CONTROL OF FUNCTION OF THE PARALYZED MUSCLE GROUPS USING STIMULATION OF IMPLANTED NERVES

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Lately, in Poland, the number of heavy injuries of the spine and spinal cord, systematically increases. With simultaneous progress of both: the level of intensive medical care, as also methods of managing spinal cord traumas, the number of tetraplegic patients, as a consequence of spinal cord injury, is more and more greater. These damages most often concern the C 5-C7 segment of the spinal cord. As a result, peripheral part of the extremity - hand- is paralyzed with simultaneous preservation of activities of the shoulder dynamic syndromes and elbow joint elexors. Patients with this kind of injury, are usually deprived of the possibility of performing even the simplest self-service functions, and are entirely dependent on the environment requiring other person care.

In the Institute of Rehabilitation and Reconstructive Surgery at Konstancin, investigations and clinical tests are carried out since 10 years aiming at reconstruction of the tetraplegic hand functions using implanted stimulation of peripheral nerves of the upper extremity.

Last years, our endeavours brought about construction of the apparatus for tetraplegic man based on the programed, controlled by the patient, alternate stimulation of the median and radial nerves.

In the present report, we wish to present attempts aiming at obtaining the best possible practical use of the constructed apparatus. Experiments were carried out on a few tetraplegic patients. Here, we present two typical cases of patients with spinal cord injury to whom stimulators were implanted on the mentioned above nerves, and who were subjected to the discussed investigations.

Case first, patient R.A., 22 years old, clin.hist. 3331/80.

On August 3, 1979 he underwent fracture of cervical spine (C5) as a result of unfortunate dive to the water. Tetraplegia from C5 level down was a consequence of compression fracture of the fifth cervical vertebra. The patient, admitted to our hospital five days from trauma, was conservatively managed-with skull fraction. The course of treatment was complicated by psychic disturbances. Because of the appearance of only a trace activity of the shoulder and elbow syndromes during his first four-month stay in the hospital- the proposition of implanting stimulators was not made to him. This procedure was performed a year later during his hollow-up stay in the hospital, when distinct improvement of strength of the shoulder and albow muscle groups was obtained. This was a condition necessary for functional using of hand activity forced by nerve stimulation.

Stimulators were typically implanted on radial and median nerves exposing them by means of two separate incisions made in the region of the ulnar pit. The patient's stay in the hospital amounted to five months, In this period, systematic timulating training was carried on, as also attempts were made of using the orthopedic apparatus based on the hand function forced by means of nerce stimulation.

Case second, patient C.A., 21 years old, clin. hist. 3729/80.

On December 17, 1980 running to the trum he struch his head

against metal bar with resulting cervical trauma from the extension mechanism with tetraplegic paralysis from C6 level down. Admitted to the Institute few hours ater the trauma, he was operated on next day. During the surgery, injury to the intervertebral disks in the area of C5-C6 and C6-C7 was ascertained. In the region of C5-C6, traumatic disk prolapse into the spinal canal, causing pressure on the spinal cord, is found. After the surgery, gradual neurologic improvement appeared, hand paralysis, however, persisted. On January 26, 1981, implantation of stimulators on median and radial nerves was made, placing the receiver in the subcutaneous tissue. Several days after the surgery, stimulating training was started. During this period, further neurologic improvement was observed, and a trace motions of hands appeared. After several weeks of stimulating trainig, the effect of active helping by the patient of the grasping motion, initiated by stimulation, was observed. This effect-in our observations- is connected, as a rule, with the occurrence of a trace voluntary motion of the tetraplegic hand.

In our investigatins on the stimulating control of the paralyzed muscle groups with the use of implanted stimulators, we are mainly concentrated on the control of grasping function of the tetraplegic hand. In cases of spinal cord injury on the C6 level, there are no possibilities of the use of any apparatus hepling grasping motion because of the paralyses of not only finger flexors and extensors, as well as small hand muscles, but also wrist extensors.

In 1975-1978, there was eleborated and initially tested two constructional versions of the apparatus for the control of grasping function of the paralzyed hand: first one-acting on the principle of "tensomatric balance", and the second one on the principle of what is called "artificial sensation". In each of them, there occurs simultaneous joint action of the orthostesis with the system of implanted stimulators, and with transducers of the position and strength. The conception acting on the principle of "artificial sensation" was accepted for realization. It was based on the utilization of the transducers of the position, touch and displacement (4). The apparatus for the programed control of the grasping function, constructed on the basis of the above conception, and developed in the next years, was applied to three patients with spinal cord injury on C5-C6 level (tetraplegia). Now, it is clinically tested in our Institute.

