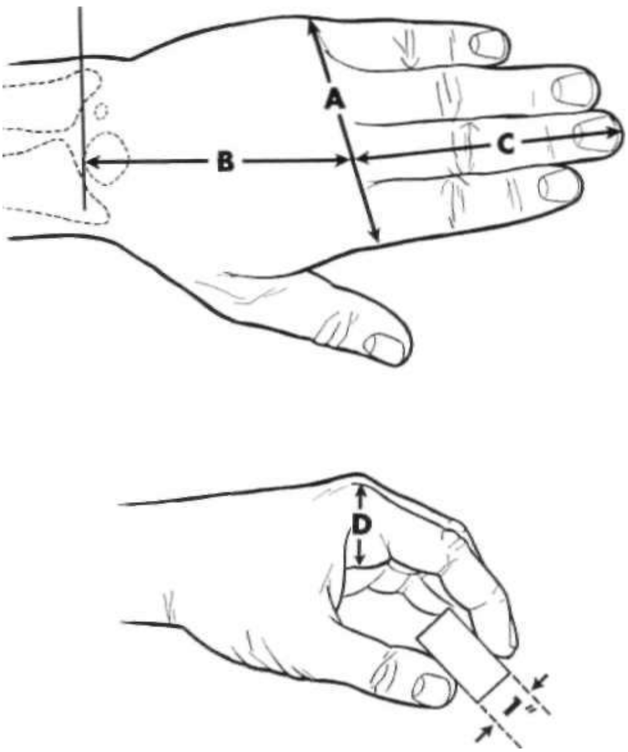

Fig. 1. Principal dimensions used in the study of hand sizes. After Birdsell *(4)*. Dimension *A* is hand breadth measured from the radial aspect of the second metacarpal head to the ulnar aspect of the fifth metacarpal head. Dimension *B* is dorsum length measured from the center of the proximal side of the lunate to the apex of the metacarpophalangeal joint of the third digit. Dimension C is the middle-finger length measured from the apex of the third metacarpophalangeal joint to the end of the third digit. Dimension *D* is the palm thickness.

breadth, dorsum length, middle-finger length, and palm thickness, taken from the Birdsell data, Gottlieb (8) calculated the ratios of hand breadth to hand length, dorsum length to hand length, middle-finger length to hand length, and palm thickness to hand length. The assumption, later proved not to be completely justified, was made that these ratios do not vary as a function of age, and, from previously published data *{14,18)* concerning juvenile hand length, Gottlieb was able to calculate average values for the various required dimensions of artificial hands for children.

In September 1954, DeFries (5) of the Army Prosthetics Research Laboratory, using the data of Birdsell for the adult male population, applying new hand-sizing data gathered by measurement of adult female hands and hands of children in the age groups 4 to 6 and 10 to 11 years, respectively, and using some of the methods suggested by Gottlieb, reported a sizing schema for prosthetic hands to satisfy the amputee population from children to adults. In Figure 2, which presents the distribution of hand breadths by population group, there is some overlapping between the large adult female hand and the small adult male hand, as well as between the large hand breadths of children in age group 4 to 6 and the small hand breadths in the age group 10 to 11. Similarly, there is a striking overlap between hand sizes of the adult female group and of the children 10 to 11 years old.

Number of Sizes Required

The target sizes for hand breadths of natural hands are indicated below Figure 2 by arrows pointing downward. The numbers of targets and their position in the distribution of the hand universe were selected by considering such factors as differences in hand breadths between normal pairs of hands, the number of amputees to be fitted by a given hand size, the rate of growth of natural hands, the importance of cosmesis within a group, and the commercial feasibility of supplying prosthetic hands in a number of sizes. Below the target sizes for the proposed hand breadths, indicated by arrows pointing upward, are the sites of the proposed prosthetic hand breadths. These represent the selected hand breadth of the natural hand less a factor designated as the "prosthetic illusion factor," an arbitrary number which is subtracted from the breadth of the natural hand. It is included because, from hand-fitting experience and impression rather than from systematic study, it is found

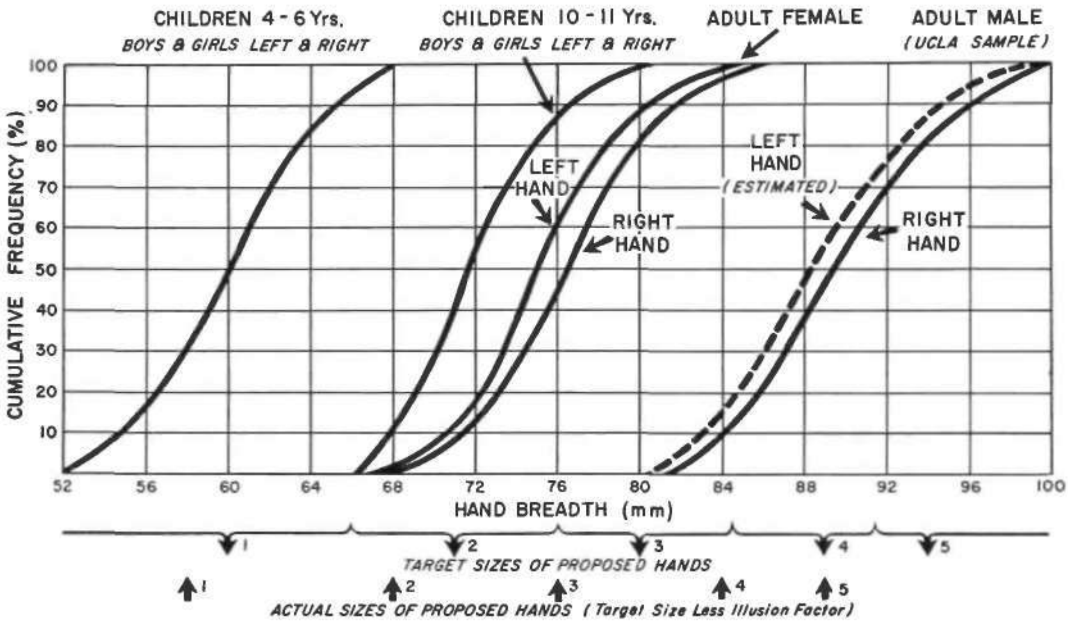

Fig. 2. Distribution of hand breadths by population group. After DeFries (5).

that for best results the prosthetic hand should be from a half to one and a half glove sizes smaller than the hand it replaces *(4).*

When the selected hand-breadth values are multiplied by the appropriate ratios of average middle-finger length to hand breadth and of dorsum length to hand breadth (Fig. 3), the desired dorsum length and middle-finger length are obtained, and the dimensions for five hand sizes may be detailed. It is interesting to note (Fig. 3) that the ratios of middle-finger length to hand breadth and of dorsum length to hand breadth increase with increasing hand breadth, indicating that adult hands have a tendency to be longer and narrower, children's shorter and wider, a result in accord with general observation and experience.

Construction of the Models

The determination of the required dimensions represents, of course, only a very early, toddling step toward the goal of achieving the five hand sizes. The next step is the construction of the physical models so that not only size but also shape and skin texture may be visually examined to compare subjective impressions. From experience with commercially available voluntary-closing hands and with experimental models, it is believed that optimum cosmetic shape is obtained if the hand shells are cast from the corrected impressions of living models. The problem, then, is to find a suitable, living hand model with the required attributes of size, shape, texture, and detail. Since the dimensions specified represent population averages, it would be fortuitous indeed to find living models whose hands had precisely the required dimensions in addition to the other appearance attributes.

Fortunately, techniques have been developed for making necessary adjustments in both size and shape after the original impression has been taken, thereby simplifying considerably the task of finding the model. Once a model is found to have the desired texture and approximate size, gross size changes may be made by solvent extraction of plasticizer from plasticized polyvinyl chloride films. This process was worked out in the laboratories, and inert but accurate hands (Fig. 4) were made for optical appraisal by a large group of experts in the prosthetics field.

THE PRODUCTION OF COSMETIC APPEARANCE

Over-all hand size is not the only measure of how large a hand mechanism may be, for the problem of producing satisfactory cosmetic appearance introduces another factor. It is difficult to conceive of a finish for metal, or other material hard enough and strong enough for an artificial hand, that would impart to the observer the texture, depth, variation in color, and other properties of the human skin. Experience teaches that the only practical means of attaining satisfactory cosmetic appearance is to cover the hand structure with a glove of some material which simulates the human skin both in texture and in color (page 57). Techniques have been developed for the manufacture of such gloves from plasticized polyvinyl chloride *(11).*

But the thickness of the glove material is dictated not only by physical properties such as tensile strength, elasticity, and resistance to snagging and tearing but also by the fact that the coloring is influenced by the thickness of material through which the color is viewed. A smooth-fitting glove must stretch when the hand flexes, and it has been established that ideally the force requirement due to stretching of the glove shall not be more than 1 lb. over that needed to flex the uncovered hand. Thus a successful glove must be comparatively thin. Yet it has been found that proper depth and other properties of lifelikeness are to be obtained only by tinting on the *inside* of the glove so that the color is observed through a thickness of the material *(11).* At present, optimum glove thickness is considered to be about 0.03S in. Thus the hand housing must be that much smaller than the over-all hand size desired.

