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# THE MAIN DIRECTIONS FOR ADVANCEMENT OF MOTORIZED LOWER LIMB PROSTHESES

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## Abstract.

The results of biomechanical and physiological studies in the amputees walking on a new experimental model of a motorized above-knee prosthesis are given in the paper, the prosthesis being supplied by an electric drive, which performs charging a mechanical accumulator during the period of each stride. The accumulated energy is used for performing a rather powerful heel-strike by the leg fitted with a prosthesis.
It has been revealed that an active pushing the prosthesis off the ground followed by the plantar foot flexion decreases significantly energy expenditures of the body on the whole,especially the musculature of a normal leg, besides it normalizes the gait of the amputee, decreases vertical displacements of a total center of a body mass, promotes more easy swinging the prosthesis over the support.
The basic directions for further development of motorized prostheses are given in the paper which will make it possible to widen their functional possibilities (walking at a quick pace, slow running), to improve the drive characteristics and the system of control the momentum of beginning the heel-strike.

## Introduction:

As it is known in the motorized above-knee prosthesis by means of an electric drive the potential energy is accumulated in the spring accumulator during the period of a stride. At the heel-strike the energy is discharged as an impulse of an adequate power by means of which pushing the prosthesis off the ground is performed as a result of jerky plantar flexion of the artificial foot /I/.

The new experimental model of the motorized above-the-knee prosthesis is characterized by a number of advantages. The power of the electric drive is increased up to 18 W that permitted to increase the work performed by the drive device at the heel-strike up to 12 J, as well as to increase the possible gait rate to 120 steps per minute. Above-mentioned power of the electric drive has proved to be quite adequate in the invalids with a mass not exceeding 80 kg.

The cam mechanism used in the drive device provides such a manner of force mementum change at the ankle joint which ensures maximal reduction of energy expenditures in the amputee's walking as well as optimization of the range of the electric drive work in the process of charging the mechanical accumulator.

The artificial foot used in the prosthesis is provided with hinges in its hind and fore parts that makes possible to realize plantar foot flexion at the heel-strike without energy expenditures caused by the resilience of the back buffer.

The use of worm gear on the first stage of the electric drive reductor allowed to decrease significantly the noise level which arises in process of walking on the motorized prosthesis.

Biomechanical and physiological studies in 5 patients walking on the new model of the motorized above-the-knee prosthesis have exposed some more convincing proofs of these prostheses efficiency. Kinematics and dynamics of walking, the rate and symmetry of the gait are normalized to a considerable extent. As an example, the plantar flexion of the artificial foot at the heel-strike reaches $15^0$ and a vector of the ground reaction in this phase grows by 10,5% on the side fitted with the prosthesis. Accordingly a vector of the ground reaction on the normal side decreases in the phase of the heel-strike.

Active pushing of the prosthesis off the support followed by sharp plantar flecion of the artificial foot promotes easy swing of the prosthesis over the support that is important as the amputee at this moment almost does not feel the prosthesis weight. Vertical shifts of a total center of mass are decreased, a pattern of movement of a toatl center of mass projected against the frontal plane becoming more symmetrical.

Fig. 1. shows the plots of weight-bearing reactions and podograms whicle the patient E. walking on the motorzied above-knee prosthesis in an active range with the drive switched-on (solid line) and in a passive range, with the drive switched-off(dotted line).

As it may be seen from fig. 1., vertical components of weight-bearing reactions during walking in an active range at the heel-strike by the normal and prosthetic legs are equal by their value. The time of stance and, respectively, the time of swing for each leg over the support as well, completely coincide.

Fig.2 shows the plots of inter-joint angles and podograms while the patient M. walking on the motorized above-knee prosthesis in the active and passive ranges. As it may be seen from fig. 2 in walking in the active and passive ranges a form of changing an ankle-joint angle on the prosthetic side approaches that one on the normal side. Maximal angles of extension at the normal and artificial hip joints have become equal. The meanings of the maximal angles of flexion at the knee during swing phase have become also equal. As a result equalisation of the length of steps takes place in both the intact and amputated limbs. The interval between the time of finishing extension at the artificial knee joint of the motorized prosthesis and putting the prosthetic leg down on the support decreases significantly which also promotes normalization of the gait pattern.

The greatest influence of motorization of above-the-knee prosthesis is revealed in the energy expenditures of the amputee during walking.

