WALK CORRECTION OF PATIENTS AFFECTED WITH INFANTILE CEREBRAL PARALYSIS USING MULTI-CHANNEL MUSCLE ELECTRICAL STIMULATION

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At present electrical stimulation of muscles has been increasingly used as a method of correction of different motor acts when the supraspinal control of muscles activity is disturbed (1-5).

When both lower extremities are considerably damaged with diplegia, which is one of the forms of infantile cerebral paralysis (ICP), the correction of numerous movements while walking is also necessary. This correction can be obtained using artificial control systems (ACS) based on the multi-channel electrical muscle stimulation (MEMS).

Both clinical and biomechanical studies make it possible to determine the muscle complexes, which are characterized by the function deficiency and, therefore, must be electrically stimulated during walking. Based on the study of 1626 muscles of 151 ICP-patients at the age of 4-20 years with their lower extremitites middle-damaged following paresis distribution has been determined: mostly often affected is the function of the m.m. flexor.dorsal.ped. (70 percent case), m.gluteus max. and m.gluteus med. (61 and 64 percent case), m.triceps surae (54 percent case); more rarely observed is the paresis of the extensors and flexors of the knee joint (25 and 15 percent case). Typical combinations of stroken muscles are as follows: shin muscles and mm.glut. (28 percent case), the muscles of the whole leg (19 percent case) or the shin muscles only (15 percent case).

As usual the spasticity of the paretic muscles in patients with ICP is typical. Mostly often affected are m.triceps surae (50 percent case), m.m. flexor.articular.gen. (26 percent case), m.rectus femoris and m.m. adduct.femor. (19 percent case).

In spite of the considerable differences of the ICP clinical manifestations the walk stereotype of such patients is characterized by a certain monotony (6,7).

In Fig.1 basic tendencies of changes of the gait kinematics and dynamics of ICP-patients are shown in comparison with the same features of the normal gait. Following facts atract our attention: a) failure of the right correlation between the supporting and the swing phase of the step (the latter is shortened almost by one third), the phases of the support are redistributed (the time of the heel-support and that of the foot-flat-support are reduced, the time for rolling over the forefoot is increased), b) the angle of the outcome appears in the main leg joints during walking, the amplitude of angular displacement, speed and movement acceleration values in the lower limb joints are reduced, at the same time the amplitude of the body movements (forward, sideways motion combined with certain rotations round the vertical axis) increases sharply, the re-phasing of the motor cycle takes place, c) the functions of supporting and pushing are reduced to judge by the diminished values of the support reaction in the "front-push" and "back-push" phases.

As it is obvious from the data enlisted the change of the walk structure is first of all connected with that of the posture characteristics of the patient's body, namely with the flexion position of the legs during the supporting phase of the step. This position is caused either by the paresis of the extensors or by the spasm of the flexors, or, at last, by the combination of the paretic extensors with the spastic flexors of the leg. Because of the fact that the anormalous position is met in 84 percent case and the fixed deformations in the leg joints - in 37 percent case this position can be said to have an adjusting, adapting character.It is of importance that in 58 percent case the adapting position of the legs is caused by the function deficiency of the m.gluteus medius and m.gluteus minimus. The function deficiency of these muscles causes also a sharp pelvis sinking (pelvis drop) on the side of the non-supporting extremity, a compensating body tilt towards the supporting leg as well as the functional elongation of the swing-extremity, in consequence of which the put-on-floor of the swing-extremity occures when all joints are excessively bent. The next group of patological features of gait is connected with the weakening of the shank muscles functions. The function deficiency of the m.m.flexor.dorsal. ped.,especially when combined with the spasm of the m.triceps surae, changes the phasing of the support (the step begins with the toes-support or the foot-flat-support) and makes the foot-lifting at the beginning of the swing phase difficult.

In its turn the paresis of the m.triceps surae causes the reduction of the "back-push", consequently the body translational motion becomes possibly only as a result of the compensating increase in the work of the muscles of the proximal leg parts and of the body muscles.

Thus,clinico-biomechanical comparisons indicate that when correcting the gait the faulty flexion position of the lower extremities must be diminished, the excessive body movements reduced, the supporting and pushing functions are to improve and the leg swinging is to make easy.