Figures 1 and 2 present the apparatus itself, and after its application to the patient.

The apparatus serves for controlling the function of the paralyzed muscle groups flexing and extending hand fingers. Its aim is to initially obtain full opening of the hand palm and then, gentle grasp of, and finger closing on, the objects with definite strength indispensable to its displacement or raising. Opening of the hand (extension of fingers) was obatained as a result of stimulation of the radial nerve, whether closing and development of the grasping force-through stimulation of the median nerce from implanted stimulators.

Main attention of the carried on investigations just now, is directed to the control of velocity and smoothness of finger flexion motion during the grasping function. The smoothness of finger flexion motion and obtainment of suitable velocity of changes of the angle of hand palm opening constitute conditions making possible performance of the precise grasp.

During investigations connected with obtainment of the smooth control of grasping function, we tested certain methods of radial and median nerves stimulation in the open system as well as with application of feedback controlling angular velocity of finger motion (2). Since our results proved unsatisfactory, the influence of dampers (supressors, attenuators) and the use of external resistance on the improvement of motion smoothness were investigated.

Figure 3 presents records of angle changes of the hand opening in the feedback system controlling duration of stimulating impulses in cases of unfavorable changes which occur after performance of several consecutive proper and smooth motions.

As results from the records, relatively high oscillations appear, whose occurrence is probably connected with the fatigue of the nervous and muscular system. This is accompanied by muscular tremor during stimulation and even after its ending. This phenomenon is connected with the psychic state and general feeling of the patient. After the period of several, and sometimes even few-minutes rest, the controlled grasping function runs in a smooth manner.

Figure 4 presents records of changes of the angle of hand palm opening as a function of time with the use of friction in orthostesis bearings, which are placed above the metacarpophalangeal articulation of the hand.

Figure 5 is a presentation of records of angle changes together with external resistance produced by springs mounted in orthostesis bearings: a) without feedback, b) with feedback controlling duration of stimulating impulses.

The most reproducible courses of the angle changes during performance of the grasping function was obtained in the system with feedback using constant resistance opposed to flexors by finger extensors (Fig.6).

Our investigations demonstrated that frasping function of hand, forced as a result of programed stimulation of paralyzed groups of muscles extending and flexing hand fingers, is consistent with the assumed program and the forced function is very useful for the patient. After the object has been grasped by him, the active muscles of the shoulder and elbor joint syndromes allow him to its raising or displacing. Control of the apparatus presents no difficulties, is simple and unfailing.

Investigations confirmed superiority of the control system of the suspenders type hung on the patient´s trunk-set in motion by shoulder motions-over the spectacles one controlled by head motions. The manner of controlling with shoulder motions is significantly more convenient for patients guaranteeing them safety of action and almost complete elimination of the possibility of accidental swith-over of the motion phase and change of the grasping strength.

Influence of the touch transducers proved satisfactory, only in the case of grasping great objects of not sharp edges. This is relatively less effective in relation to objects of small dimenskons and sharp edges. This is because only three touch transducers of relatively great dimensions were used in the apparatus, and their action is the most effective when the pressure is exrted in the centr-al part of each of them. Condition of improving the security of action of touch transducers, and therefore their reliability, is miniaturization of them and the appkication of greater number of them in the apparatus in question. Transducers should be placed on the whole

internal surface of the hand palm and fingers.

Because of difficulties with touch transducers miniaturization, experimental tests are carried on aiming at modification of the apparatus in such a way as to eliminate the need of their application.

The trials we have made hitherto, did not bring positive results. This was because touch transducer fulfils very important role making independent the stimulation level (tension amplitude or duration of impulses) on the changes of stimulation conditions both external as well as internal (decrease of nerve excitability), on displacement of stimulating electrodes in relation to the nerve and on the coupling of the stimulator's circumferences, etc. Besides, it establishes the level of stimulation parameters with which grasping force amounts to 2N ± 10% what constitutes the basis for further control of this force magnitude through parameter changes in the external part of the implanted stimulator.

