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APPLICATION OF ACTIVE EXOSKELETONS IN THE REHABILITATION OF HANDICAPPED PERSONS

M. Vukobratović, D. Hristić, Z. Stojiljković

Summary

During the last three years the Biotechnical Department of the Mihailo Pupin Institute in Beograd, Yugoslavia, conducted in cooperation with the Orthopedic Clinic in Beograd, the Rehabilitation centers in Beograd and Ljubljana several experiments with a certain number of paraplegic and paralytic patients in order to gain experience and evaluate the man-machine systems in the case of active exoskeletons. Some results of the experiments are illustrated and details for self-mounting of the active orthosis by the patient are presented. A way of autonomously using the orthosis inside the living space of the patient is also demonstrated. Prototype of a new model of pneumatic artificial joint actuator is described and shown.

Introduction

This paper deals with experiments conducted from beginnig 1972 to the end of 1974 with the pneumatically driven active anthropomorphic exoskeletons, which have been developed during the same time period /1,2/. Several patients participated in the trials with varying success. It should be said here that the working version of the active exoskeleton with pneumatic drives was not equiped with the stabilizing function with respect to great perturbations, but was dynamically stable in nominal regimes /3,4/. Some sort of stabilization was indispensable, notably from the standpoint of psychological reassurance of the patients, who, most naturally, were obsessed by more or less expressed fear, which diminished slowly in the course of the experiments progress.

Mostly used auxiliary equipment for the gait experiments with paraplegics, were

- special pathway with hand bars, 6 meters long (Fig. 1),
- light four-legged support, carried by the patient himself (Fig.2).

Very good training results were achieved in the pathway, most of the patients achieving quite stable and dependable walk after only approx. 1-2 hours training. It is our opinion that this sort of pathway is very useful for clinical training of patients, as well as evaluation of the equipment.

With the light four-legged support, made in the form of a welded frame from aluminium tubes, weighing only 2 kp, the following results have been achieved:

- the patient was able to walk without any physical external help after only half an hour's training, but after previous walking experience in the mentioned pathway with bars;

- the patient mastered shallow turns to either side, with radii of approx. 5 meters, after supplementary training of one hour duration;
- the patient achieved easily the performance of passing through comparatively narrow doors, without any trouble.

It is important to stress out here,that these experiments were all conducted in the presence of a whole team of technical and medical experts, participating in the trials. External control of the actions was exclusively used. The patient did not take decisions and give commands himself; that action was performed by a member of the team.

The very vulnerable phychological state of the heavy handicapped persons /5/, caused in some aspects a too sympathetic and pitying approach of the members of our technical team towards the patient, which resulted in underrating the importance of self-supported rehabilitation of the patients, meaning their participation in the trials and all auxiliary actions in the greatest possible degree. The medical side of the team, being on one side unsufficiently experienced with the new apparatus, caused also exapperated caution and care regarding the patients, and, on the other side, gaining only gradually confidence in our work and the results of the associated efforts, was not able to signal us in time this very important moment.

It was a very refreshing experience to establish in the newest period cooperation with a settled-down case of a heavy polio case in the person of a male patient of medium age, working full time in a place, calling for a diploma degree, which he possessed, driving his own adapted car, and in general living a possibly most normal life for such a heavy degree of handicap. Medically regarded, he was very similar to a paraplegic, since in the legs was not preserved any muscle power, the legs themselves being typically atrophied to the dimensions of a normal human arm, and the waist region possessing quite expressed muscle actions, while the torso and arms were rather athletic. So this case could be compared with a flaccide paraplegia of approx L-2 lesion height. Psychologically regarded, the person was of expressed inteligence, but without great technical knowledge, which proved to be of lesser importance, this lack being supplemented by great motivation for the experiments, relative abscence of fear and rather developed feeling of stability in the specific circumstances. As opposed to all these positive features, drawback had to be noticed in the habit of walking by arm power, the patient having used normal crutches since the illness, which meant in the particular case, for a period of more than 20 years, so an appreciable period had to pass in order to re-adapt the man to walking by means of his legs, his weight being supported by its greatest part by the exoskeleton structure and power being feed externally. This created the feeling, noticed also by the paraplegics in the course of the previous experiments, of "flying", which is a rather specific and new notion in rehabilitation, associated only with active orthoses and is also to be expected during the eventual future trials with active leg prostheses. This feeling, although described by most of the patients as relatively pleasant, was, at the least most unusual, which could be understood if one recalls the great effort, normally exerted by paraplegics and similar handicapped persons in the course of locomotion by means of crutches. Externally supplied power means in the same time, possibility to change place in the environment with much less effort, to surmount up to that moment almost impassable barriers, like staircases, but also some relaxation and leisure on the patient's side, which could be compared to locomotion of men on powered wheeled vehicles and airplanes, opposed to walking on own feet the same distances.