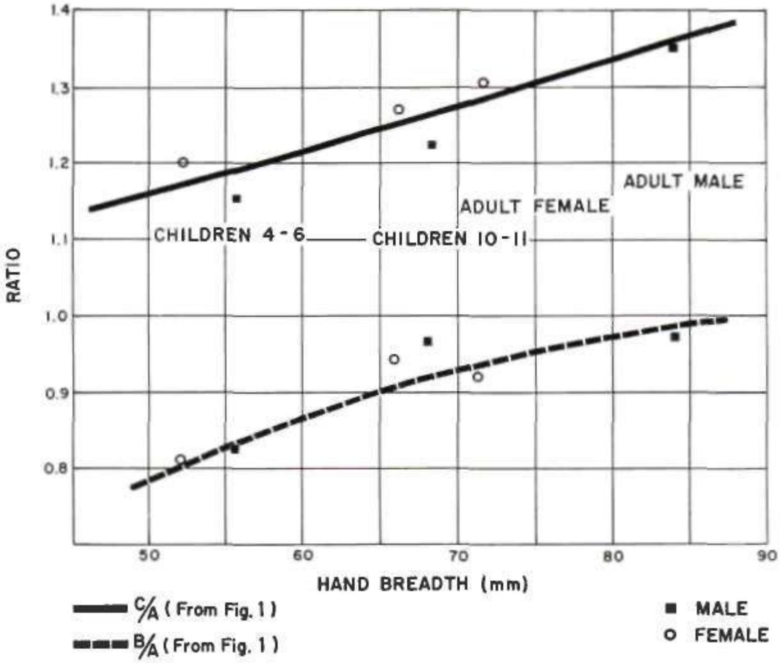

Fig. 3. Ratio of middle-finger length to hand breadth and of dorsum length to hand breadth from age four to maturity. After DeFries (5).

DESIGN OF THE HAND SHELL

If a single hand design is to be provided for all upper-extremity amputations, then, in order to accommodate the long-below-elbow and wrist-disarticulation cases, it is necessary to provide within the hand sufficient space for a mechanism or mechanisms.[5] But the forces involved in the hand are high compared with the size of the device, while at the same time space is extremely limited. Maximum volume for the installation of mechanisms within the hand can best be achieved by employing a thin-walled, hollow casting of the palm section (Figs. 5 and 6). Light alloys such as those of magnesium and aluminum have been employed successfully in this application using the investment-casting technique. Sufficient rigidity for the forces involved can be obtained in aluminum with a wall thickness of 0.035 in. Thus the net space available for mechanisms is the gross size of the hand less the thickness

[5] For amputation at other levels, mechanisms might be installed in the prosthetic forearm.

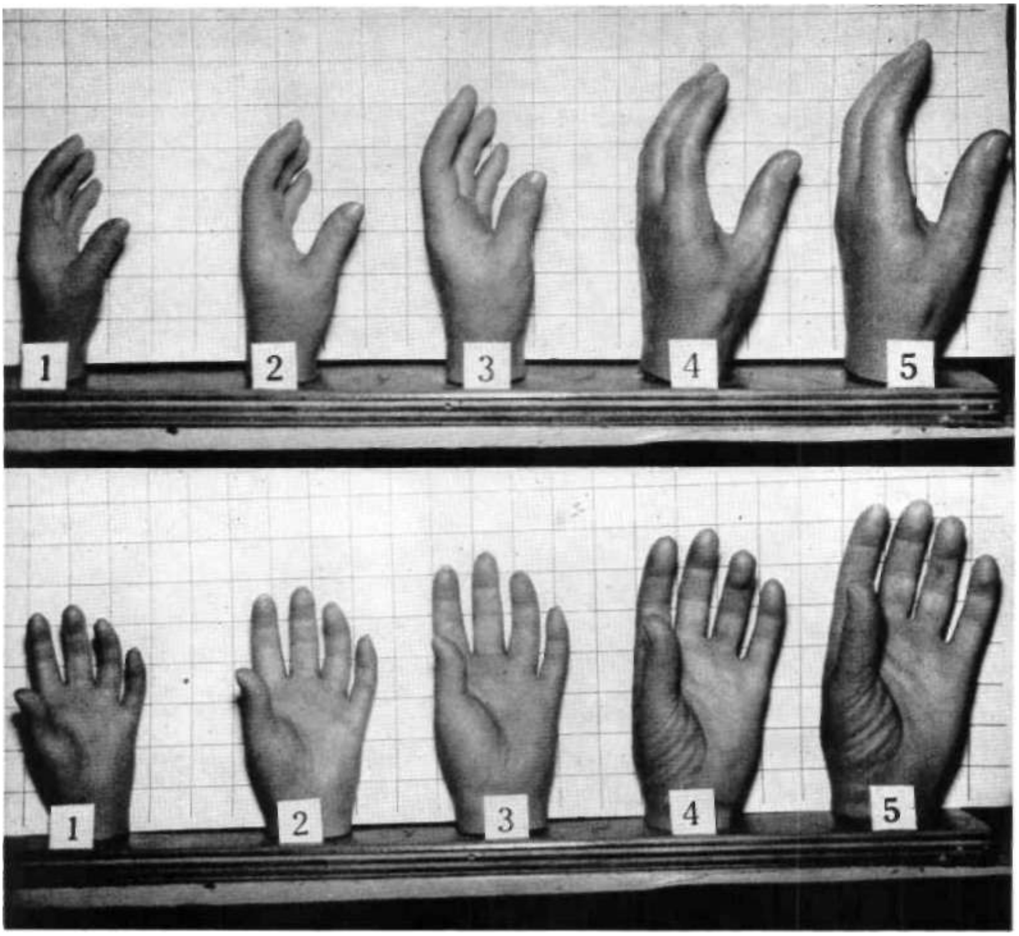

Fig. 4. Prototypes of the five hand sizes required to satisfy the population from age four to maturity. *Courtesy Army Prosthetics Research Laboratory,*

of the cosmetic glove less the thickness required in the hand shell.

Accordingly, after the hand models have been reviewed both objectively and subjectively, appropriate corrections are made, and electroformed molds are constructed and reduced by the thickness of the cosmetic glove. The molds then are cut on pre-established lines, again corrected for the mechanical considerations by establishing pivot bosses for the mechanism, assembled, tested for natural movement

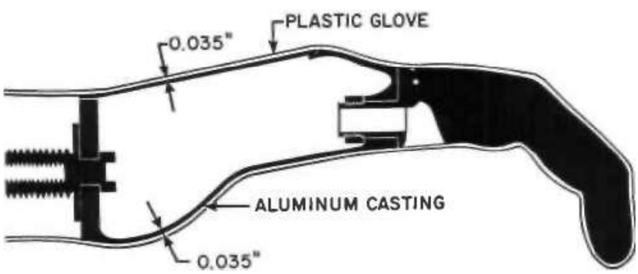

Fig. 5. Section through palm and middle finger of an artificial hand of monocoque construction. The technique of investment casting keeps the thickness of the hand shell at a minimum and thus provides maximum space for operating mechanisms

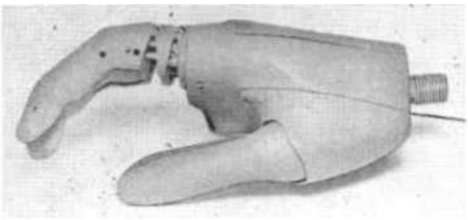

Fig. 6. Experimental hand with palm section of monocoque construction. The finger design shown, also experimental, is one of many tested. See Figures 9 and 10. *Courtesy Army Prosthetics Research Laboratory.*

and coordination with a glove, and used as patterns for the final castings at the foundry. The original molds from each of these hands are used as master molds, and duplicate or "use molds" are electroformed for production of the cosmetic glove, which will then fit the finished hand mechanism precisely.

PROBLEMS OF POWER AND CONTROL

Once the required sizes have been established for the hand shell, attention must be directed toward the choice of source of power and control because design of hand-operating mechanisms is clearly influenced by the amount of power and excursion available. Since certain levels of force are required in the prehensile mechanism, and since input and output are related through the mechanical features of the hand itself, the nature of the control forces must be known before mechanisms can be designed.

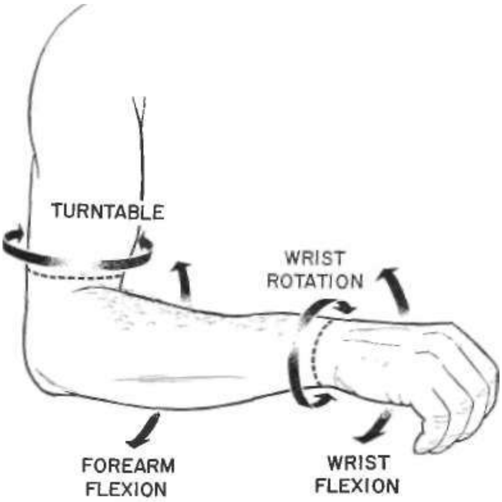

Fig. 7. Basic features of the arm as a device for positioning the hand.

