Need for Research in Fundamental Biomechanical Studies[1]

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The Subcommittee on Fundamental Studies of the Committee on Prosthetics Research and Development is interested in the promotion of scientific and technological investigations that are fundamental to applied research studies of prosthetic and orthotic devices. Hopefully, the results of the subcommittee's efforts will lead to the establishment and dissemination of knowledge that is of common interest to researchers and clinicians concerned with the design and development of assistive devices.

Past experience with such research and its current state of development suggest that future studies should be made in the areas outlined in this article.

CONCEPTS of METHODOLOGY

SYSTEMS ANALYSIS

It is believed that the application of modern techniques of systems analysis to discern and clearly define the needs of the disabled could lead to the establishment of appropriate specifications for use in the design of devices.

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THE DISABLED CONDITION AS IT AFFECTS EXPERIMENTATION AND EVALUATION

Studies of the disabled condition should include investigation of psychological reactions to the use of prosthetic and orthotic devices. Thought should be given to the interplay of psychological and physiological reactions to the application of constraints and restraints. A study of the interactions of physiological systems might prove to be beneficial since it is apparent that there is an interplay of effects from one anatomical system to another.

DISABILITY EVALUATIONS

Corrective assistive devices alter the joint of the musculoskeletal system. Since positions, forces, kinematics, or stresses of the original condition may be changed by the therapeutic device, it is essential that the biomechanics of the normal, abnormal, and treated condition be well understood. This information is necessary for the proper use of such devices and the design of improved devices.

The biomechanical analysis of any system must necessarily be preceded by an adequate, accurate description of the system. If forces are involved, it is essential to know the points of application of the forces and the direction of forces applied either by muscles or by constraining passive tissues such as ligaments.

The addition of an assistive device to any part of the anatomy results in a hybrid mechanical-anatomical system. Complete understanding of the effect of such assistive devices rests upon the proper analysis of the hybrid system as a whole.

Analysis rests upon quantitative data which can be secured only by measurement. Taking such measurements often involves the design and development of the experiment and instruments. This subject in itself is a worthwhile area of investigation.

SPECIFIC RESEARCH AREAS

FUNDAMENTAL PHYSIOLOGY OF MUSCLE

Inconvenience, negative psychological reactions, and the complexity of design of exoskeletal devices all lead to the hope that one day it may be possible in appropriate cases to stimulate muscles which have been denervated by trauma or disease. Some research in this area has been conducted, but very little is known about the optimum type of stimulation, the response characteristic of stimulated muscle in the disabled condition, and the ultimate possibility of using electromyographic signals of one muscle to control stimulation of another.

Since muscles represent the actuators of the musculoskeletal system, it would be helpful to know more about the mechanical characteristics of muscle in terms of its strength, endurance, and efficiency. Hopefully, modern methods of measurements would permit the accumulation of quantitative data *in vivo* if research were pursued in this direction.

While upper and lower motor neuron lesions usually lead to atrophy of associated muscles, it has been shown that exogenous stimulation of muscle counteracts atrophy to some degree. If research should lead to solutions of this type, it will be necessary to know more about stimulative hypertrophy of muscle.

BODY AND DEVICE MECHANICS

Data for proper design of orthotic and prosthetic devices require a knowledge of existing force capacity and range of motion for both normal and various selected abnormal conditions of frequent occurrence. It would be of much benefit to the designers to have such data assembled in a convenient reference volume.

More knowledge of the kinematics and kinetics of the upper extremity, comparable to that of the ambulation cycle in the lower extremity, would also represent essential and valuable data for the design of devices. The existence of accelerometers and potentiometers for measurement of inertia forces and position facilitates the gathering of such information by experimental means.

Recent advances in the art of simulation of linkages in engineering suggest that the musculoskeletal system of the upper extremity can be treated in a manner that will permit study of the effects of constraints or supplemental power to upper-extremity orthoses. It may prove to be possible to optimize designs with regard to various possible constraints to meet the needs of common motion patterns.

COMPARISON OF MECHANICAL WORK AND PHYSIOLOGICAL ENERGY CONSUMPTION OF NATURAL AS WELL AS PATHOLOGICAL MOVEMENTS

Since one of the important criteria of evaluation of assistive and prosthetic devices is the conservation of the energy of the patient, it would be most helpful to devise ways and means of measurement of physiological energy consumption of discrete muscles or muscle systems for a determinable quantity of mechanical work output in the performance of needed tasks. While total oxygen-consumption measurements have been made for subjects with and without assistive devices in ambulation, very little has been done with regard to the upper extremity, particularly for discrete activities.

