DESIGN PRINCIPLES OF PROSTHETIC APPLIANCES AND APPARATUSES FOR THE LOWER LIMBS

L. M. VOSKOBOINIKOVA

The movements made by man during walking are a complicated physiological and biomechanical process. Disturbance of the function of the lower limb owing to a defect, amputation, or an affection of the muscles leads to sharp changes in the whole of man's locomotor apparatus.

Prosthesis, being an integral part of the complex orthopedical treatment given to the patient, to some extent restores the lost functions of standing and walking. Prosthetics is no longer the exclusive occupation of practical workers or an empirical approach to the solution of problems of design.

At present, the designs of prosthetic and orthopedic appliances are based on a study of the clinico-physiological and biomechanical features of the gait of both a healthy man and one using a prosthetic or orthopedic appliance. The laws of movement of a healthy limb and the specific features of the process of walking with the help of a prosthetic appliance are determined both by studying these features by various objective methods and by analytical examination of artificial lower limbs.

In order to elaborate the theoretical principles of prosthesis, the Central Research Institute of Orthopedics and Prosthesis has made it a rule to minimize asymmetry of the steps of a healthy person one with an artificial limb. In the normal state, the static and dynamic conditions of the functions of both sides of the organism when standing or walking are practically the same. When the limb is diseased, or after amputation, these conditions are disturbed. Therefore, in prosthetics the relative position of the parts of artificial limbs is determined by the demand for the minimum asymmetry and minimum expenditure of energy. This rule makes it necessary to establish the relation between the individual features of the patient and the parameters of the prosthetic appliance. Hence, the basic principle in making prosthetic appliances is compliance with the patient's individual specific features. In its turn, the collection of information on the peculiarities of standing and walking in different patients and analysis of these results enable us to systematize these data and determine the natural relations between the patient's individual specific features and the parameters of the artificial limbs which he needs.

A design of a prosthetic appliance for the thigh has been worked out by the lower limbs laboratory of our Institute. It is based on the rule of minimizing asymmetry of the steps of the healthy and the artificial limb and compliance with the individual anatomic and physiological features of the patient. Here we take into account the established relation between the length of the stump and the adequate ratio of the thigh socket to the knee-shin-foot unit in the sagittal and frontal planes, and also the relation between the level of amputation and the direction of the socket with respect to the horizontal plane and frontal axis of the knee hinges. These rules have been recorded in a reference table. The decisive data for choosing the parameters of an artificial limb are the level of amputation, the suspension system, and the design and size of the foot. The level of amputation is determined by the ratio of the length of the stump, measured from the greater trochanter, to the length of the healthy thigh, measured from the greater trochanter to the articular orifice of the knee joint. Definite rules have been established concerning the necessity of greater displacement of the thigh socket in the sagittal and frontal planes relative to the knee-shin-foot unit for a shorter stump, and vice-versa, reduced inclination of the thigh socket relative to the horizontal plane, and reduction of its inward turn relative to the frontal axis of the knee hinge for a longer stump.

Individual designs of prosthetic appliances for the thigh considerrably increase the patient's functional possibilities, bringing the kinematics of walking with a prosthetic appliance nearer to normal. The classification of the results of analytical and biomechanical research into the specific features of walking, in simple and concise tables, promotes extensive use of these data in the practice of prosthetics. At present, the design of the prosthetic appliances for the thigh elaborated at our Institute is being used at all Soviet prosthetic-orthopedic enterprises which have been furnished with special equipment and instruments for this purpose.

A comprehensive study of the process of walking is being made at the Institute with the help of clinical, physiological and biomechanical methods. The specific anatomic and functional features of patients are being studied, as well as their compensatory potentialities and social and domestic inclinations.

The biomechanical analyses of the process of walking normally and with prosthetic appliances and apparatuses are based on a study of the changes in the duration of separate stages of the step, and of the elements of the support reactions and turning angles of the hinges and joints. For instance, a prosthetic appliance for the thigh usually ensures maximum mobility of the knee hinge. A study of patients' gaits with a prosthetic appliance for the thigh showed that absolute mobility of the knee hinge tends to increase asymmetry of the movements of the healthy leg and the stump with the prosthesis. The patient's functional possibilities are reduced in their turn. As researches have shown, the movements of the knee joint are corrected by the functions of the muscles which control the motion of the shin. The ordinary devices for prosthetic appliances for the thigh, in the form of a shin brace or a driven buffer device regulate the mobility of the knee hinges only at the moment of bending, preventing »jack-knifing.« When extending the knee hinge, on the other hand, the action of these devices accelerates the movements of the shin and causes asymmetry in walking. In order to normalize walking with an artificial appliance for the thigh, it was suggested to furnish the knee hinges with a braking device. The friction of the braking device is adapted to the individual requirements of each patient, taking into account the weight of the leg and the distribution of the bulk. Naturally, these parameters change for one and the same patient with a change of footwear. Therefore, the knee unit of a thigh with a braking device is provided with a mechanism regulating the intensity of friction.

In recent years, the staff of the Institute has elaborated methods of simultaneously establishing the magnitude of the angular displacements, angular velocities and angular acceleration, both in any joint of a healthy limb and in the hinges of a prosthetic apparatus or appliance. Moreover, the periods of rest and motion during the step are simultaneously recorded.