At first thought it would seem a comparatively simple matter to simulate all the articulations represented in the metacarpal bones and the phalanges of the natural hand. One might then reasonably expect such a device to perform many of the functions of its normal counterpart. But all such attempts have ended in complete failure, chiefly not for want of adequate structural and mechanical details but for lack of a sufficient number of workable controls *(15).* The normal hand is powered by some 24 separate but highly coordinated muscle groups controlled by an elaborate pattern of nerves emanating from the brain (page 22). Because the motions of the normal hand are controlled automatically as though by reflex action, little conscious effort is required to manipulate the hand or fingers into positions of utility. In the arm amputee, "mind-controlled" power sources and nerve supplies are seriously reduced. Hence it is necessary to find for a prosthetic arm and hand a source of power and excursion that involves only simple operating motions but at the same time provides the forces necessary for adequate prehensile function.[6] When the power available to the arm amputee is analyzed, it is found that, except for cineplasty *(3)* and external power such as electricity *(1,2,9),* no more than one useful hand power source is available—and that operable in one direction only *(15).*

Sources of control should therefore be so chosen as to eliminate unnecessary exertion and undue bodily contortion in using the artificial hand. In current practice, scapular abduc-

[6] In order for a hand to perform its functions, it must of course be placed in position, and positioning of the hand requires some type of suspension. A satisfactory artificial arm should involve a minimum number of motor sources but should be capable of the movements needed to place the hand in position for grasping an object. If such an arm is equipped with an active elbow, a lock for stabilization of the elbow, a turntable for positioning the forearm laterally, and a wrist unit for positioning the hand in flexion and rotation (Fig. 7), it should meet the requirements of an efficient "crane."

tion provides a satisfactory major source of control. It can be used to best advantage when coupled with humeral motion on the amputated side. Where such is the case, the opposite shoulder is used mainly as an anchor point, arm flexion providing the force and displacement required to operate the terminal device *(15,17)*. Considering the limitations of available motor sources for hand function, and the desirability of complete independence of the artificial hand from the other hand, whether that hand be normal or artificial, it is clear that, for simplicity and ease of operation, input control should be a single control requiring but one cyclic motion.

Because it is desirable that the hand be suitable for the majority of arm amputees, it is necessary to determine the excursion and power available for hand operation by the weakest amputees, and at the same time the hand mechanism must be stressed for the forces that might be exerted by the strongest amputees. Thus, extensive biomechanical studies are necessitated in order to establish the minimum and maximum limits of motion and forces available *(10,15,16)*. Analysis of the resulting data shows that an arm amputee should be able to grasp with a force of at least 15 lb. objects of all sizes and geometrical shapes up to about 3 in. in diameter. Minimum anticipated available work is calculated to be 37.5 in.-lb. or l-1/2 in. of excursion with 25 lb. of force. This condition means that the designer should strive for an over-all output-to-input ratio of 0.6 for hand and control system.

THE CHOICE OF DIGITAL MECHANICS

Once the lower limits of the available motor input are established, it then becomes necessary to determine which hand function or functions this force is to provide. To do so requires a complete survey of hand biomechanics, including accurate, detailed studies of the uses of the hand, the finger forces necessary to accomplish myriad tasks, the frictional characteristics of the skin, exact finger attitudes, approach to the object to be grasped, and the stability of the grasp on objects of various geometrical shapes.

In the natural hand nearly every segment is capable of stabilization by antagonistic muscle groups, thus affording a fixed base upon which flexion or extension of the next distal segment can be produced. Because such an arrangement in an artificial hand would require a multiplicity of controls, it would be very difficult, if not impossible, to simulate the natural plan of digital mechanics. Designs of artificial hands incorporating all phalangeal segments, but with a single coupled flexion system omitting the multistabilization feature of the natural hand, have been uniformly disappointing. Consequently, all differential digit motions, all variations in thumb opposition but one, and all distal phalangeal joint motions may have to be sacrificed.

Type of Prehension

From the intricate and varied function possible in the normal, then, there must be selected a single action pattern similar to that type of prehension used most frequently in everyday activities. To make such a selection requires fundamental study of hand prehension patterns in normal subjects (Fig. 8). On the basis of such investigations, it is possible to list the most common and most essential manipulations of the hand in relation to objects to be handled, including such activities as opening various types of door locks, dialing telephones, using eating utensils, writing, combing the hair, dressing, carrying various objects, and a host of other functions *(10)*. When the data thus accumulated are reduced to a frequency chart, it is found that the basic prehension type most used involves closure of the first and second fingers against the thumb in a three-jaw-chuck pattern known as "palmar prehension" (page 33).

In the normal hand, the third and fourth fingers act mostly as reinforcing agents, as a resting shelf for holding certain objects, and as gliders in activities such as writing. When, however, sensation has been lost, the third and fourth fingers interfere with the normal approach of the first and second. In the artificial hand, therefore, they are necessary only for cosmetic purposes and should yield so as not to interfere with the approach of the active fingers. The output utility of the hand thus may be considered as residing in the thumb and first and second fingers, and the next

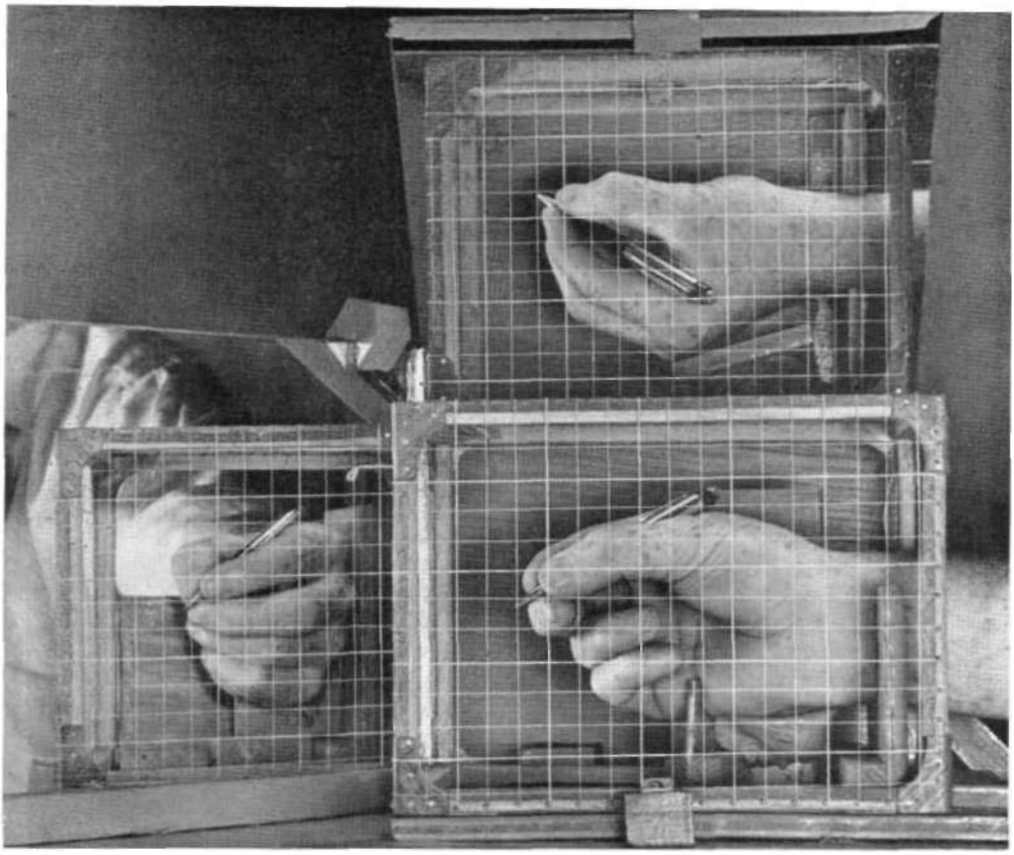

Fig. 8. Cage for observing hand prehension patterns in three dimensions simultaneously. The grasp shown is the typical palmar prehension of the three-jaw-chuck variety. *Courtesy University of California at Los Angeles.*

problem is to decide how these digits may best be activated.

Finger Design and Orientation

Aside from the problems of control introduced by fully articulated fingers, multisegmented artificial digits present problems of functional stability in use (Fig. 9). Because a finger comprises, in effect, a slender column, it presents a great lever disadvantage. To simulate each finger joint therefore introduces excessive lateral instability.

Fig. 9. One form of multisegmented artificial finger. Complexity such as this leads to lateral instability.

Moreover, it is difficult to design an operating mechanism that will fit within such a small space and that nevertheless will be rugged enough to withstand the stresses imposed upon the fingers. Careful selection of fixed knuckle angles, with articulation at the metacarpophalangeal joint only, lends greater strength, better lateral stability, and improved control of the prehensile pattern and confines bearings

Fig. 10. Artificial finger of monocoque construction with fixed knuckle angles so chosen as to cause grasped objects to be drawn into the hand rather than rejected.

and levers to the largest portion of the finger column (Fig. 10). The volar surfaces of the fingers and thumb should be padded to provide the prosthesis with a resilient and contour-conforming grip. Resilient pads afford the amputee additional surface-contact area and consequently increase the stability of grasp.

Thumb Design

Although in the normal hand the thumb is mobile, a feature which contributes greatly to hand versatility, it has been found that, in the artificial hand, which is lacking in sensation, a fixed-position thumb offers the best over-all advantage. A fixed thumb provides a registering point, an arrangement which lessens the possibility of accidental displacement of the object grasped, as is the case when both thumb and fingers move simultaneously and the amputee must guess the point of contact in motion. Moreover, a fixed thumb eliminates the necessity for complicated linkages between thumb and fingers.