CONTROL MODES AND LOCATIONS IN PATIENTS

Underlying the problem of control of external power by electromyographic signals is the problem of proper association of biological signal and motion to be executed. In the case of amputation, the existence of the electromyographic signal of a remote muscle might be used as a control signal. However, this involves a retraining procedure for the subject. The improper or irrational selection of a control site may lead to an excessively complex learning procedure that would defeat the purpose of the design. The effects of paralysis may bring about a similar situation where the cause is a pathologic condition other than amputation. In any event, the success of any external power system controlled by electromyographic signals is highly dependent upon the rational selection of the site from which the biological signal is taken. The pursuit of such knowledge is highly important to the success of electromyographic control.

Recent investigations of the feasibility of single motor units of muscles as a source of biological signal for controlled purposes indicate the value of pursuing this idea as an eventual method of associating thought processes with limb action. Such solutions should lead to utilizing a portion of the muscle signal without impairing the usefulness of the muscle for its original intended purpose. As this study is in its infancy, considerably more information is needed in order to evaluate its potential.

RHEOLOGY OF HUMAN TISSUE

In the study of the biomechanics of joints, it becomes evident that the forces applied through bones find their reactions in the soft, passive tissues of constraint. Relative displacements of the bones of the joint are then a function of the mechanical characteristics of these tissues. The stress-strain ratio of the collagen tissue of tendon has been shown to be rate dependent for low and moderate rates of loading. Also, strain is a function of time; the tissue shows a recovery capacity when unloaded, demonstrating that viscosity plays a role in the mechanism of response. Investigations of some of the factors of some discrete tissues are examples of what can and should be done in the future by way of establishing factual knowledge of the response of component tissues and joints as a whole to the types of loading brought to bear by corrective devices.

Past achievements have demonstrated that this kind of information is also useful in detecting the reasons for certain types of deformities. Such understanding leads to better therapy and to devices designed to counteract the system of forces causing the deformity.

It is hoped that future research in this area will bring more knowledge of the factors involved. Investigation of more of the tissues involved is also essential.

Further studies of the mechanical characteristics of bone, especially under loadings of the type encountered in orthoses and prostheses, are, of course, part of this picture.

PHYSIOLOGICAL AND RHEOLOGICAL CHARACTERISTICS OF THE STUMP

In addition to knowledge of the rheological characteristics of the tissues of the stump, which is needed for the determination of pressure and tension on skin and subcutaneous tissue, knowledge of tissue compartitions and the interplay of effects of forces thereon is also necessary. Interference with the flow of blood brings deleterious effects to the health of the tissue, and faulty distribution of pressure or skin tension can affect nerves and bring pain, Knowledge of the type proposed here would assist in avoiding these dangers.

One of the problems encountered in the fitting of prostheses is that of edema. Measurement of the pressure encountered and the deformations involved should permit compensatory procedures providing better design.

Since rheological experimentation has shown that the stress-strain ratios are rate dependent and load dependent, it seems that special studies of the properties of compressed and deformed tissues should prove to be beneficial.

RESPONSE OF BONE AND CONNECTIVE TISSUE TO EXTERNAL LOADS

Knowledge of the nature of the distribution of stress and strain in bone as a response to the implantation of pins in the marrow, such as those encountered in endoprosthetic joints and transcutaneous pylons, will be essential if these experimental methods are to develop into practical, clinical therapies.

The tolerance of the tissues to implantation and to the magnitudes and types of loading will also be an important factor in this research.

IMPLANTATION OF ARTIFICIAL ORGANS OF THE MUSCULOSKELETAL SYSTEM

Another aspect of the possibility of utilizing as much as possible of the natural anatomical system instead of exoskeletal devices is the use of implanted artificial muscles. It is envisioned that plastics capable of contraction excited by external signal will become available. Study of the materials and the tolerance of biological tissues for them will be required to realize this possibility.

The effects of implantation on endoprostheses and endoorthoses need more comprehension if materials are to be developed to make approaches practicable. This will include the chemical and physiological reactions as well as the biomechanics of the arrangements.

Of vital importance is knowledge of the tissue reactions to implants if methods of this type are to succeed.