INVESTIGATION TECHNIQUE AND GAIT CHARACTERISTICS OF PATIENTS WITH STATIC FEET DEFORMITIES

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Abstract

Biomechanical research techniques make a significant contribution to general information on human gait. Electropodo- and tensiography are the most prefereble for the study of support and kinematic functions. Considering anatomy and functions of the foot, 3-contact electropodography technique, conducted simultaneously with tensiography, was developed. Unification of podographic investigations and accuracy of the measurements was reached on account of linear (sagittal) sizes unification with respect to the foot length.
Elaboration of the podography technique permitted to distinguish two more time intervals of stance phase, providing an opportunity for the more profound study of support and kinematic functions, and in combination with synchronous tensiographic investigation of spring function of normal and pathologic feet.

10 persons with normal locomotor systems and 114 persons with flat valgus and broad deformities of feet underwent gait examination. The conducted research indicated that normal gait is characterized by a successive loading of all parts of the foot. Static feet deformities change the process of loading, depending on the degree of abnormality. Tendencies to load the plantor surface of the foot momentary and to prolong double stance phase are observed. They are the protective reaction against excessive pressure on separate poihts and regions of the foot, caused by its support and spring properties loss. Clinical, anatomic and functional changes, resulting from static feet deformities, can be stopped only by their pathogenetic treatment.

Introduction

Mass investigation results of different population groups showed that static foot deformities are considerably wide spread. They lead orthpedic pathology list /1.2.3.4.5.6.6.8/. Foot deformities impair locomotor function, cause callosities, pain, fast fatique, lower working capacity. That is why it is becoming very important to work out objective investigation techniques of a normal gait and of a gait, affected by foot deformities, and compensatory adaptation processes. It is also important to work out therapeutic measures, prosthetic devices and to estimate the efficiency of treatment.
Biomechanical research techniques make a considerable contribution to the information on human gait. In this work we used

measurement techniques of gait cycles,time intervals and forces parameters of body weight affect on the foot support surface in gait. These techniques permitted to obtain sufficient information on kinematic and dynamic functions of normal feet and of feet, affected by static deformities. Electropodography and tensiography are the most suitable in our view for the investigation of gait and feet interaction with floor.

Contact electropodography technique is very simple and reliable. Its instumentation involves contact cells, resistors, a power supply and a graphic information recording instrument. Informational value of a podogram depends on the number of time intervals, the placement of contact cells and their location correspondence with support points and stance phases of the foot. A number of the intervals is determined by number of contact cells placed in the electric circuit. A two-contact podography technique, developed in the Central Prosthetic Institute by M. Chyrskov /9/, won the recognition in our country. One contact is located in heel region, the second covers the plantar surface region of slipper´s front section.

A significant shortcoming of this system is that individual features of a subject are not taken into account, namely:sizes of the foot, major footprint parameters, kinematic functions of the foot and the stride structure. The use of this technique makes it impossible to carry out a reliable investigation and characterization of the foot functions kinematicsand of the temporal stride structure.

Taking into consideration the facts stated above, a new improved podography technique was developed. Its purpose was to make experiments more close to usual conditions of walking. The insoles, used in it, had contact cells in heel, fascicular and toe regions (10,11). Through 3 contact areas for the heels; the fascicular (metatarsal bones) and the toe´s regions were discriminated, the transducers, located in the heel region of the foot and in the region of the heads of the metatarsal bones, were electrically connected, making this technique similar to the two-contact one.

A podogram, recorded by means of the two-contact technique in temporal stride structure, is shown in Figure 1.

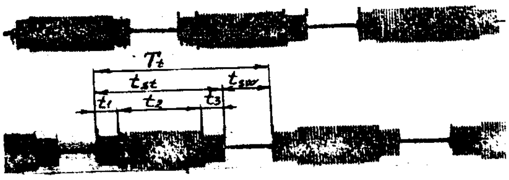

Fig. 1. A podogram of the intervals in stride structure whre:

T - stride time

t_{st}-stance phase

t_1- heel support time (HT)

t_2-full support of the foot time (HT)

t_3- forefoot support time (HT)

t_4- double stance time

t_5- single stance time

t_{sw}- swing phase

Here we can discriminate 3 time intervals in stance period of one foot. Both feet stance process is characterized by 6 parameters: $t_{st}, t_1, t_2, t_3, t_4, t_5$, while a single foot stance process is characterized by 5 parameters: t_1, t_2, t_3, t_4, t_5.
Leningrad Prosthetic Institute has developed a four-contact technique of multi-channel recording of support intervals for different regions of the foot. The number of the recording instrument channels is equal to the number of stance intervals (12,13, 14,15. 6 cm^2 brass contacts are placed at the heel of a slipper, at the level of the heads of the first and the fifth metatarsal bones and the toe area, permitting to investigate additionally the stance time for the heads of the first and the fifth metatarsal bones. O. Senn/16/ and E.G.Gray /17/ discriminated five phases analysing the results of the electromyographic and filming investigation of human gait during stance period. But their data cannot cover the temporal structure of a gait cycle which involves the kinematic function of the foot, making impossible to investigate its abnormalities thoroughly enough.
It should be noted, that there is no unity of opinion about sizes and location of contact transducers. It made us carry out our

own research investigations and in some cases led to incomparablility of the data, obtained by different scientific institutions and separate investigators.