It has been established through time-and-motion studies that a hand opening of approximately an inch and a half is adequate for 90 percent of all average activities, but an opening up to 3 in. is necessary for the remainder of the time. Since 1-1/2 in. of control-cable excursion is all that can be allotted for operating the terminal device, and since for maximum feedback of position sense a ratio of 1:1 between finger-tip travel and control-cable excursion is desirable, it is necessary to provide a mechanism that allows the thumb to be set at two positions relative to the hand itself in order to permit grasp of objects up to 3 in. in diameter.

A two-position thumb (Fig. 11) is made possible through the use of a unidirectional alternator mechanism which allows the thumb to be placed in either of the two positions by application of pressure on the dorsal side. When the thumb is in position to provide an opening of 1-1/2 in., pressure on the dorsal side releases the lock, and upon release of pressure the thumb is extended by spring force to an opening of 3 in. Application of pressure on the dorsal side a second time forces the thumb from the outer to the inner position where the lock engages

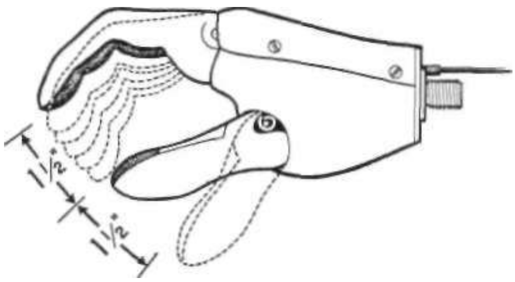

Fig. 11. The two-position thumb, set manually from either position to the other by application of pressure on the dorsal side. Inner position provides for objects up to *1-1/2* in. Outer position accommodates objects between 1-1/2 and 3 in.

automatically. When the lock engages, a slight, audible click indicates to the user that further pressure is not required. Such a thumb can be set by pressing it against some part of the body, a table, or the like, and thus does not require use of the other hand. With respect to the palm, the thumb should be located in such a way that, when the tips of the operating digits are touching each other, they fall in a plane forming an angle of 15 deg. with the longitudinal axis of the forearm (Fig. 12).

APPLICATION OF POWER

Currently the prosthetic fingers can be operated by one of two basic systems—voluntary-opening or voluntary-closing. In the voluntary-opening system, the amputee, using his motor control source, opens the fingers of the hand against the tension of a spring, and the spring, in turn, performs the clamping action in much the same manner as does a common spring clothespin. But the voluntary-opening device, although offering the advantage of simplicity, presents a number of disadvantages. It does not, for example, afford the amputee willful control over finger-tip pressure. Instead, the gripping forces are limited strictly to those provided by the spring tension, and the amputee must overcome a fixed, relatively heavy load each time the device is used. Since provision must be made to accommodate certain heavy tasks, the force needed to operate the voluntary-opening device is, for a large percentage of the time, much greater than is needed because the most

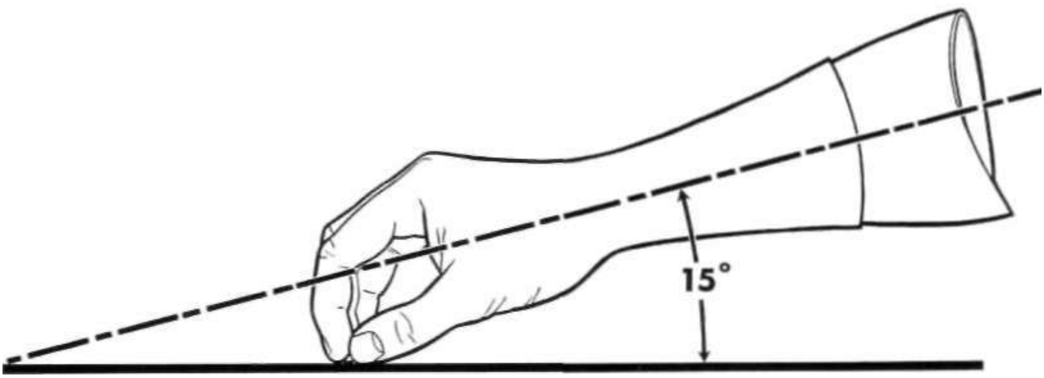

Fig. 12. Finger-thumb-palm orientation. The three-jaw-chuck pattern is so modified that the plane formed by digits I, II, and III forms an angle of 15 deg. with the axis of the forearm. Such an arrangement provides the most effective approach at table height.

frequent prehensions are in the light-grasp category (approximately 3 lb.). The amputee thus is subjected to excessive energy drain. Conversely, the voluntary-opening hand is unable to grasp delicate objects without crushing them. Besides all this, the motion required to operate the voluntary-opening hand is just the reverse of that in the normal, a needless complication.

In the voluntary-closing hand, the amputee, using his motor control, closes the device, and opening is effected by spring force. Because the voluntary-closing mechanism affords a natural pattern of motion and graduated, controlled finger-tip pressures, it offers the most likely possibility of duplicating the action of its normal counterpart. It can be used on delicate or fragile items and is capable of performing heavy tasks as well. Moreover, the force exerted by the amputee is related directly to the output forces desired. Forces equaling average natural prehension (18 lb.) are easily possible. Although the spring necessary to return the fingers to their open position and to withdraw the operating control to its starting position detracts from the over-all mechanical efficiency, if the spring is substantially linear in its characteristics it does not impair the amputee's ability to operate the device effectively.

With respect to grip, approach, and operating characteristics, the voluntary-closing hand performs efficiently. But unless a lock or clutch of some kind is incorporated, the hand would be carried in the open position, creating an awkward appearance, or else the amputee would have to exert continuous force on the control system to keep the hand closed. To overcome this problem, and also to relieve the amputee of expending energy for holding objects for relatively long periods of time, a lock or clutch appears indicated. To eliminate the necessity for using the other hand in engaging such a lock, an action which is not only inconvenient but which also often imparts awkward appearance, the locking operation must be independent. In the past, attempts to free the other hand from participation have involved use of a ratchet, but this expedient results in a limitation in the number of locking positions. The method which has given the most success to date is based upon a cam-and-quadrant system (Fig. 13). Relaxation of tension in the control cable from the energy source results in engagement of the cam regardless of the position of the fingers. Reapplication of tension in the cable dislodges the cam and frees the system.

It is important that the unlocking force be held rather high to eliminate inadvertent unlocking. A formula that has worked out rather well to date is that the unlocking force required should be about the same as that initially applied to the system when grasping an object and locking the mechanism.

Regardless of the method employed to

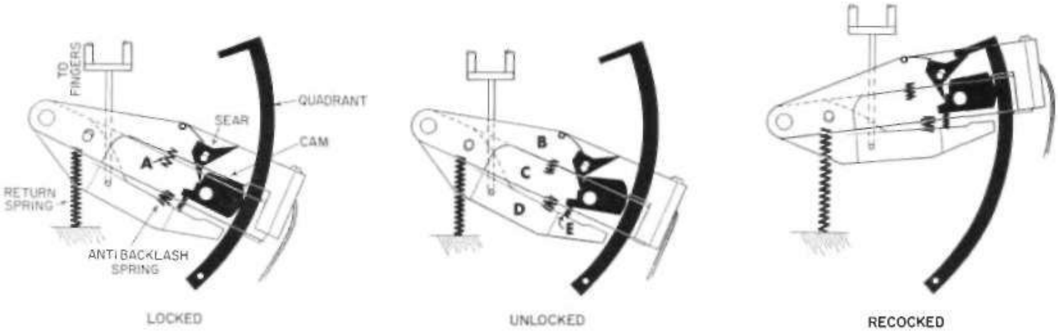

Fig. 13. The cam-quadrant clutch, schematic. The cycle is pull to close, release to lock, pull to unlock, release to open. In the locked position, compression force in return spring jams cam against quadrant to immobilize fingers. Small leaf spring maintains lower lip of sear in upper notch of cam but, owing to the separation of lever arms *B* and C due to compression spring *A*, *not* in such position as to rotate cam. Next pull on control cable closes lever arm *B* on lever arm C by compressing spring *A*, thereby causing sear to rotate cam counterclockwise against spring *E*. Mechanism thus is unlocked, and hand is free to open when tension in cable is released. Upon full opening, stop in fingers retains lever arm *B*, while stop on quadrant trips lower lip of sear into lower notch of cam to recock in preparation for next locking cycle. With next pull on control cable, cam idles along quadrant as fingers close, lower lip of sear remaining in lower notch of cam by virtue of slot in sear. When cable travel stops and tension is released, cam jams against quadrant again to lock, sear moves up on its slot to accommodate motion of cam, lever arm *B* is displaced from arm C by compression force in spring *A*, and lower Up of sear drops back into upper notch of cam in preparation for next unlock. Throughout the cycle, the compressed antibacklash spring tends to separate lever arms C and *D* and thus compensates for any slack induced in the course of the locking action. Since the quadrant is continuous, locking may be effected at any position whatever between full open and full closed.

achieve automatic operation of the lock, none can be successful unless some provision is made to eliminate the effect of backlash, an action inherent in all mechanical linkages. Unless backlash is eliminated, all or part of the prehension force is lost upon engagement of the lock, and no doubt several ingenious designs have failed to gain acceptance because this problem was overlooked or not solved.