On the basis of a biomechanical study and experimental investigations it has been ascertained that the multi-channel gait correction of patients with ICP can be obtained using alternating electrical stimulation of all gluteal muscles (m.gluteus maximus and m.gluteus medius) in the first two thirds of the supporting phase as well as during the swinging phase of the step.

The stimulation carried out in the manner described must secure: a) straightening of the legs in the supporting phase, b) diminishing of the internal rotation, hips' adduction and body movements relative to the frontal and sagittal planes, c) improvement of the step phasing, d) facilitation of swinging the leg over the support.

A four-channel ACS has been developed at the CRIP, Moscow, in order to promote multi-channel gait correction of stroke-affected patients.

As it is evident from Fig. 2 the system consists of syncroniza-tion transmitters (I), electrodes (2), distribution box (3), attached to the waist-band of the patient, a cable assembly (4), a four-channel electrical stimulator (5), a cathode-ray oscillograph (6) and a recorder (7). As synchronization transmitters are used two analoque angle-data transmitters, which are attached on both patient's legs coaxial with the knee and hip joints. The electrodes are made of several layers of flexible materials containing carbon-filled current-conducting textile. The four-channel electrical stimulator consists of channel modules I-IV and a general section.

The channel module (I) contains a series connected selector (8) of the synchornization transmitters and synchronization phases (flexion or extension), univibrators (9,10) for delay and stimulation duration, a switch (11), a diode-capacitance stepping-up voltage convertor (14), a power amplifier (15) as well as a generator (12) and a univibrator (13), which give the period and duration of stimulating pulses, respectively. The univibrators (9,10) produce adjustable commands for delay and stimulation duration 0-1,0 and 0,1-2,0 s, respectively. The generator forms a cycle of stimulating pulses from 10 to 30 ms (100 Hz). The univibrator (13) sets the duration of stimulating pulses, which is adjusted in a smooth manner 30 to 350 µs. The stimulating voltage is formed by the converter with an average output current by 40 or 20 mA, respectively. The power amplifier provides the pulse current passage over the electrodes up to 1 A with a leakage current between the separate pulses less then 10^{-5}A. The pulse stretchers (16) placed inside of the channel modules II-IV are used to separate the pulses of the next channels in time by 2,5 ms.

The general section contains a unit (17) for switch-on, change--over and connection of the electrodes as well as for sound indication of the stimulation currents in every channel. The adjustment device (18) produces the synchonization pulses at the different levels of the transmitter signals. The unit (19) obtains the matching of the switches, which produce signals to register the stimulation pulses, with a recorder and a summer (20), which makes it possible to observe the signals of every transmitter together with the stimulation markers on the cath de-ray oscillograph (6). The secondary source (21) converts the voltage value of the power network into stabilized voltage + 10 and - 10 V to energize the channel modules.

When carring out the gait correction the transmitter, level and phase of synchronization, delay, duration as well as intensity of stimulation are selected individually for each channel by the investigator on the basis of clinico-biomechanical study of walking. The adjustment of the stimulation program and parameters is obtained by the use of the cathode-ray oscillograph and the sound indication.

On the basis of theoretical and experimental investigations modifications of the synchronization between the stimulating actions and the step phases have been elaborated by means of the angle-data transmitters of the different muscles. As seen in Fig. 3 when using angular displacement in the knee joint in the swing phase of the step for synchronization purposes the synchronization moment in the middle of the extension phase is common for all the muscles acting at the end of the swing and in the first half of the supporting phase, as well as the synchronization moment in the middle of the flexion phase is common for exciting the muscles acting in the swing phase.

Patient A-n. Diagnosis: paraparesis of the lower extremities with the left leg more affected; mainly damaged are m.m.glut.max. and med., m.m.flexor.and extensor.ped. The patient is walking with his legs half--bent, the movements in the knee joints, especially in the left one, are limited, frontal and sagittal body swingings can be observed.

As it is evident from Fig. 4 the gait peculiarities of this patient are typical gait characteristics of an ICP-patient: the flexion angle of the knee joint is sharp increased at the beginning of the support phase and diminished in the swing phase; some of the kinematic curves (those of the knee and hip angles) are placed upwards of the zero line owing to the flexion position of the legs while walking; the dynamogram of the vertical and longitudinal components of the supporting reaction is distorted.