In the course of investigations, the necessity of the use of external orthostesis put on the paralyzed extremity was also confirmed. This serves for forming palm shape as also for stabilization of the wrist joint and the thumb. It was ascertained that in the case of the lack of orthostesis, there occurs, as a result of stimulation of finger flexing muscles, also flexion in the wrist joint and the thumb moves to the interior side of the palm. Such behavior of the hand during the grasping function is nonfunctional and makes impossible grasping of the object. Even if the patient succeeded in performing this function then, after development of the grasping strenth indispensable for object raising, sliding down of fingers from the object follows with resulting dropping of it from the hand.

Investigations demonstrated that external orthostesis should be well adjusted to the patients' hand and be possibly light to limit to the least degree motor possibilities of the paralyzed extremity, not great of necessity.

As it was mentioned before, during investigations of both: the apparatus as well as the influence of systematic stimulating traning on the improvement of function of the paralyzed upper extremities in the case of tetraplegia, the effect of active influence of the patient on the stimulation result, was observed. In our earlier publications (1,5), we have mentioned about this phenomenon. This effect is seen as an active increase or decrease by the patient of the value of strenth developed by muscles as a result of stimulation. Positive effect-assiting stimulation-is most evidently observed with low stimulation level(sometimes above the threshold), whether negative effect decreasing the magnitude of strength- with the level close to the maximum. These effects are seen after several weeks (four to six) of application of stimulating training. The positive effect, according to the last observations, is as a rule connected with the appearance of a trace voluntary function of the paralyzed hand. In investigation on this phenomenon, we undertook an attempt of using the method of "evoked potentials" received from the shoulder plexus, cervical spine and the cortex cerebri. Our first works already pointed out to the occurrence of the phenomenon of facilitating paralyzed nervous pathways by electrical impulses from the implanted stimulators. This gives a basis for assuming that the formerly accempted hypothesis, attempting to explain the mechanism of these phenomena, is in the principle correct and investigations in this direction should rather be continued.

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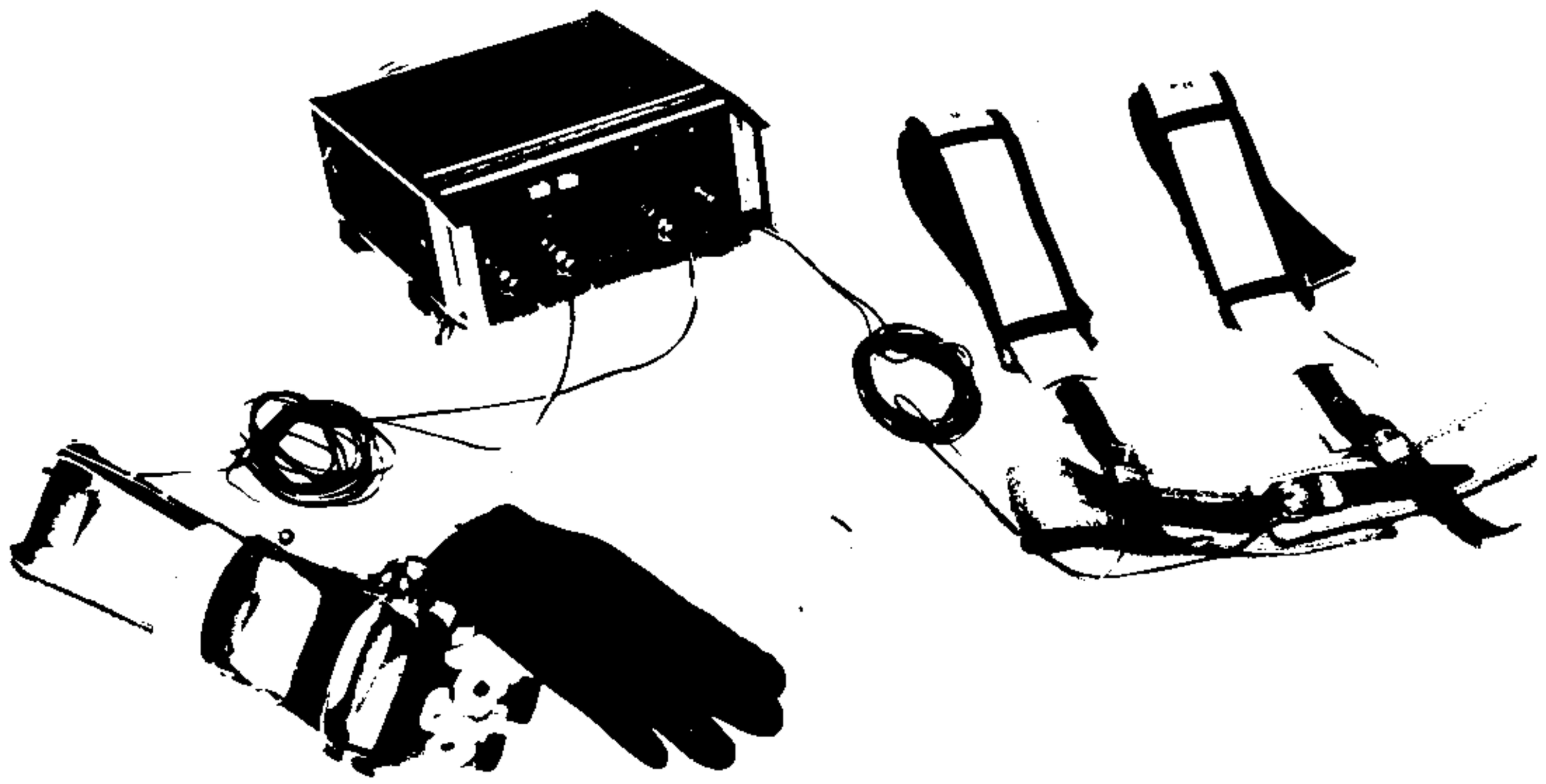