THE REFLEX HAND

Although the voluntary-closing system probably represents the best available method for operation of an artificial hand, voluntary-closing should be viewed only as one stage in the development of a satisfactory hand substitute. One desirable addition to the voluntary-closing system would be to combine its advantages with those found in the voluntary-opening method. In the normal, for example, the hand usually is carried in a relaxed attitude. When it is brought to the zone of approach, it opens by visual cue to receive the object and then closes upon it. On relinquishing the grip, the hand drops back to its normal, or relaxed, position.

This "reflex" action can be duplicated mechanically and could be incorporated into a "reflex" hand (Fig. 14). At the first impression of force on the control cable the fingers open rapidly. When pull on the cable is continued, they close at the velocity of cable travel. The "push-pull" action is made possible by a lever system that presents a relatively high mechanical disadvantage when opening the fingers and then transfers to an advantage lever in the closing motion. Because of the transfer of lever characteristics, the system inherently provides a cue at full opening. Thus, one continuous motion of the control cable opens the fingers from the relaxed to the full-open position and then closes the fingers on the object approached. When the grip is relaxed, the fingers open to release the object and then return to the normal, relaxed position. Hence, the reflex hand would give the amputee all of the advantages of the voluntary-closing device and, at the same time, have some of the advantages

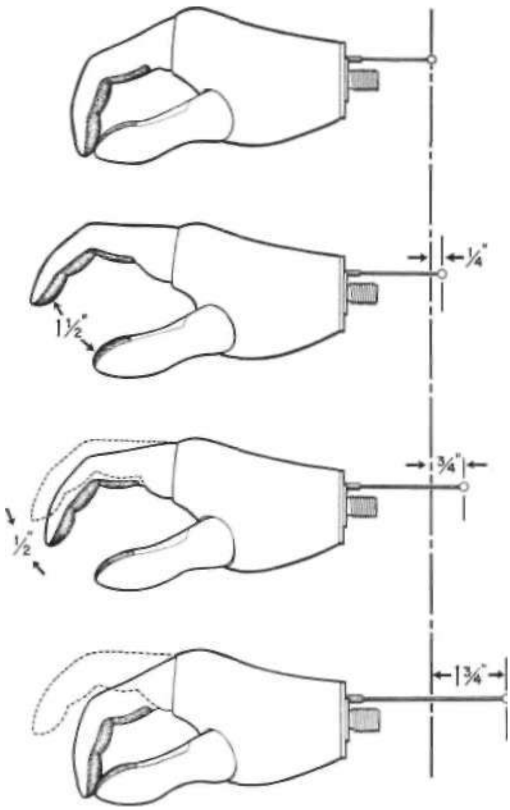

Fig. 14. The principle of the reflex hand. First 1/4 in. of excursion in the control cable opens the hand to the full 1-1/2 in. Further pull on the cable closes the hand at a 1:1 ratio of finger-tip travel to cable travel. Thus, after 1-3/4 in. of cable travel, the hand is fully closed again. The difference between the 1-3/4 in. total excursion and the ideal l-1/2 in. may be compensated for during the closing cycle by lineating mechanisms which give 1-1/4 in. actual cable travel. Upon release of tension on the cable, the action goes through the reverse cycle. The hand first opens fully (at a ratio of 1:1). Last 1/4 in. of cable excursion allows hand to return to closed or "rest" position. The excursion relationships suggested here are approximations; they may need minor modification on the basis of actual experience with test wearers.

inherent in the voluntary-opening device. Because of the "powered" opening *and* closing, it would also eliminate the major portion of the spring return, thus increasing the efficiency ratio of input to output force. In addition, powered opening furnishes a means of spreading pockets and the like to accommodate "blind grasp."

As in the voluntary-closing hand, a clutch is required to eliminate the need for the amputee to exert continuous pressure, and again it should be entirely automatic. If a one-motion cycle is to be achieved, the clutch must engage during the closing operation and then retain the maximum impressed grip force while the cable force is reduced. The average amputee can easily maintain 2 or 3 lb. of tension on the control cable. If, therefore, the clutch could retain the full grip of 15 to 30 lbs. of finger-tip pressure with, say, only a 2-lb. force on the cable, the amputee would not have to exert continuous maximum pressure. At this point some sensory cue must be provided to inform the wearer that further relaxation would release the clutch and return the fingers to their normal or starting position. Details of such a clutch design remain to be worked out.

To make the reflex mechanism versatile and adaptable, it should be a packaged, adjustable unit which, through its adjustment features, can be applied universally to all hands from the smallest to the largest. Standardization is perhaps the easiest feature to achieve because, if the clutching unit itself can be designed so that its case fits the smallest hand, adjustable lever shoes or arms can be attached externally to provide the greater lever advantage needed in larger hand sizes.

Other mechanical devices, currently available, can be used in the construction of an efficient reflex hand. Among them is a force multiplier that can be used to give the greatest impression of tip force at the time of contact with the object to be grasped. Also available are various lineating mechanisms that can be used to make the force response consistent over the entire range of finger motion.

THE FUTURE IN ARTIFICIAL HANDS

Successful transition from the natural hand to the prosthetic one depends in effect upon the judicious selection of the limited number of functions that can be replaced. The choice, in turn, depends upon three important considerations. First, it is necessary to determine those functions most essential to the activities of everyday living and of occupation in order to suit the mechanism to the operating requirements. Second, it is necessary to consider the practical possibilities of inanimate mechanisms and the details of stability, of friction, of linkage between components, and so on, to determine the characteristics of a feasible device within the bounds of cost, durability, ease of operation, and general ruggedness. Third, adaptation of the device to the amputee must take into account not only his functional needs but also to some extent his physiological and psychological characteristics. Such design problems in the matching of a mechanical device to the human being represent a particularly challenging example of biotechnology.

Because of the scarcity of available controls, present-day artificial hands are limited to a single pattern of prehension. Developments which would provide a second control, even of low power, would offer a great improvement, for example by adding an independent locking control. Such an eventuality would do away with the present disadvantage of the voluntary-closing hand, which now requires a second pull on the control cable to disengage the lock, followed by full opening to recock for the next locking cycle. Although the reflex mechanism described, which cycles first through an opening phase and then through a closing phase, would reduce and naturalize any movements required in preparation for locking, a second, and independent control source would represent a practical solution to problems associated with the existing voluntary-closing hand. Whatever the type of mechanism that finally emerges, the objectives are two in number. The first is concerned with preserving the graded prehension of the voluntary-closing device. The second relates to synchronizing the locking action so that, as in the normal hand, isometric grasp may be managed without additional time and motions beyond those made in the basic movements of prehension.

Other than the one additional independent control, no further motor functions are foreseen for mechanical hands any time in the near future. At some time more remote, hand prostheses may be powered externally by electric or hydraulic systems, but the inherent limitations of these power sources—the intricacy of structure, the difficulties in control and feedback, and the general complexity of operation and maintenance—make such developments long-range projects requiring much further study.

A major deficiency in all prosthetic equipment is the lack of any direct replacement of the sensory functions of the normal member. The natural hand, it has been noted, is richly supplied with sense organs mediating touch, pressure, and muscle and joint movement. It is therefore possible for the normal to recognize objects by shape, to sense magnitudes and directions of loading, to differentiate textures, and to perceive movements of objects, all via the intrinsic sensory mechanism. In the arm amputee, normal feedbacks from joints, muscles, and skin, stimulated by movement and pressure, are lost. In their place the amputee has only visual cues and the imperfect impressions from socket and harness pressures to aid in directing and operating the prosthesis.

Although visual control of a prosthesis can be shown in simple tests to be fully as precise as that in the natural hand, it obviously fails in the dark and, in any case, requires excessive concentration on the part of the amputee. Consequently, many aspects of manipulative function which are ordinarily habitual and subconscious become costly of time and visual attention when carried out with the prosthetic hand. Despite the possibilities of using substitute sensation from harness and control cable, many arm amputees never progress beyond the stage of simple visual control, and hence their concentration upon the task of operating the prosthesis introduces awkwardness in sharp contrast to the quasi-automatic operation of the natural extremity.

Fortunately, there is now a strong likelihood that feedback devices, signalling to proximal skin surfaces the extent of hand opening and prehension pressure by electronic, mechanical, hydraulic, or pneumatic means, will become a practical reality in the foreseeable future. Although there is still great need for extensive research and development in this field, satisfaction of the criteria for successful sensory replacement would constitute a significant advance in upper-extremity prosthetics and would give to the arm amputee greatly improved adeptness and sense of security.

Another area for research closely allied with the problem of sensory feedback is that of providing the "cosmetic" reflex movement in prehension and some realistic motion of the digits when the hand is idle, such as when it is carried empty at the side during walking. Experience to date with many arm amputees indicates that, were some slight movement of the fingers possible without too much conscious effort on the part of the wearer, perhaps merely through a coupling into a free-swinging elbow, the cosmetic effect would be enhanced appreciably. Still another area for improvement lies in providing a skeletal structure that will give a "live feel" more nearly like the anatomical counterpart.