In consequence of correction of movements in both hip joints the kinematics and dynamics of the gait can be improved to a certain extent: a) the amplitude of the sagittal movements of the pelvic is diminished, b) the extension angles and their speeds in the hip and knee joints (especially in the right one) grow in the first half of the supporting phase, c) the flexion angles become more symmetrical in both knee joints, d) the amplitude of certain components of the supporting reaction increases slightly.

The correction of movements in the ankle joints (dorsal flexion at the end of the support and during the swing phase of the step) exercises rather small influence on the gait structure: noticeable is a certain amplitude decrease of movements in the ankle joints as well as the symmetrization of movements in the knee joints.

Both correction forms change the step phasing considerably: there is an increase of the foot-support, at the same time the duration of rolling over the forefoot decreases.

Normalization of gait kinematics and dynamics also causes the considerable diminishing in the activity of muscle forces calculated basing on the mathematical modelling. This effect is observed mainly when correcting the movements in the hip joints.

Thus, already one-time correction of gait by the use of the electrical stimulation of the m.m.glut. and m.m.flexor. dorsal.ped. in the patients with ICP decreases the body movements, reduces the flexion-adduction position of the extremitites and diminishes the energy cost of the gait (approximately by 12%).

The use of the angle-data transmitters of a single leg or of both extremities together with adjusted levels and synchronization phases makes it possible to develop a time program for the muscle stimulation in the different step phases with the minimum stimulation delay, which is put in the operation only the synchronization moment being distant from the correction phase. In those cases when it is impossible to realize the synchronisation by the angle of the joint flexion is a little one or when the flexion angle in the supporting phase is approximately equal to that of the swing phase a hip-angle-data transmitter can be used. In that case the flexion phase of the hip joint is used to excite muscles acting in the first half-time of the support; the extension phase is used to excite muscles functioning in the middle and at the end of the supporting phase.

10 patients affected with ICP in the diplegic form have been treated by the use of the considered multichannel movement correction. 20 days electrostimulation course has been carried out for the total of ten patients while everyday walking at a distance of 1-2 km.

The object of correction were movements in the hip and ankle joints of both legs. The correction was realized using alternating stimulation of two muscle groups of both lower extremitites: m.gluteus maximus and m.gluteus medius in the first two thirds of the support phase, m.m.flexor. dorsal.ped. at the very end of the supporting and during the swing step phases.

In order to estimate the results of the gait correction following multi-channel recording of biomechanical parameters has been carried out: podogram, pelvic sagittal and frontal tilts, angular displacement in the hip, knee, ankle and metatarsophalangeal joints, vertical and longitudinal components of the supporting reaction, marker of stimulation action; then the work of the muscle forces during the walking cycle has been determined by the method of mathematical modelling; furthermore, the energy loss was measured using the indirect calorimetry.

The total of investigations have been carried out in four variations: walking without correction, walking while correcting movements in both hip joints, walking while correcting movements in the ankle joints and at least walking while correcting movements of four joints indicated.

Principal kinematic and dynamic regularities of the gait, noted after having the MEMS can be showed taking example by one of the patients.

After completing a MEMS-cure the muscle forces increase by 50-60% an improvement of the locomotion stereotype can be observed also without the application of MEMS. The gait correction as well as more optimal state of the locomotor system cause additional reduction of the energy expenditures (up to 25%). The registred treatment results remain during 6-12 months, after which they go down gradually.

Such are the first results of application of multichannel artificial control systems in patients with ICP in the diplegic form.