Records of the electric activity of the muscles during walking help to establish the mechanisms of the complicated locomotor act of walking. At the Institute we simultaneously record the biomechanical parameters of walking and the electric activity of the muscles (Fig. 1). This method helps to reveal changes in muscular electric activity at different stages of the step. The electromyogram is recorded by an integrator, in order to find its total value.

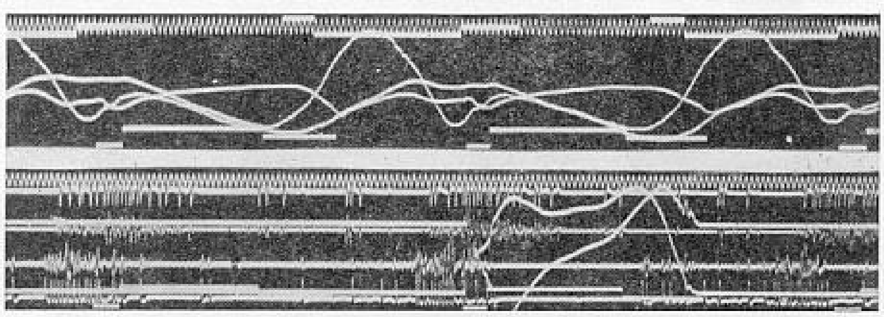

Figure 1.

By an analytical examination of the movements of an artificial limb a number of specific features can be found. Thus, the movements of the artificial appliance for the thigh during the stage of motion were compared to the laws of the dynamics of a double physical pendulum suspended from the hip joint. The desire to ensure identical movements of the healthy and the artificial lower limb led to the solution of the problem of rational distribution of bulk in the prosthetic appliance, achieved by balancing the artificial limbs.

By studying the process of walking by the above methods we can determine the direction to be followed in designing prosthetic-orthopedic appliances, and also control the implementation of the theoretical results in the designs. These methods are also used to appraise the efficiency of finished prosthetic-orthopedic appliances, as well as their defects.

All prosthetic and orthopedic appliances must be functional. This can be ensured by the rational shape of the receiving plane of the prosthesis or the socket of the apparatus and the choice of material from which they are made, by rational structure and distribution of bulk, regulation of the mobility of the hinges, the use of shock-absorbing devices, etc.

For several years past a latchless orthopedic apparatus has been widely used for patients with total paralysis of the lower limbs, as well as prostheses for patients with congenital under-developed lower limbs, for cases of dislocation of the thigh-bone, etc. In the latchless orthopedic apparatus stability of the knee joint of the paralyzed leg is ensured by the relative position of the hinges of the apparatus. The knee joint is situated at the level of the epicondyle of the thigh, while the hip and ankle joints are moved forward if the backward flexion of the foot is limited. This design of the latchless apparatus enables a patient with paretic muscles to make use of the movements of the joints of the limbs during walking. This considerably enhances his functional possibilities and, besides, serves as a restorative factor in treating the paralyzed muscles.

When building functional prostheses for patients with congenital under-developed lower limbs, their specific anatomic-physiological and biomechanical features are taken into account. For instance, the atypical movement of circumducting the foot, seen in patients with a very short leg owing to under-development of the thigh, is used to control the movements of the prosthetic knee hinge.

For several years we have been using a rational form of the socket of the prosthesis of the thigh, thanks to which no braces are needed. Work is proceeding on the elaboration of different types of sockets for the thigh depending on the functional condition of the stump muscles. In order to estimate the functional properties of the thigh corset, the pressure of the socket on the stump and the state of the blood circulation in the stump fitted with the prosthesis are being studied.

One of the conditions for functional prosthesis is to prepare the patient adequately. This includes conservative and surgical methods of treatment with the aim of eliminating deformities of the lower limbs or defects and diseases of the stumps.

In order to improve the functions of an affected limb, transplantation of the muscles, is done as well as a number of other reconstructive operations. During the preparation for prosthesis, the tissues of the stump are formed, the patient develops compensatory adaptation and acquires the habits of using the prosthesis. All types of conservative and surgical treatment given before prosthesis are selected with a view to the subsequent prosthesis; for the design of prosthetic-orthopedic appliances is chosen with due regard for the specific anatomic-physiological and biomechanical features of the patient and improvement of the residual functions of the affected limbs is used to control the artificial limbs.

One of the most important conditions of modern prosthesis is teaching the patient how to use prosthetic appliances. Moreover, it is obligatory both when first fitting the patient with the appliance and when repeating it. Training in the use of prosthetic-orthopedic appliances is closely connected with the preparation for prosthesis, as the latter serves the aims of improving the function of the subsequent prosthesis. All preparatory measures are carried out with due regard for the requirements of using a prosthetic appliance. Already when learning to stand and walk with an experimental appliance or in a plaster cast the patient acquires the initial habits of using prosthetic appliances. Therefore, the primary training must be particularly thorough. Training is conducted along the lines of gradually increasing the difficulty of the tasks to be performed and consolidating the acquired habits. A great role here belongs to work therapy, during which the process of training is facilitated by the emotional factor.

Hence, modern prosthesis is based on clinico-physiological and biomechanical researches, the extent and volume of which are continuously increasing.

Modern prosthesis develops along the lines of enhancing the functional potentialities of the patients, both by using and increasing the residual functions of the patient's skeletal motor apparatus, and by perfecting the design of the units of the prosthesis and its assembly. Here, the patient's individual specific features must be taken into account. The preparation of the patient for prosthesis and teaching him how to use prosthetic-orthopedic appliances form an integral part of prosthetics.