Durability and ease of cleaning are, of course, important considerations in the choice or rejection of a cosmetic hand, but these problems would presumably be amenable to solution by the development of new and improved materials. Since in recent years technological advances, particularly in chemistry and in metallurgy, have provided a rapidly expanding list of materials with an ever wider range of physical properties, it seems reasonable to expect rather early improvements in the problems of hand maintenance, with respect both to the mechanical features of the hand itself and to its cosmetic covering.

Finally, it should be pointed out that the interpretation of research results and reduction of new ideas to practice both take time. Several years will be required before full utilization can be made of basic data already in existence. Meanwhile, further research and development proceeds apace. Perhaps, then, the most important requirements in the improvement of present hand substitutes are patience and perseverance on the part of all concerned.

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Digest of Major Activities of the Artificial Limb Program

Presentation at HEW

In response to a request from the Children's Bureau of the Department of Health, Education, and Welfare, a number of persons active in the Artificial Limb Program spoke before members of the Bureau's regional staffs at the annual Washington conference on January 18. Purpose of the presentation was to acquaint Bureau personnel with the objectives of the Artificial Limb Program and to outline certain projects currently under way.

DR. DEAN

Of especial interest was the concluding address delivered by Dr. Carleton Dean, Director of the Michigan Crippled Children Commission. In his remarks, Dr. Dean explored in detail the complexities of administering a statewide amputee program for children.

Others on the program included Brig. Gen. F. S. Strong, Jr., Executive Director of the Advisory Committee on Artificial Limbs, who opened the meeting with a brief history of the Program, and Lt. Col. Maurice J. Fletcher, Director of the Army Prosthetics Research Laboratory, who exhibited and described a number of components, some experimental, that comprise the provisional children's armamentarium.

Problems encountered in training children to use prosthetic devices efficiently were discussed by Capt. Frederick E. Vultee, of the Physical Medicine Service, Walter Reed Army Hospital. Dr. Charles H. Frantz, Orthopedic Consultant to the Michigan Crippled Children Commission, then described, with the aid of colored motion pictures, the technical aspects of the Michigan Juvenile Amputee Program. The plan and objectives of the current Prosthetics Field Study were explained by Dr. Sidney Fishman, Director of the Prosthetic Devices Study, New York University.

Presiding was Dr. Lucille J. Marsh, Chief of the Program Services Branch, Division of Health Services of the Children's Bureau.

Symposia on the Navy Below-Knee Prosthesis

On January 10 and 11, the Prosthetic Devices Study of New York University, in cooperation with the Bureau of Medicine and Surgery of the United States Navy, conducted a two-day demonstration and discussion of the Navy below-knee prosthesis at the Prosthetic Testing and Development Laboratory, Veterans Administration, New York Regional Office. A complete fitting of this leg, which consists of a soft socket, plastic shank, and Navy functional ankle (ARTIFICIAL LIMBS, May 1954, p. 17; September 1954, pp. 23-25), was performed before a group of prosthetists and physicians from the New York Metropolitan Area. During and after the fitting, discussions were conducted on Navy techniques in below-knee prosthetics.

Among those attending the session were Martin Durec, C. R. Goldstine, Bruce Jacobson, John F. Mitchell, and W. Sampson of the Institute for the Crippled and Disabled, New York City; James McAteer, M.D., Gabriel Rosenkranz, M.D., and Morris L. Schneider of the Veterans Administration Regional Office, New York City; George R. Hartman and Charles Ujamras of the Institute of Physical Medicine and Rehabilitation, New York City; Arthur A. Beitman and Gerhard Beil of the Arthur A. Beitman Co., Newark, N. J.; Konrad Hoehler and H. Hainz of Konrad Hoehler Co., New York City; Walter J. Henzel and Charles E. Weinhold of the Henzel Artificial Limb Corp., New York City; Mr. and Mrs. R. L. Rohe of the C. H. Davies Co., Philadelphia, Pa.; Robert N. Bennington of the Modern Limb and Brace Co., Freeport, N. Y.; Arthur L. Boland of the Cosmevo Surgical Co., Paterson, N. J.; Mary S. Dorsch of the Dorsch United Limb and Brace Co., New York City; Fred

NAVY DEMONSTRATES BELOW-KNEE PROSTHETICS—In upper right are (left to right) Dr. Sidney Fishman, Project Director of the Prosthetic Devices Study, New York University; Capt. Thomas J. Canty, MC, USN, Director of the Navy Prosthetics Research Laboratory; and Brig. Gen. F. S. Strong, Jr., Executive Director of the Advisory Committee on Artificial Limbs.

J. Eschen of the John N. Eschen Co., Inc., New York City; William F. Francis of the W. F. Francis Co., Newark, N. J.; and Leo C. Greehan of the Leo C. Greehan Co., Yonkers, N. Y.

Also present at the meeting were Fred Greimel of the County Surgical Co., Brooklyn, N. Y.; Herbert B. Hanger of J. E. Hanger, Inc., New York City; J. V. Hill of the Winkley Artificial Limb Co. and the Marks Artificial Limb Co., New York City; Jerome S. Kessler of Kessler Associates, Inc., Newark, N. J.; Jerome Lucarelli of J. A. Lucarelli and Sons, New York City; John A. McCann of the John J. McCann Co., Burlington, N. J.; Adolph A. Margoe of the City Surgical Co., New York City; Herman Pheffer of the American Legion, New York City; Herman M. Press of the Yale Surgical Co., New Haven, Conn.; David E. Stolpe of the Pomeroy Co., Inc., New York City; and William A. Tosberg of NYU-Bellevue Medical Center, New York City.

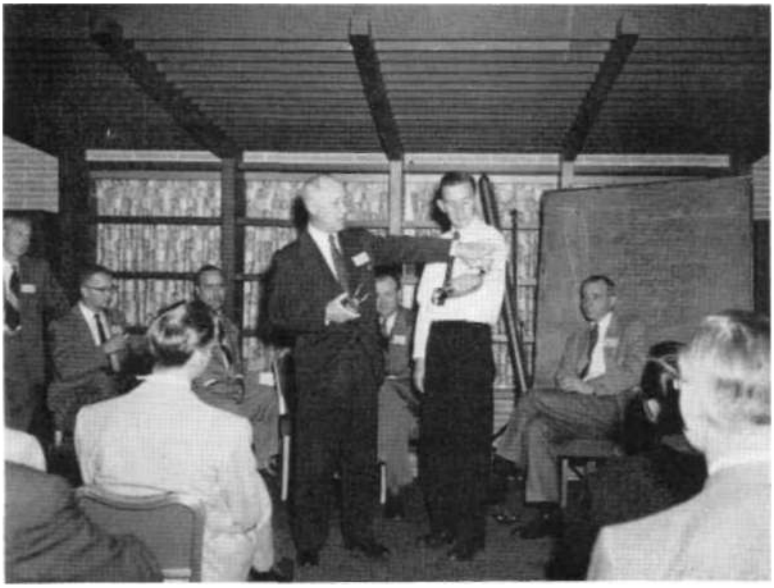
Captain Thomas J. Canty, MC, USN, Director of the Navy Prosthetics Research Laboratory at the U. S. Naval Hospital, Oakland, Calif., led the discussions, and Harry Conrad, Chief Pharmacist's Mate at NPRL, carried out the demonstration. F. S. Strong, Jr., Executive Director of the Advisory Committee on Artificial Limbs, National Research Council, and Sidney Fishman, Project Director of the NYU Prosthetic Devices Study, addressed the group at the conclusion of the meeting.

The below-knee amputee fitted at this demonstration appeared before the Metropolitan OALMA meeting two weeks later, at which time further discussion was held. Questions were answered by Chief Conrad, representing NPRL, and the discussion was moderated by Edward R. Ford, Laboratory Supervisor of the NYU Prosthetic Devices Study.

These symposia are part of the evaluation of the Navy below-knee prosthesis currently being conducted in Chicago and New York City.

Meeting of American Academy of Orthopaedic Surgeons

The Artificial Limb Program was represented in several respects at the twenty-second annual meeting of the American Academy of Orthopaedic Surgeons at Los Angeles January 29 through February 3. A large number of individuals active in the research program or in cooperating VA, military, and civilian clinic teams participated in informal discussions while attending the meeting.



AAOS SESSION ON UPPER-EXTREMITY PROSTHETICS—Lt. Col. Maurice J. Fletcher, Director of APRL, demonstrates the principles of cineplastic prostheses during the instructional course in upper-extremity prosthetics held as part of the convention of the American Academy of Orthopaedic Surgeons in Los Angeles January 29 through February 3. The amputee subject is Allan Heath, professional racing driver. Left to right behind Colonel Fletcher are Dr. Robert Mazet, Jr., of Wadsworth General Hospital, Veterans Administration Center, Los Angeles; Dr. Donald B. Slocum of Eugene Medical Center, Eugene, Oregon; Harry Campbell of the Artificial Limbs Project, UCLA; Dr. Rufus H. Alldredge, member of ACAL, of New Orleans; and Dr. Clinton L. Compere, VARO Clinic Chief, Chicago.