In any case, locomotion of handicapped persons by means of active orthoses (and prostheses) must provoce new procedures of rehabilitation, new methods of evaluation, as well as new viewpoints regarding the problem of rehabilitating heavily handicapped people.

The experience, gathered with several patients and the few last models of the pneumatically driven active exoskeleton, urged us to pass over to a new phase of experiments, intended to evaluate the possibility of the most autonomous use of the rehabilitation apparatus by the patient himself.

Self - mounting of exoskeleton

One of the geatest reproaches, expressed by medical and other interested people in the general use of the active exoskeletons, including the patients, was the rather difficult procedure of mounting the exoskeleton structure onto the patient's body, or "dressing" the apparatus. The reason for the rather complicated solution of links, fasteners and the like, could be sought in the main direction of the research being aimed at the solution of the more important current problems of the hardware, as for instance, general dependability, weight, problems of the body and leg corselets from the standpoint of decubital danger, to mention just a few of the same. The very important human factor of the patients, being in the majority of cases "frest" paraplegics, played also a very important role.

Self-mounting, or "dressing" of the active anthropomorphic exoskeleton is foreseen to be effected either on the bed, or in a chair. In both cases it is made possible by special quick fasteners of the corselet cover and the covers of all the leg connections with the machine. All covers are hinged by means of leather hinges, which allow for a certain amount of misalignement of the axes, on one side and on the other side the links are realized by means of quick-fasteners, typical on ski-shoes and similar equipment (see Fig. 3).

In the case of dressing the exoskeleton on the bed, the patient has to take the orthosis, "sitting" on a chair, beside the bed, and put it to lie on his side, all the covers being loose and wide open. Then he must lift himself by means of muscle power of his arms and put himself to sit in the space between the main corselet and the corselets of the thigh parts of the legs. After that, he is to fasten all four covers of the leg parts to the orthosis (the shank and the thigh parts). After that he must put himself in lying position on his back into the body corselet, close the cover of the same and engage the quick-fasteners to join the corselet into an entity. After that the patient has to lift his body to sitting position, put his legs down the sides of the bed, helping this action with his hands and convert his position into a sitting one on the edge of the bed. He is now ready for the operation of standing up, to be described in detail in the following paragraph.

The procedure of "dressing" the orthosis in a chair is quite similar to the above described one, only in this case the patient has to lift his body into the chair, standing beside his bed. Some patients, with greater muscle power of their arms and better training will probably prefer this procedure to that, described before, but this is still to be proven. In any case, both of the procedures bring the patient into a sitting position, either on his bed, or the chair beside the same.

Procedure of standing up

This procedure is conceived for the moment only for the use of the active exoskeleton with pneumatic drives. It will be elaborated in the future for the case of the electrically driven exoskeleton, but this is not the object of description in this paper.

The procedure of standing up autonomously, by the patient being alone in his living space, is a very difficult task. In spite of the fact that it might seem relatively simple, it has to incorporate solution of many delicate problems, in the first place, stability during standing up, sufficient energy surge to perform this motion with sufficient speed to render it acceptable, absolute security during the same, etc.

The process is illustrated in Fig. 4. The patient being in the sitting position, grasps with both hands the inclined aft bars of the light four-legged support, the same being fastened to the bed, or chair, by means of relatively simple easily engaged and disengaged mechanism, which can be depicted from the illustration. In the described position, the patient operates a simple switch, mounted on the inclined bar of the support, which is nearby to the optimal position of the hands in the grasping action, and which, on its side, activates a normally-closed solenoid valve, which introduces compressed air from the reducing valve on the compressed air bottle, or the compressed air mains from the compressor tank, into the air menifold of the active orthosis, which in the desactivated position of the electronic control system is always in the "closed" (or inactive) state. So for the moment nothing will happen. The patient has now to flip another switch, which energizes the electronic control system, this bringing the orthosis into a standing or upright position, the patient helping this process and stabilizing it by means of his both hands.

Quite similar procedure is prepared for standing up from the mentioned chair.

The patient is now ready for the next action - starting to move by means of the active orthosis in the limits of his living environment, limited only by the length of the compressed air supply tube (which can easily be 25 meters long, in the case of a plastic tube of 8/4 mm section).

Starting of the motion

This is also a critical part of the locomotion process; it has been proven by numerous trials in our experimental work with several patients and types of the active orthosis.