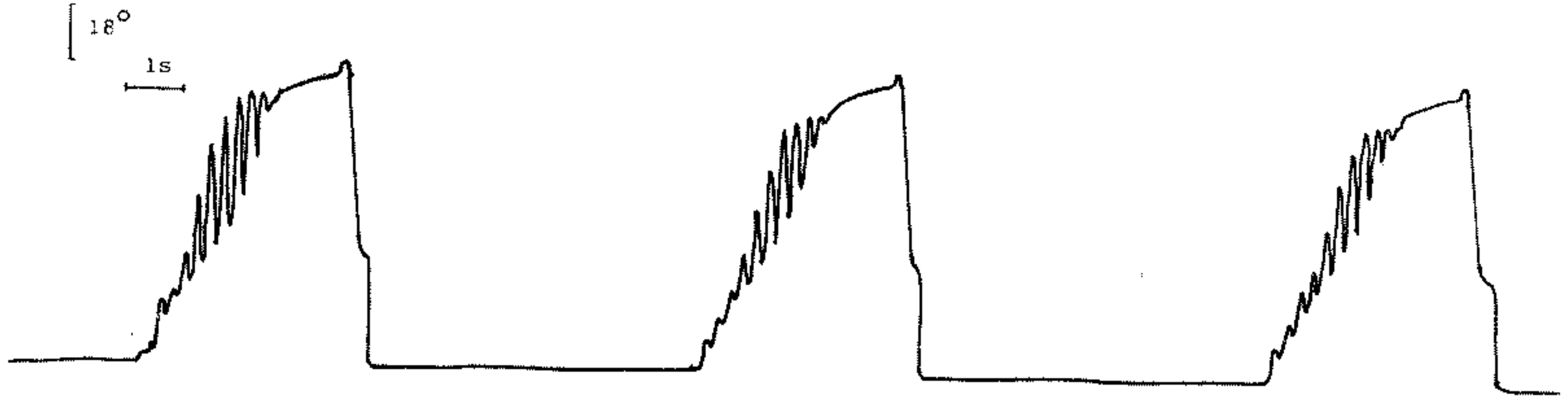

Fig. 3. Records of angle changes of the hand opening in the feedback system controlling duration of stimulating impulses in very unfavorable cases.