A three-hour instructional course on amputations and prostheses for the upper extremity, offered with the cooperation of the Upper-Extremity Prosthetics Training Center, Department of Engineering, University of California at Los Angeles, was presented before a sell-out audience by a panel composed of Dr, Charles O. Bechtol, New Haven, Connecticut, Chairman; Dr. Rufus H. Alldredge, New Orleans; Dr. Clinton L. Compere, Chicago; Lt. Col. Maurice J. Fletcher, Washington, D. C; Dr. Charles H. Frantz, Grand Rapids, Michigan; Dr. Robert Mazet, Jr., Los Angeles; Dr. Donald B. Slocum, Eugene, Oregon; and Mr. Harry Campbell, Los Angeles. The team approach was stressed in demonstrations of a considerable series of amputees with stumps of various lengths. In addition, participants in the research program presented other instructional courses in wounds of the extremities, bone tumors, fractures, braces, and muscle physiology.

The UCLA group presented a scientific exhibit entitled "Progress in Upper-Extremity Prosthetics," with armamentarium items and frequent demonstrations by amputees.

TCP Meeting

The second meeting of the Technical Committee on Prosthetics was held February 4 at the Hotel Statler in Los Angeles. The principal topic of discussion was the role of the Committee and of the Artificial Limb Program in prosthetics education. It was generally agreed that the Program has a responsibility for disseminating useful information and that, although the printed word is indispensable, it alone cannot solve the problem. Formal training of several types appears to be indicated, but it was decided that, for the immediate future, the Artificial Limb Program should confine its activities to the "upgrading" type of program, using data accumulated therein to guide research and development. Minutes of the meeting have been distributed to members and other interested individuals.

Panel Meetings

Meetings of the Lower- and Upper-Extremity Panels on Research and Development took place in the Town House, Los Angeles, on February 8. At a combined luncheon session problems common to both groups were studied.

The next meetings of the Panels are scheduled to be held in Washington on Monday, June 27. They will be preceded by meetings of the Phase Subcommittees on June 23 and 24, also in Washington.

ABC Exhibit Program

In planning activities for 1954 and 1955, the American Board for Certification voted unanimously to expand the program aimed at acquainting other professional groups with its efforts to improve standards in prosthetic and orthopedic care. As part of the new campaign, the Board has prepared a series of displays designed to be exhibited wherever interested professional bodies meet.

To date, the exhibits have appeared at the meeting of the National Rehabilitation Association in Baltimore October 24 through 27, at the Clinical Session of the American Medical Association in Miami November 29 through December 2, and at the convention of the American Academy of Orthopaedic Surgeons in Los Angeles January 29 through February 3 (see cut). Another exhibit is planned for the annual meeting of the American Medical Association, the largest medical gathering held on the American continent, in Atlantic City June 6 through 10.

Literature distributed at the exhibition booths includes the *Official Registry of Certified Facilities,* sample certification forms, the ACAL quadrimesterly ARTIFICIAL LIMBS, and the *Orthopedic and Prosthetic Appliance Journal.*

—Weaver, Los Angeles

ABC EXHIBIT AT AAOS MEETING—Two founder-members of the American Board for Certification and six other persons active in the prosthetics field visit ABC's display at the convention of the American Academy of Orthopaedic Surgeons in Los Angeles earlier this year. Dr. Henry H. Kessler, of Newark, N. J., and Lee J. Fawver, of Kansas City, Mo., Past-President of OALMA, were members of the Board when it was organized in 1948. Pictured are (left to right) Harvey G. Lanham, of Long Beach, Regional Director of OALMA for Southern California; Milburn J. Benjamin, of Glendale, Calif., member of the Certification Board; Mr. Fawver; Dr. Kessler; Dr. T. Campbell Thompson, of New York City, President of AAOS and member of ACAL; Dr. Charles 0. Bechtol, Chief of the Division of Orthopedic Surgery, Yale University, and Chairman of the Technical Committee on Prosthetics, ACAL; Carlton Fillauer, of Chattanooga, another member of the Certification Board; and Charles A. Hennessy, of Los Angeles, Vice-President of OALMA

OALMA Regional Meetings

Key personnel associated with the Artificial Limb Program have appeared on the agenda of several of OALMA's regional meetings this spring. Their participation marks a continuance of ACAL policy designed to make available to the limb industry knowledge of new developments in prosthetics research. OALMA's eleven Regions schedule the spring sessions in order to reach those prosthetists and orthotists who are unable to attend the National Assembly held each autumn, On March 12 and 13, a two-day session dealing with prosthetic and orthotic devices brought together at the Statler Hotel in Los Angeles a record attendance of prosthetists, orthotists, and orthopedic surgeons. This annual medical and technical Assembly is sponsored jointly by the Society of Orthotists and Prosthetists of Southern California and Region IX of OALMA (Southern California and Arizona). Robert V. Bush of Los Angeles served as General Chairman, and Charles A. Hennessy, also of Los Angeles and President of the Society, was Presiding Officer.

Many of the papers read before the group were of special interest to those associated with the Artificial Limb Program. Dr. Verne T. Inman of the University of California Medical School discussed the problem of pain in the amputee and summarized the results of several years of research conducted at the University of California, Berkeley Campus. Dr. Charles O. Bechtol, Chief of the Division of Orthopedic Surgery at Yale University and Chairman of the Technical Committee on Prosthetics, reviewed the subject of cineplastic surgery for upper-extremity amputees. He was accompanied by John Niwa, who had undergone a biceps cineplasty procedure in 1954, the operation being televised to the 1954 Assembly over a closed circuit. Mr. Niwa appeared at the 1955 Assembly to demonstrate the progress of his training with the cineplasty prosthesis.

The subject of suction sockets (ARTIFICIAL LIMBS, May 1954, p. 29; January 1955, p. 35) was explored by Jack J. Vollmer of Los Angeles. Charles W. Radcliffe, of the School of Engineering, University of California, reported on the Lower-Extremity Clinical Study being conducted at Berkeley (ARTIFICIAL LIMBS, January 1955, p. 4). Included in his remarks was a discussion of the Canadian hip-disarticulation prosthesis (ARTIFICIAL LIMBS, September 1954, p. 30). The status of upper-extremity devices was outlined for the Assembly by Jerry Leavy, Vice-President of A. J. Hosmer Corp., Santa Monica, Calif., who exhibited prostheses developed largely through the Artificial Limb Program. Cosmetic appearance of upper-extremity devices was reviewed by C. O. Anderson, Manager of Prosthetic Services of San Francisco.

DR. INMAN—Addresses orthotists and prosthetists of Southern California.

The prosthetics clinic team (ARTIFICIAL LIMBS, January 1954, p. 9) was the topic of a panel discussion that included Dr. Charles G. Hutter, Jr., Edward Ruzika, and Herbert Rosoff, all members of the VARO clinic team at Los Angeles. Prosthesis for a foot amputee was the subject of a report given by L. Benson Marsh, of Walnut Park, Calif., and Dr. Charles L. Lowman, of Los Angeles, reviewed the problem of lower-extremity prostheses for children.

There also were many topics of interest for those active in the bracemaking profession. The subjects covered included the bracing of the poliomyelitis patient, by John A. Metzger; brace prescriptions for the poliomyelitis patient, by Vernon L. Nickel; functional bracing of the upper extremity in cerebral palsy, by George B. Robinson; surgical corsets and their application to braces, by Stanley Carlton; and physical therapy and bracing for the paraplegic, by Charles Magistro. Dr. Kenneth B. Jacques, Lee Roy Snelson, and Bernice Ringman comprised a panel whose subject was bracing and rehabilitation in cases of cerebral palsy. The splinting of dysplasia and congenital dislocations was discussed by Dr. Frederic W. Ilfeld and Hyrum Christensen.

The annual Awards Banquet of the Society was held on the evening of March 12. Charles A. Hennessy, Vice-President of OALMA, was named "Prosthetist of the Year," and Lee Roy Snelson received a similar award as "Orthotist of the Year." W. P. McCahill, Executive Secretary of The President's Committee on Employment of the Physically Handicapped, was guest of honor and the principal speaker. Miles H. Anderson, Educational Director of the Prosthetics Training Center at UCLA, was guest of honor and principal speaker at the luncheon meeting on March 13.

In addition to his appearance at the Los Angeles meeting, Dr. Bechtol also took part in the program of the Scientific Assembly sponsored by the New York City Limb Manufacturers Association and Region II of OALMA on April 30. He led a discussion of the problems arising from cerebral palsy and assisted in a demonstration of the braces currently in use. At the same meeting, Edward R. Ford, Laboratory Supervisor with the Field Project at New York University, exhibited some of the new devices for children and also reviewed new developments in this area of study.

Chester C. Nelson, of Minneapolis, and Jerry Leavy attended the meeting in Kansas City, Mo., sponsored by Region VII of OALMA, April 16. They presented a program designed to show the current state of development of upper-extremity prostheses.

Memorials to Dr. Gordon

In recent months, two significant events have honored the late Dr. Donald Gordon who, from January 1949 until April 1953, was Surgical Consultant to the Prosthetic and Sensory Aids Service of the Veterans Administration. Dr. Gordon was struck by an automobile on April 19, 1953, and sustained multiple injuries. He died August 14, 1953.

On February 26, 1955, Dr. Robert H. Kennedy, Director of Surgery at Beekman Downtown Hospital in New York City, delivered the Donald Gordon Memorial Lecture at a meeting of the New York and Brooklyn Regional Committee on Trauma of the American College of Surgeons. Dr. Gordon had been a member of that committee from the time it was founded in 1919. Further recognition was afforded Dr. Gordon's contributions to surgery when the Donald Gordon Surgical Wing was dedicated at the Beekman Downtown Hospital April 12.