According to the newly concepted solution, this task is to be performed by the patient himself in the following way:

The patient is standing erect in the four-legged support, grasping by both hands the horizontal hand bars of the same. On the side of tis leading hand (right or left) there is mounted a master potentiometer (see Fig. 5), which is in easy reach of the second finger of the patient's leading hand. This potentiometer is activated by means of a small curved lever, similar to the trigger - of a gun, which is spring-loaded towards its "zero" position. In this position, the potentiometer feeds into the electronic system the command for step period T= infinite, so the exoskeleton is resting in the standing position. By pulling slowly the "trigger" of the potentiometer, the patient is starting to move, first very slowly, than, according to his desire and the circumstances, faster, up to the fastest pace of approx. T= 1,2 sec.

In the course of walking, the patient can very easily stop motion by letting the "trigger" turn back automatically to its starting, or "zero" position, which will happen in the case of reaching some typical obstacle, e.g. a closed door, or change of programmed profile of surface. With sufficient training, the patient will be able to open the closed door, by leaning out from the four-legged support, or changing the program switch on the electronic control system, located on the chest part of his doby corselet.

The process of sitting down is a reverse of the standing - up process and will not be described in detail here.

Special case of sitting down is preparation for using the W. C. The only supplement in this closed environment is foreseen in the form of one strong inclined bar, fastened to the wall beside the place in question. The patient can hold himself firmly to that bar in the course of sitting down and standing up, for a very short time interval (0,2-0,3 sec) with one hand only, while giving with the other one the command signal for the needed action to be performed, immidiatelly after that grasping the bar with both hands in order to stabilize the motion, specially in the case of standing up.

It is evident, that the living space of a paraplegic, who is forced or willing to spend certain portions of the day time all alone, must be adapted to a certain extent for the use of this time of rehabilitation equipment. In any case it is felt, that these adaptations are minimized due to the greater possibilities and power content of the equipment in question, as compared to the classical passive orthotic aids, e.g. the wheelchair or crutches /1,5/.

New type of pneumatic actuator

During the quite long time period of experimental trials with the active exoskeletons with pneumatic drives, it was concluded that the classical form of double acting pneumatic cylinders, although quite perfected in the course of development, resulting in extremely light and dependable pneumatic actuators, which were absolutely "dry" and demanded occasionally greasing only at extended inspection intervals, did not satisfy the very strict demands of such a driving structure, notably from the standpoint of cosmesis and simplicity. In the first place, such design of actuators demanded the corresponding linkage in the from of driving horns, then, rather clumsy and rugged artificial joints, thus preventing even the idea of possible concealment of the active othosis under the garment of the handicapped person.

Much better solution was found in a pneumatic vane-type actuator, illustrated in Fig. 6. The actuator itself presents the driving element, the basis for the solenoid valves, the main artificial joint and the potentiometer housing.

The solution of the actuator is quite simple, when regarded generally, but the incorporated details demanded some special technological solutions.

The main housing of the actuator and its cover was produced from light alloy, the gliding inner surfaces having been anodized and polished to attain a smooth hard surface. In this case experience from the development of the pneumatic cylinders was profited of.

The main shaft and the vane itself was produced from stainless steel, the shaft being hardened and connected to the vane by close fitting and subsequent cementing by epoxy glue. The sealing dry elements are in the form of teflon strips, crossed at the corners to form some sort of labyrinth seal and spring-loaded by means of small springs, located in holes inside the vane. The main shaft is carried by two corresponding ball-bearings, located at either end of the same in the main housing and its cover.

The solenoid valves are mounted directly on the flanks of the actuator, this reducing the tube length of the feeding lines practically to zero, giving much better responce of actuator.

The potentiometer is under its cover on the outer side of the actuator main axis. It is accessible from outside for zero correction.

This new type vane actuator is designed to produce a torque of approx. 15 kpm at an air pressure of 4 bars, this torque having its value independent from the actuator position, which was not the case with pneumatic cylinders, the torque of the same depending on the angular position of the driven joint.

The low value of compressed air pressure was chosen to enable the use of a simple single-stage air compressor.

The actuator is undergoing its prototype testing and is going to be incorporated in the new model of active exoskeleton with pneumatic drives.

Conclusion

The experience, gained in the course of numerous experiments with active orthosis of the active exoskeleton type, engaging several patients and types of pneumatically driven machines, enabled to trace new direction towards perfectioning of this new rehabilitation system. One of very important tasks, which is not concerned with development of the equipment itself, nor its control basic system, is the "dressing" of the exoskeleton by the patient himself, without help by another trained person, as well the procedure of standing up and sitting down, either from and on the bed or a chair, then using the W.C., pass through relatively narrow doors, etc.