For example, the energy expenditures of the normal leg in walking on the motorized prosthesis (the drive switched on) with respect to the enegy expenditures of the same leg during walking in the passive range( the prosthetic drive is switched off) have been reduced on the average by 24% (one case- 35%). The total energy expenditures (including the normal and truncated limbs) have been reduced on the average by 20.3%, and in the separate amputees-by-26%.

With this kept in mind the work being performed by the muscles at the hip joint of the normal leg at the heel-strike is decreased, on the average, by 28%, at the knee joint-by 13 percent, at the ankle joint-by 33,5 per cent.

Comparative investigations of the integrated muscular activity of eight muscles on the intact leg and four muscles on the above-knee stump have also proved functional efficiency of the above-knee prosthesis with an active heel-strike. In different patients a load on the muscles of the normal leg has been reduced at switching the active heel-strike on, from 16 to 29 percent( as the data of the integrated electromyogram show). Reduction of the load on the muscles of the thigh stump has been also revealed, nevertheless there is no definite regularity in it.

For the purpose of determination of the influence of the active heel-strike on the pressure distribution in the field of a sitting ring of the thigh socket an appropriate investigation has been

carried out with 8 tensosensors being placed at a certain sequence along the perimeter of the sitting ring. The investigations have shown that the summarized load on all the sensors is constant for both ranges (active and passive). Minor deflections of separate meanings of the pressure (not exceeding 3%) in the field of the ischial seat, great trochanter, abducting muscles in the different ranges of walking took place. These deflections are contained within the limits of precision of the method used for the measured value registration. This way it has been proved that motorization of a prosthesis does not have a negative effect on the pressure distribution along the stump inside the socket.
Fig.3 shows the invalid M. on the motorzied above-knee prosthesis in process of fitting it (the prosthesis without covering).An important direction of advancement of motorized prostheses is their provision with more functional units (two-link foot, two-joint knee-unit, appropriate bumper devices) that allows to make use of these prostheses for fulfilling rather complicated supportive-motional functions, as for example, walking at a quick pace and slow running. In particular it is achieved by that fact, that two-joint artificial knee allows bending and subsequent straightening under the load of a body weight that is very important in a quick pace walking and quite necessary for running.
The study of biomechanical characteristics of slow running has revealed that they may be reproduced in a motorized above-knee prosthesis. Consequently, using this prosthesis it is possible to fulfill slow running, (sanitation running, for example). On the base of studying 8 patients the following fitures have been exposed, which allowed to make recommendations with respect to the motorized above-knee prosthetic design taking into consideration the possibility of slow running.

1. A total duration of a cycle in slow running composes 0.75-0.88 s, on the average-0,82 s, with about 30% of time presenting the time of stance.
2. Full motional range at the hip joint increases to 47°in slow running (scattering from 35°to 53°)
3. The angle of bending at the knee under the load at the beginning of the stance time is equal at an average 35°, beginning of bending under the load from the flexed position of the leg composing the angle equal about 10°.

4. The maximum angle of flexion at the knee in the swing phase composes 73° (scattering from 65-90°), the bending beginning at the moment of push the leg off the support.

5. The support against the heel begins in the position of the dorsal foot flexion (10°), the angle of plantar foot flexion during support on the heel, at an average, also composing 10°, i.e. plantar flexion is being performed till the value of the angle accords with mid-stance of the foot. The angle of dorsal flexion during roll-over with respect to the foot approaches 24° and the angle of plantar flexion during roll-over with respect to the toe approaches, at an average, 20° (from the mid-stance position). Thus the full motional swing at the ankle-joint composes at an average 44°.

6. The vertical component of the foot-floor reaction, common for the toe-off and heel-strike phases, in slow running approaches at an average 240% from the weight of the patient (instead of 110% while walking in voluntary rate). At the same time the longitudinal component of the heel-strike approaches 37% from the weight, in walking. Sharp increase of the vertical component may be explained mainly by the enforcement of the strike at the toe-off and consequently is little connected with increase of the power developed at the heel-strike. As regards to the increase of the longitudinal component of the foot-floor reaction at the heel-strike it may be achieved partly on account of development of increased power at the push off the support and partly is achieved on account of change of the slope angle of a total vector of the weight-bearing reaction with respect to the supportive surface.

7. Comparison of integrated electrical muscular activity with the work being wasted on motions at the joints shows that in comparatively negligible increase of a total electrical activity of eight selected lowerextremity muscles (on the average, by 26%) a significant increase of the work at the lower-extremity joints (more than two times) takes place. This fact proves highly economical expenditure of the metabolic energy in slow running that may be explained by an intesive use of visco-elastic components of the muscular apparatus. Owing to this phenomenon a potential energy stored in the muscles during yielding range of the work (with lengthening of muscles) is effectively used in overcoming range (with shortening of muscles).