Those in the Artificial Limb Program who were privileged to know Dr. Gordon will be grateful for these fitting tributes to a highly respected friend and associate.

Honors for Bernstock

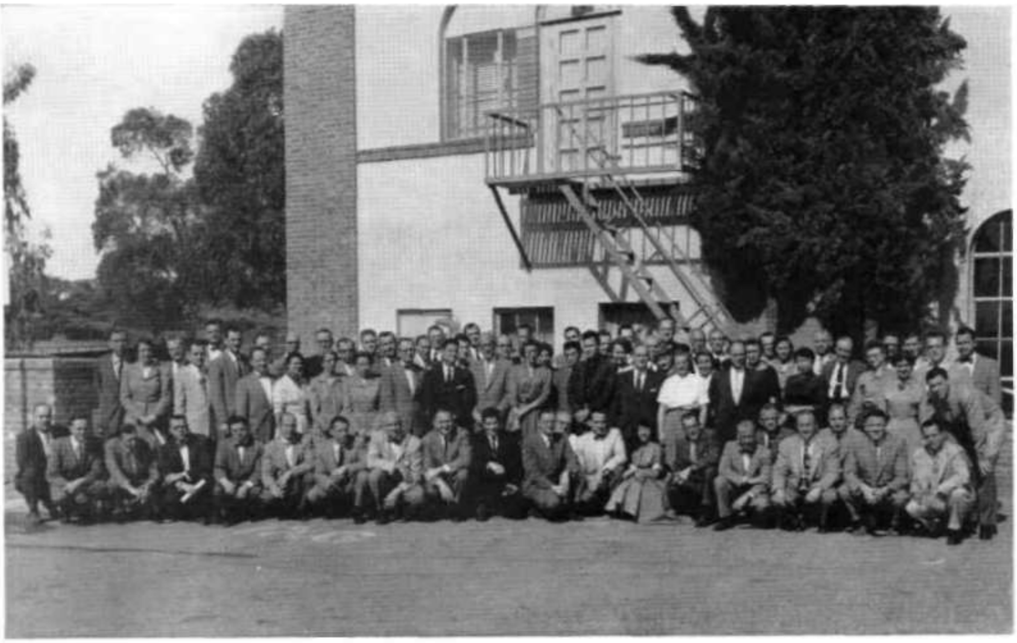
A cash award and a certificate of appreciation for superior accomplishment, signed by Dr. William S. Middleton, Chief Medical Director of the Veterans Administration, were presented recently to William M. Bernstock, Chief of the Prosthetics Education Division of the Prosthetic and Sensory Aids Service. In a letter dated April 20,1955, accompanying the award, Dr. Augustus Thorndike, Acting Director of PSAS, paid tribute to Mr. Bernstock's "outstanding performance and fine service . . . in the education of professional, technical, and other specialized groups engaged in serving and assisting in the rehabilitation of handicapped veterans, and in giving information to professional and laymen alike who have problems in the prosthetic field."

MR. BERNSTOCK

Before assignment to his present position in October 1951, Mr. Bernstock served five years as Chairman of the Rehabilitation Board of VARO, New York, and was responsible for advice and guidance to seriously disabled veterans. Over the past 17 years, he has been closely identified with the testing, counseling, training, and selective placement of handicapped persons toward improved manpower utilization. Currently, Bernstock is Representative from New York to Region II of the National Rehabilitation Association.

Upper-Extremity Prosthetics Training Center

The twelfth session of the Upper-Extremity Prosthetics Training Course at the University of California at Los Angeles was completed on February 11. Enrolled were 12 prosthetists, 19 therapists, and 34 physicians. The total number of clinic teams trained in upper-extremity prosthetics at UCLA now stands at



TWELFTH UPPER-EXTREMITY SCHOOL. Last of the current series of Upper-Extremity Training Courses at UCLA.

86. Included in the total are 28 teams from the Veterans Administration, 8 teams from the Armed Forces, and 50 civilian teams. Of the 452 individuals trained in the program, 120 are prosthetists, 150 are therapists, and 182 are physicians.

Graduates of the twelfth school are as follows:

PROSTHETISTS

WILLIAM JAMES BRUNNFR
J. E. Hanger, Inc.
3211 Tulane Ave.
New Orleans 19, La.

JACK L. CALDWELL
J. E. Hanger, Inc.
2715 Nebraska Ave.
Tampa 2, Fla.

CHARLES H. DANKMEYER
J E. Hanger, Inc.
226 W Monument St.
Baltimore 1, M<l.

LEE J. FAWVER
W. E. Isle Co.
1121 Grand
Kansas City, Mo.

CARLTON FII.I.AUER
Fillauer Surgical Supplies
930 East Third St.
Chattanooga, Tenn.

JOHN J. GLANCY
Rhode Island Hospital
593 Eddy St.
Providence, R I.

RICHARD M. LOCKE
J. E. Hanger, Inc.
2220 5th Ave , N
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WM. C. MCCALL
McCall-Rising, Inc.
2145 1st Ave., S
St. Petersburg, Fla.

DAVID C. MCGRAW
Snell's Limbs-Braces
715 Jordan St.
Shreveport, La.

THEODORE MEYER
16221 Lahser Rd.
Detroit 19, Mich.

MOODY L. SMITHERMAN
Birmingham Artificial Limb Co.
518 South 80th St.
Birmingham, Ala.

BERT R. TITUS
2411 Highland Ave.
Durham, N. C.

THERAPISTS

JOSEPH A. CORN
571 Suwanee Circle
Tampa, Fla.

EVAN V. DAVIES
424 Talivva Dr.
Knoxville, Tenn.

ROBERT HICKOK
9125 North Swan Circle
Brentwood 17, Mo.

SARAH C. HILL
212 Sequoia Dr.
Chattanooga, Tenn.

HARRIET HOLBROOK
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El Paso, Texas

BARBARA ANN HUMMON
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Orlando, Fla.

HELEN LOVELESS
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Wichita, Kan.

FREDERICK MANN
Enid General Hosp.
Enid, Okla.

MARY MASON
Johns Hopkins Hospital
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SHIRLEY ANNE MASON
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Boston 19, Mass.

MARGARET JONES NEAL
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Birmingham 6, Ala.

WILLIAM NEILL, III
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Ruxton 4, Md.

EDITH NYMAN
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New Haven 4, Conn.

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Madeira Beach
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HELEN POWELL
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720 N. Michigan
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CHESTLEY L. YELTON, M.D.
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Although it has not been possible to make the upper-extremity courses available to all clinic teams throughout the country, it has been necessary, because of prior commitments, to bring the UCLA courses to a close. Under development, however, are plans for conducting schools at several different locations throughout the country. Final arrangements depend upon the results of a pilot school to be held during the summer and upon other developments. The proposed schedule would provide first for courses in certain phases of lower-extremity prosthetics, to be followed by classes in upper-extremity work where the need is indicated.

Autumn Meeting of OALMA

New Orleans will become the prosthetic-orthopedic capital of the world October 16-19 when the National Assembly of the Limb and Brace Profession convenes there this autumn. Sponsored by the Orthopedic Appliance and Limb Manufacturers Association, the sessions will be held at Assembly headquarters in the Jung Hotel. Paul E. Leimkuehler of Cleveland has been named Program Chairman; Benedict G. Pecorella of Buffalo will serve as Chairman of the Committee on Scientific and Technical Exhibits.

The three-day program of this annual professional gathering will include a day-long discussion of the relationship between orthotists-prosthetists and various segments of the public, including amputees, other handicapped persons, and such professional groups as physicians and surgeons. Another session will be devoted to a review of prosthetic services and new developments, with emphasis on reappraisal of devices available currently. Also on the agenda will be a consideration of the expanding frontiers of prosthetic services. Special attention will be focused on appliances designed for the aged and the very young.

NATIONAL ACADEMY OF SCIENCES—NATIONAL RESEARCH COUNCIL

The National Academy of Sciences—National Research Council is a private, nonprofit organization of scientists, dedicated to the furtherance of science and to its use for the general welfare.

The Academy itself was established in 1863 under a Congressional charter signed by President Lincoln. Empowered to provide for all activities appropriate to academies of science, it was also required by its charter to act as an adviser to the Federal Government in scientific matters. This provision accounts for the close ties that have always existed between the Academy and the Government, although the Academy is not a governmental agency.

The National Research Council was established by the Academy in 1916, at the request of President Wilson, to enable scientists generally to associate their efforts with those of the limited membership of the Academy in service to the nation, to society, and to science at home and abroad. Members of the National Research Council receive their appointments from the President of the Academy. They include representatives nominated by the major scientific and technical societies, representatives of the Federal Government designated by the President of the United States, and a number of members-at-large. In addition, several thousand scientists and engineers take part in the activities of the Research Council through membership on its various boards and committees.

Receiving funds from both public and private sources, by contribution, grant, or contract, the Academy and its Research Council thus work to stimulate research and its applications, to survey the broad possibilities of science, to promote effective utilization of the scientific and technical resources of the country, to serve the Government, and to further the general interests of science.