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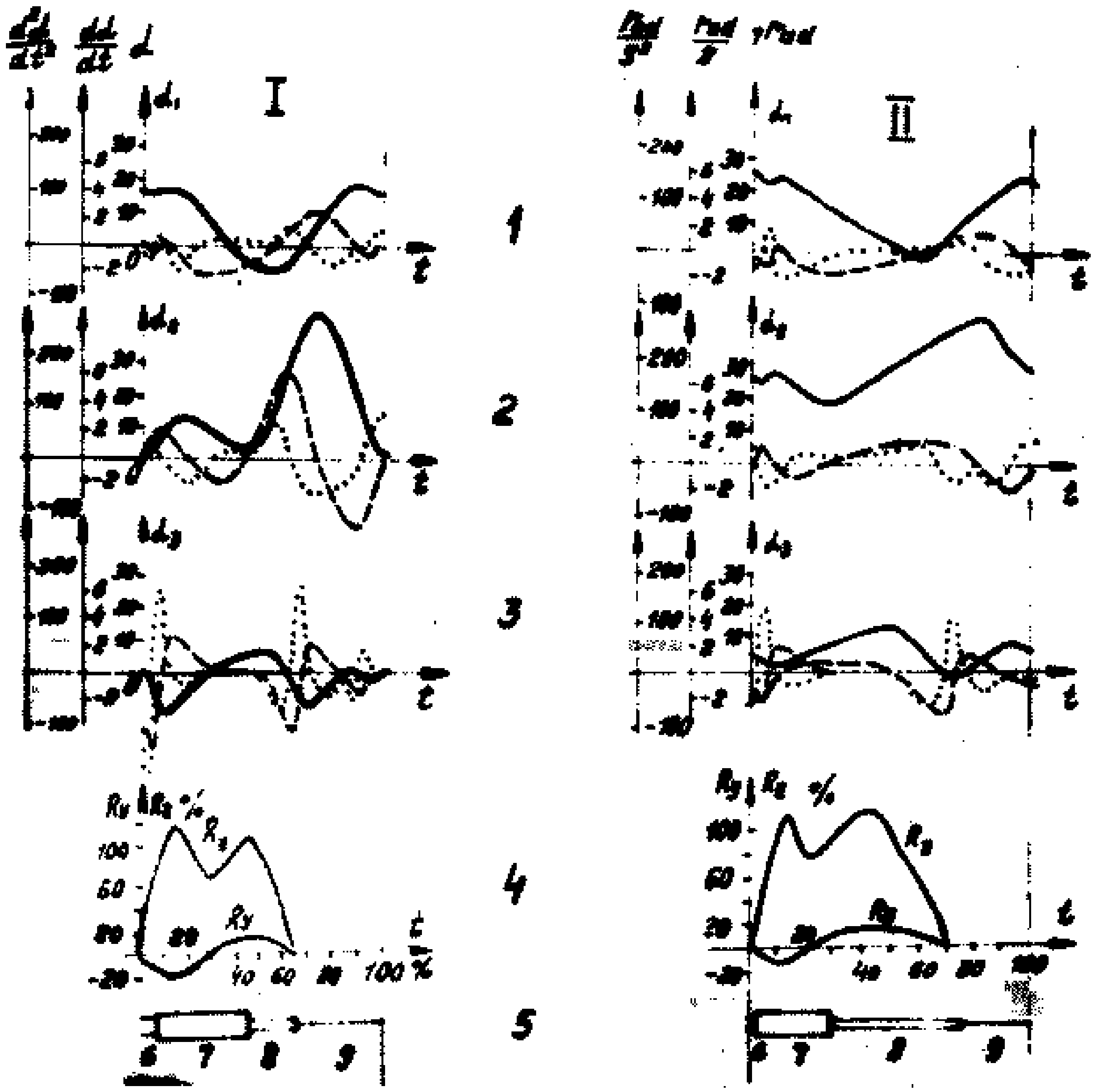

Fig. Change of gait parameters during locomotion cycle (100%): I - normal gait; II - paretic gait; I - (α_1) angles in the hip joints (continuous lines - angles α, dotted lines - speeds $\frac{d\alpha}{dt}$ $\frac{ra\alpha}{s}$, pointed lines - accelerations $\frac{d^2\alpha}{dt^2}$ $\frac{ra\alpha}{s}$, 2- (α_2) angles in the knee joints. 4 - (R_y, R_z) longitudinal and vertical components of the supporting reaction (percentage relative to the patient's weight). 5 - podogram: heel-support - 6, foot-flat-support - 7, forefoot-support - 8, swing - 9.