The presented solutions show some possibilities to arrive to some acceptable procedures of the kind. It is clear, that much is still to be done in that direction alone, in order to enlarge the applicability of active exoskeletons as rehabilitation means with paraplegic and similar handicapped persons. Anyhow it is our opinion, that gradual progress could be noted in the development of these devices during the last three years, which is of a definite promising character.

Great expectations are with the active exoskeleton with electric drives, being not the subject of this paper /6,7,8,9/.

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Fig.1 Paraplegic training in special pathway

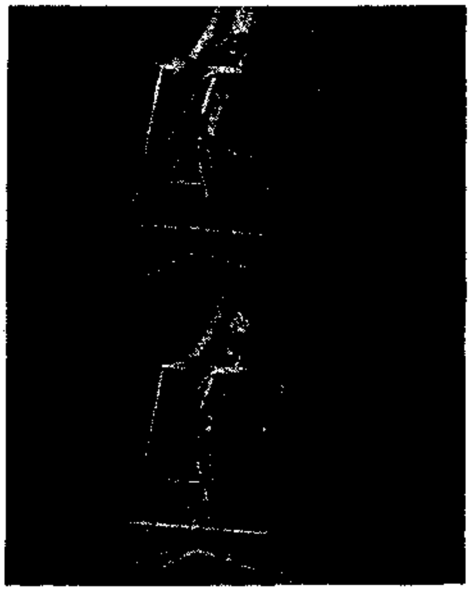


Fig.2 Paraplegic walking w.four-legged support

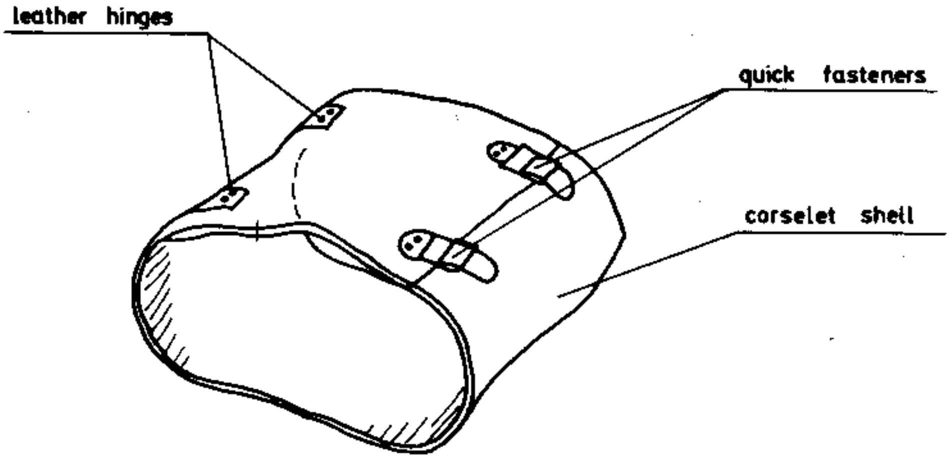


Fig. 3 New solution of closing the corselet

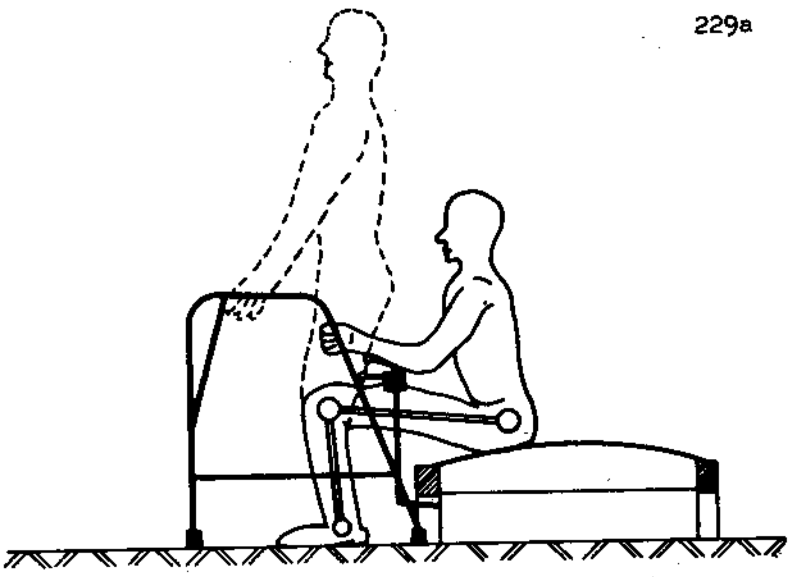


Fig. 4 Process of standing up from the bed

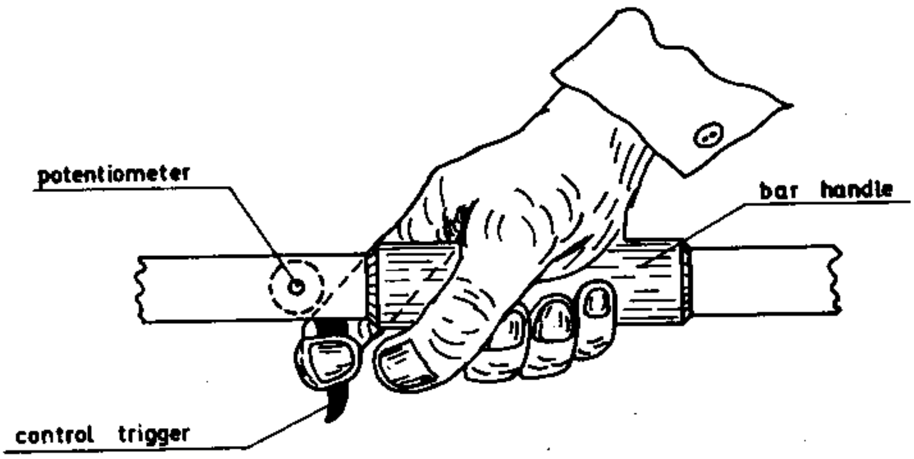
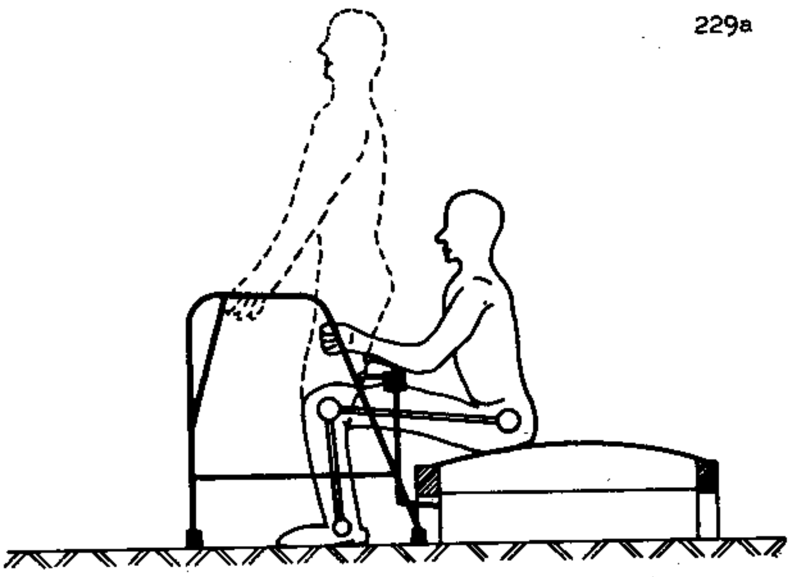


Fig. 5 Master potentiometer with control trigger

Fig. 6 New type actuator for leg artificial joints



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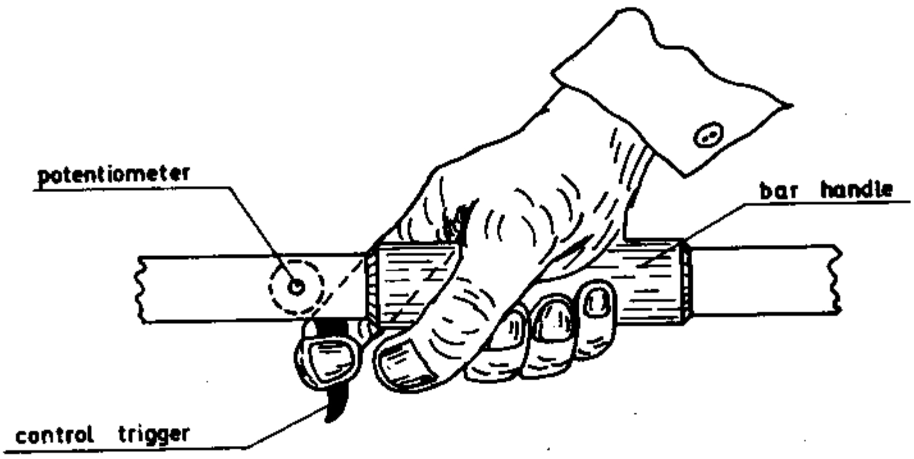

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