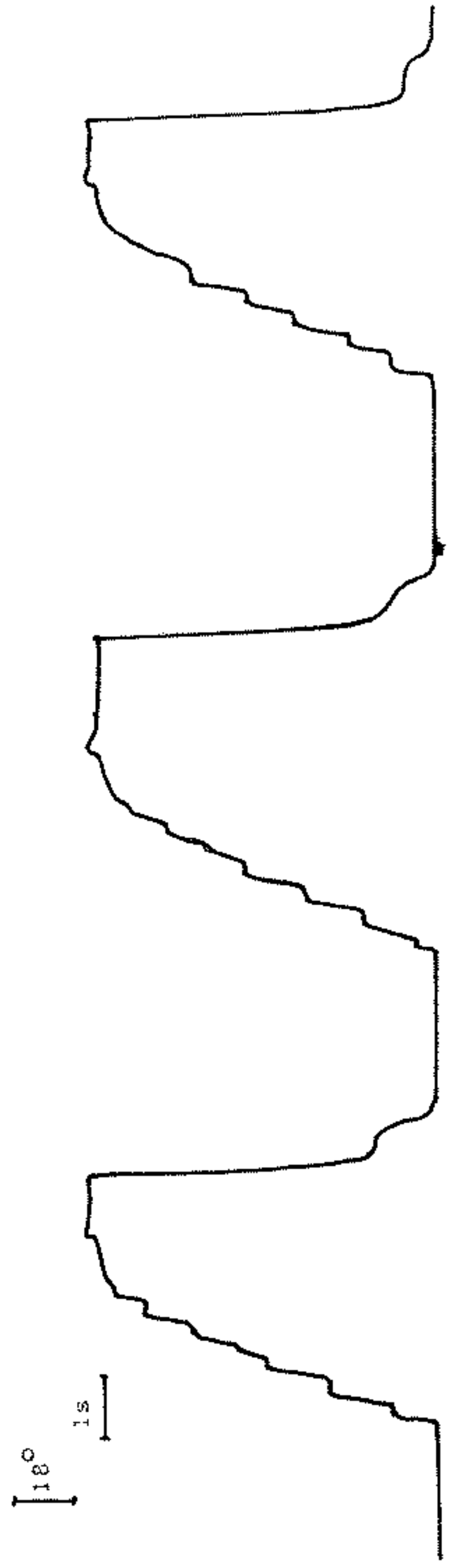

Fig. 4. Records of angle changes of the hand opening as a function of time and withe the use of friction in orghostesis bearings.

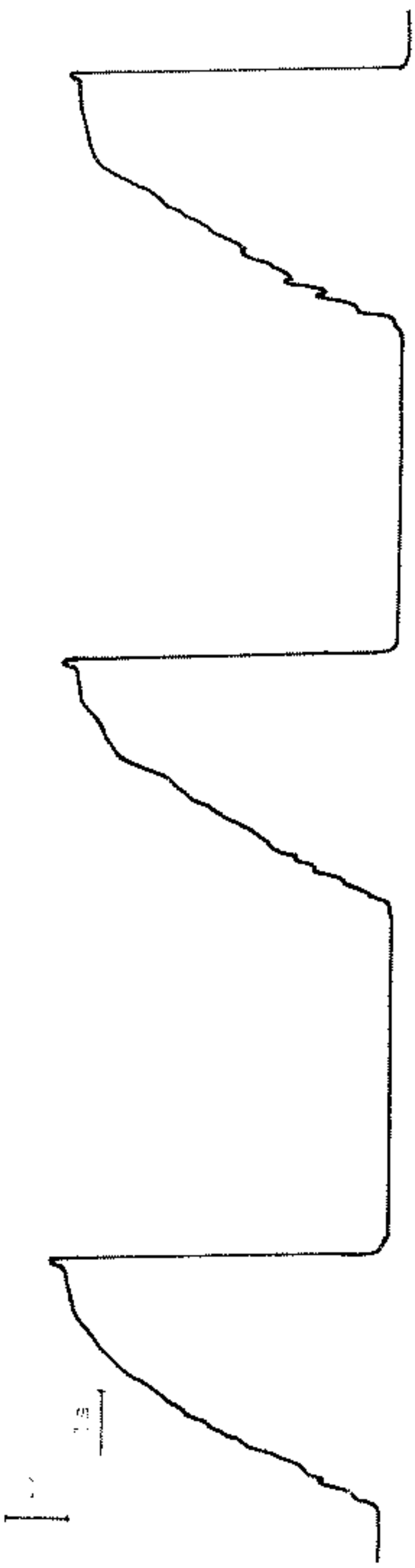

Fig. 5. The course of changes of the angle of hand opening with external resistance produced by springs mounted in orthostesis hearings
a/ without feedback