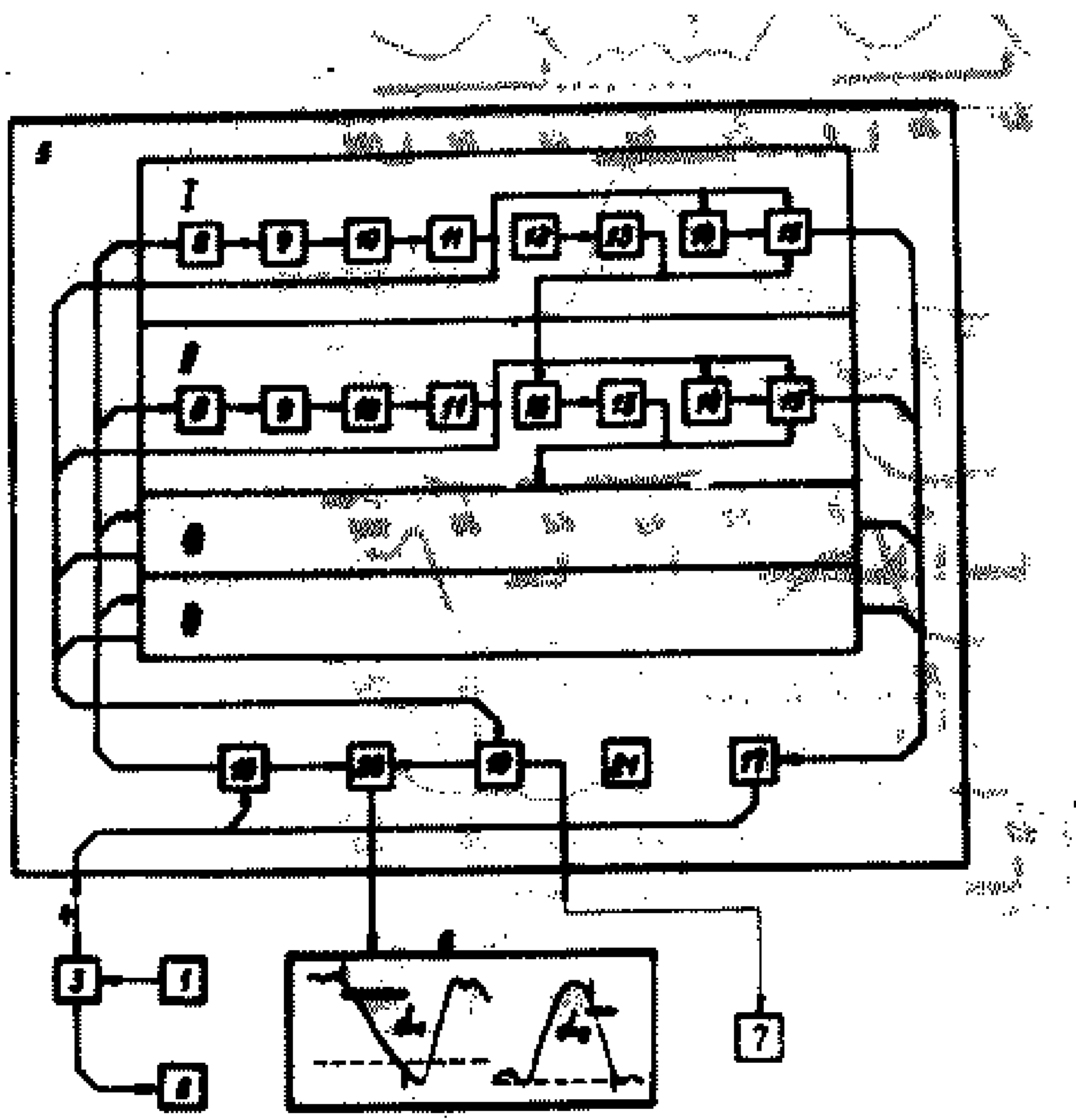

Fig. 2 Functional diagram of a four-channel artificial control system for movement correction during walking: I - synchronization transmitter, 2 - electrodes, 3 - distribution box at the patient's waist-band, 4 - cable assembly, 5 - four-channel electrical stimulator, 6 - cathode-ray oscillograph, 7 - recorder.