With consideration of biomechanical peculiarities of slow running the units of the motorized above-knee prosthesis are being adapted. This concerns mainly the components of the two-joint knee unit and two-link foot, as well as the parameters of the electric drive. The power of the drive is increased by 20% and the number of its work cycles approaches 65-75 per minute (at a rate of 130-150 steps per minute).

Another direction in development of motorized prostheses is improvement of the electric drive characteristics: lowering the weight, providing its noiseless and reliable work, increase of economic efficiency.

The research is also carried out for the purpose of development of many types of control by the prosthetic drive supposing different ranges of work;

- automatic control with the help of a sensor triggering at the moment of approaching the calculated value of the dorsal foot flexion;
- bioelectric control by means of signals from one of the truncated muscles of the thigh stump;
- combined control supposing cooperative triggering a posture sensor and an actuator relay of the bioelectric control system;
- switching off the drive on emergency;
- passive range when external energy is switched off;

Realization of above-mentioned types of control by the time of the beginning of the active-heel-strike widens the possibilities of motorized prostheses use in more complicated conditions of walking.

## References

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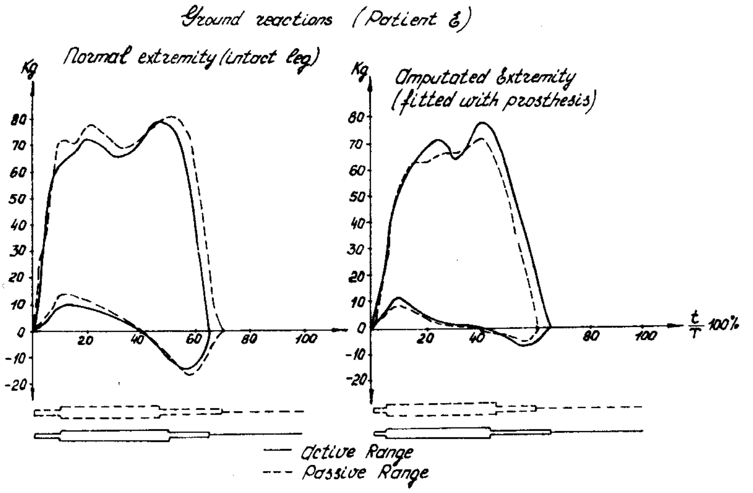

Fig.I. The plots of weight-bearing reactions and podograms while the patient E. walking on the motorized above-knee prosthesis in an active range with the drive switched-on (solid line) and in a passive range, with the drive switched-off (dotted line).

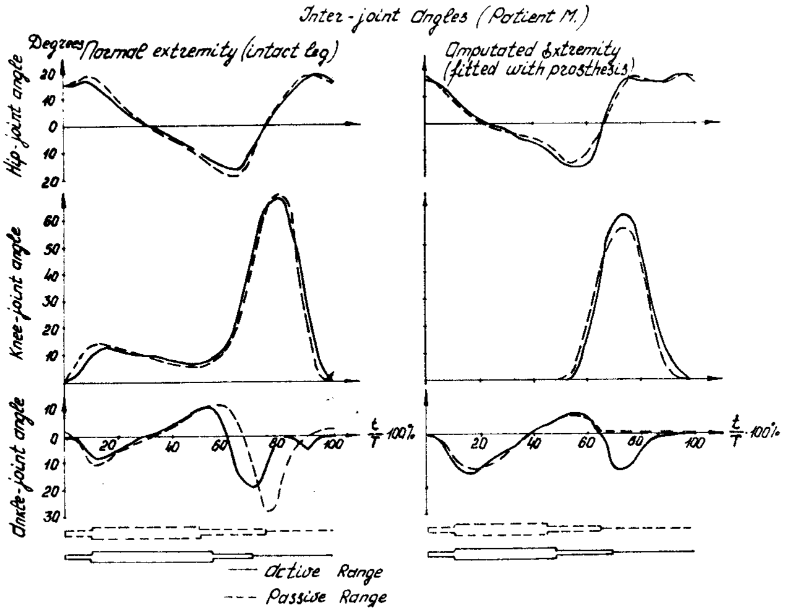

Fig.2. The plots of inter-joint angles and podograms while the patient M. walking on the motorized above-knee prosthesis in the active and passive ranges.

Fig.3. The patient M. on the motorized above-knee prosthesis in process of fitting it (the prosthesis without covering).