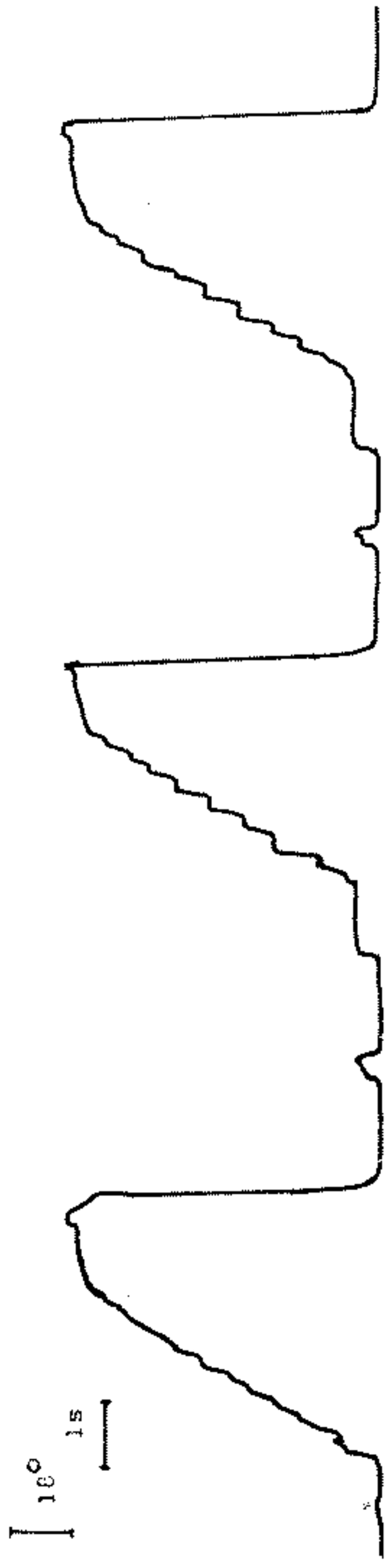

Fig.5b. The course of changes of the angle of hand opening with external resistance produced by springs mounted in orthostesis bearings
b) with feedback controlling duration of stimulating impulses

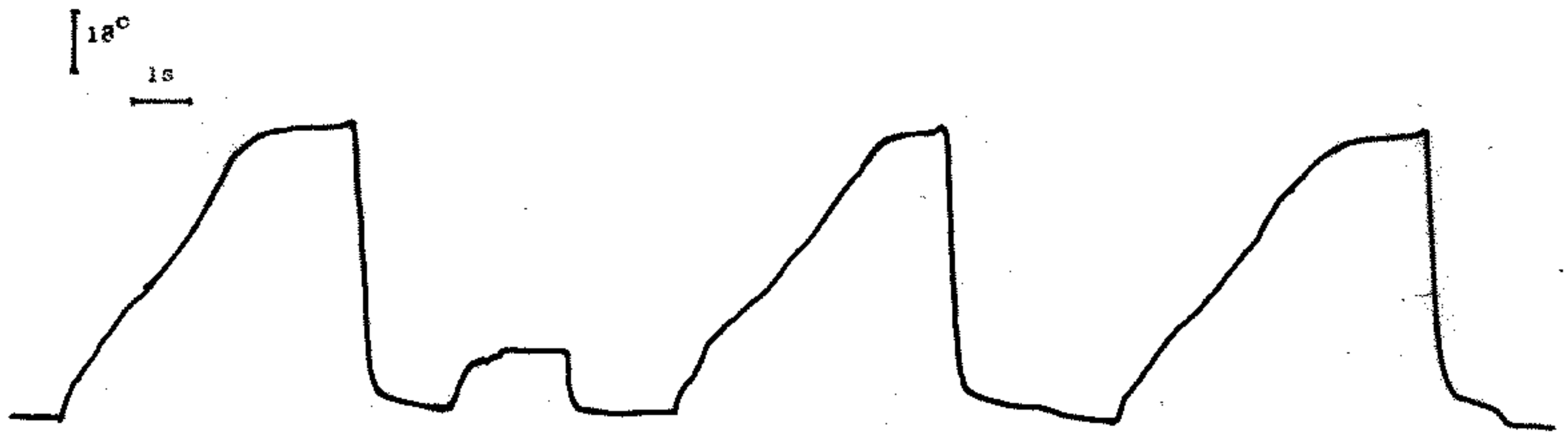

Fig.6. **The course of angle changes during performace of the grasping function** in the **feedback system with the use of constant resistance opposed to flexors** by **finger extensors.**