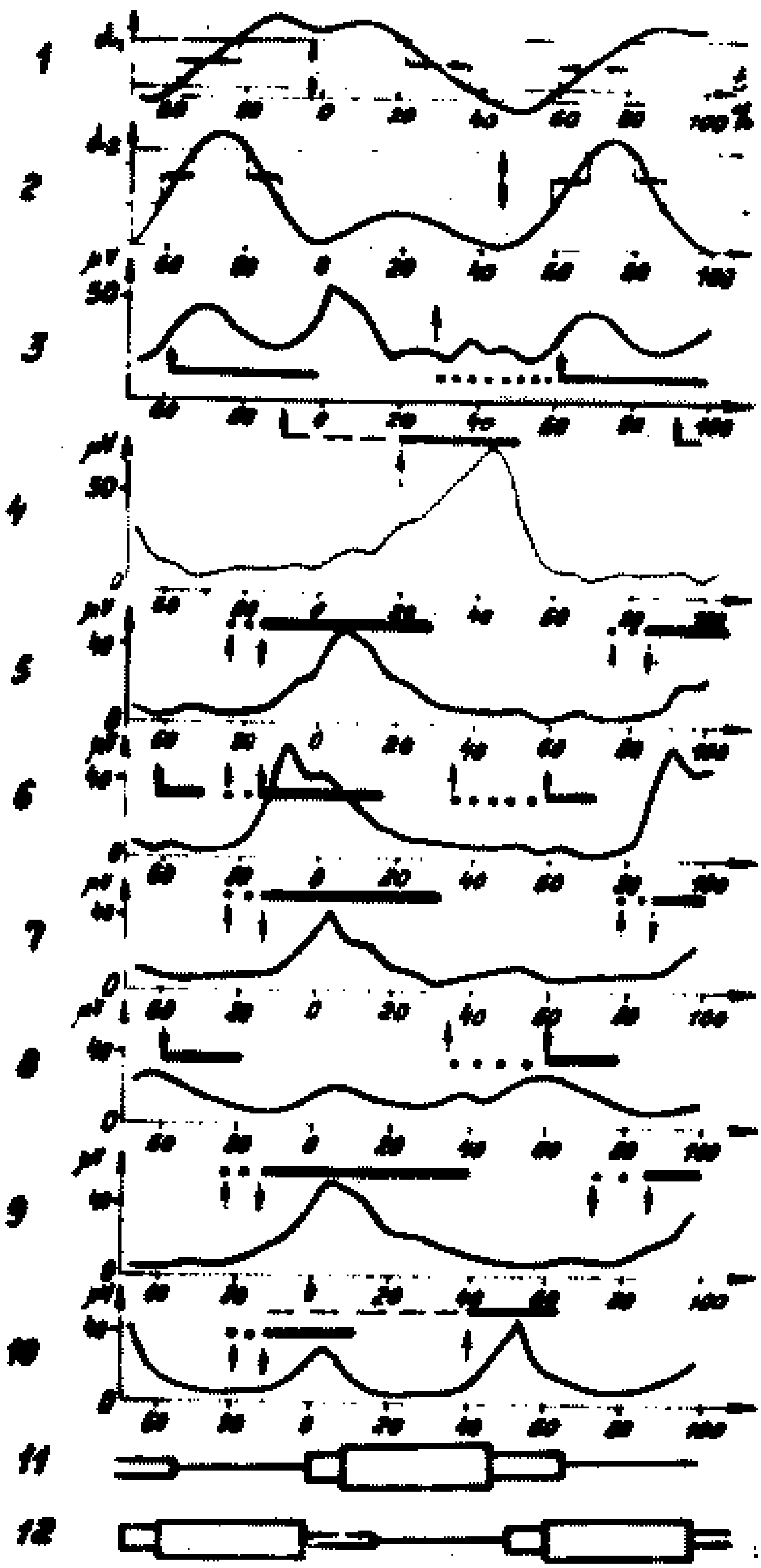

Fig.3 Modifications of the synchronization between the stimulating actions and phases of locomotion cycle. Change of parameters of the normal gait: 1 - (α_1) angle in the hip joint, 2 - (α_2) knee joint angle. Change of integrated electrical muscle activity: 3 - m.tibialis anteriror, 4 - m.gastrocnemius, 5 - m.vastus lateralis, 6 - m. semitendinosus, 7 - m.glut.max., 8 - m.tensor fasciae latae, 9 - m.glut. med., 10 - m.sacrospinal. Muscle stimulation program during walking: ↕ - range of synchronization levels, ↔ - synhronization periods, ↑ - synchronization moment at α_1, ↓ - synchronization moment at α_2, continuous line - stimulation duration, pointed line - stimulation delay (synchronization at α_1), dotted line - stimulation delay (synchronization at α_2).

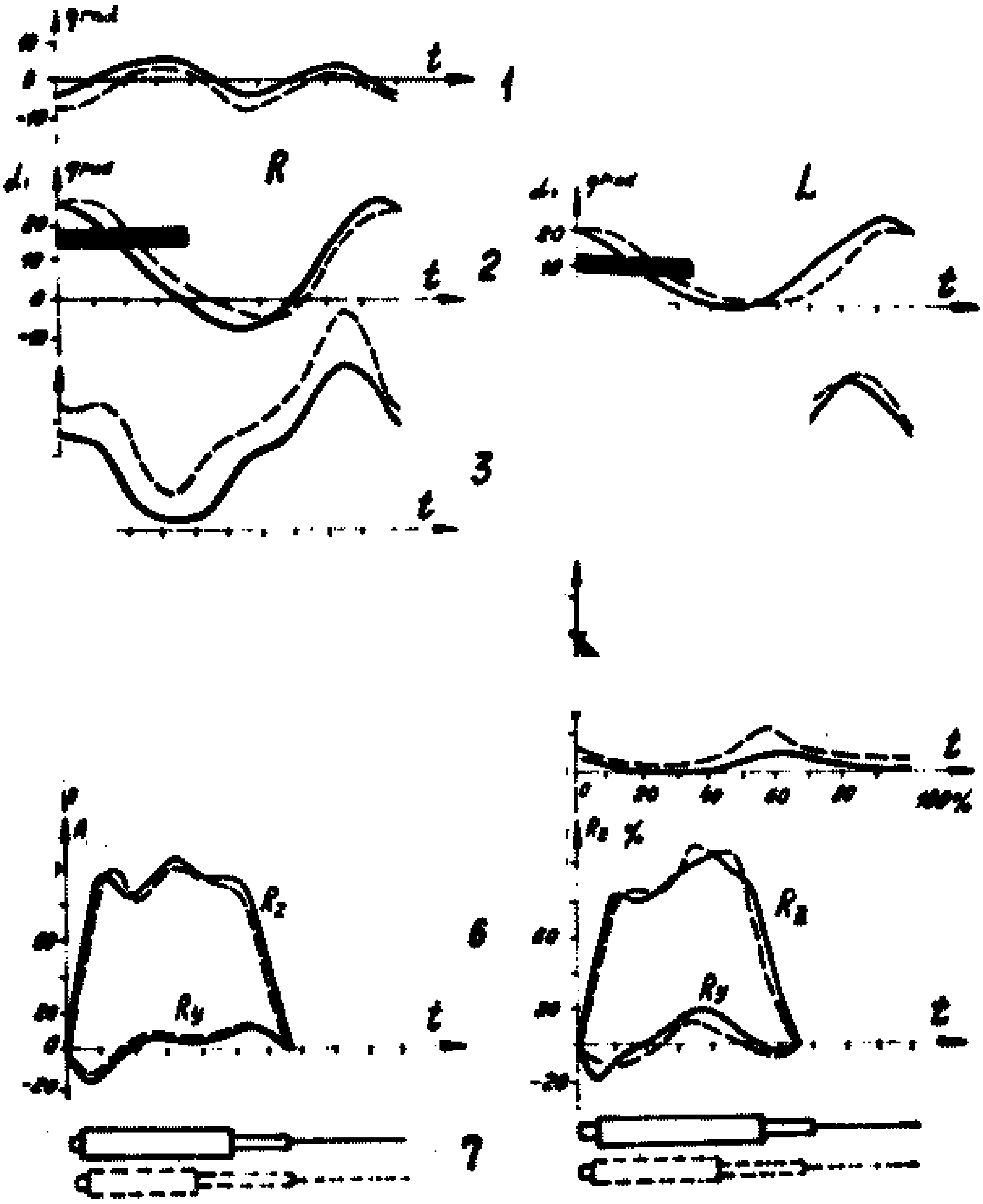

Fig. 4 Gait parameters of the patient A.: (continuous line - when correcting the movements, dotted line - without movement correction): R, L - right leg, left leg, 1 - sagittal body tilts (upwards - - forwards), 2 - 5 - (α_1 - α_2) the angles in the hip, knee, ankle and metatarsophalangeal joints, 6 - (R_y, R_z) longitudinal and vertical components of the supporting reaction, 7 - podogram, black rectangle - stimulation marker of m.gluteus max., med., light-coloured rectangle - stimulation marker of m.tibialis anterior