Considering anatomy, functions of the foot and the purpose of this work, we improved the podography technique. Electropodography is recorded simultaneously with tensiography. We used sandals, the sole surfaces of which were supplied with three contact transducers made of fine brass network in heel, fascicular and toe portions of the foot.

t_3- full support of the foot time (HMT);
t_4- support of the metatarsal region time ($\overline{HMT}$)
t_5- toe support time (HMT)

Two additional middle of the foot and metatarsal support time intervals permit to examine more throughly functional features of normal and pathological feet.

Reliability and precision of the podographic measurement results depend on placement and geometric sizes of the contact transducers. To solve the question of the contact transducers placement and sizes we used the results of our clinical X-ray, podometric and plantographic examination of 1835 persons, suffering from different static foot deformities, tha data of comlex (clinic, podometric and plantographic) examination of 4975 people, groups of children, juveniles and adults, including 1200 people, examined by plaster footprints of plantar surfaces.

By the results of feet measuremets, plantograms, X-ray examinations and by the standard sizes of low heel shoes we determined the contact area length of the sandal heel portion to be 0.25 of the foot (sandal) length. Figure 3.

Sagittal sizes of metatarsal (fascicular) contacts were determined by the following foot parameters. Profile X-ray measurements of feet show, that the fissure of the first metatarsophalageal joint is located on the level of 0.75-0.76 of the foot length and the fissure of the fifth metatarsophalangeal joint is at the level of 0.64-0.66 of its length. The middles of the first and fifth metatarsal bones are located at the level of 0.72-0.73 and 0.62-0.63 correspondingly. The center of the contact portion in the region of the metatarsal bones heads is on an inclined line,

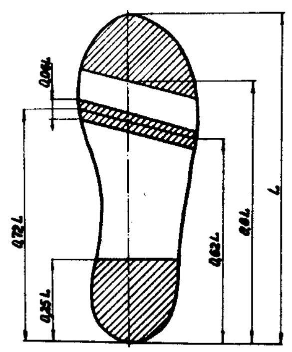

Fig.2. Contact transducers placement on the foot plantor surface

The instrument, realizing this technique, involves three parallel circuits of contacts and resistors,

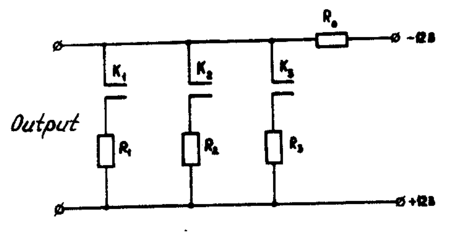

Fig.3. Electric circuit with contact transducers permitting to time five intervals during stance phase of a step, instead of three. Namely:

t_I - heel support time (HMT - heel, metatarsal, toe);

t_2 - middle of the foot support time (H̅M̅T);

drown from 0.72 of the inner side to 0.62 of the outer side, passing through the longitudinal axis of the foot at the distance of 0.68 of its length. The contact zone does not come out of the limits of the metatarsophalangeal joints fissures and its length is not more than 0.03 of the foot lenght from the middle of the contact area. Consequently, total length of contact area at the heads of the metatarsal bones is 0.06 of the foot length with regard for their curvature.

Proximal boundary of the contact zone for the toes portion is determined by the results analysis of plantograms and X-ray exchange and passes inclinedly from the first to the fifth toe parallel to the axis of the contact area at the metatarsal bones heads, via longitudinal axis of the foot at the 0.8 of its length level. This division of the foot is very close to location of the joints in the artificial feet of the existing prostheses.

For podographic investigation we manufactured 7 pairs of sandals, sizes from 18 to 30 (in metric system) with class interval of 2 cm, so that we could investigate gait at different feet lengths with footwear and barefoot.

Improvement of the electropodography technique allowed to determine and meassure the following temporal step intervals at the podogram as shown in Figure 4,

where:

T_t- stride time,
t_{st}- stance phase time,
t_1- heel support time,
t_2- middle of the foot support time,
t_3- full support of the foot time,
t_4- fascicular support time,
t_5- toe support time,
t_6- double stance time,
t_7- single stance time,
t_{sw}- swing phase time

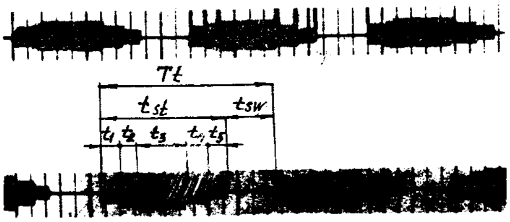

Fig. 4 Improved podogram

The unification of podographic investigations will permit to obtain easily comparable results of research, carried out in different laboratories.
It is also very important to study forces, acting between the foot and support. To obtain sufficient information of the intersection of these forces, total load of the plantar foot surface, which is the result of the body weight action and of the dynamic moments, is determined. Relative pressure values in separate foot points are also studied. During this research simultaneously with podography, kinematic and dynamic functions of the foot are studied and efficiency of certain therapeutic measures and orthopedic devices is examined.
The study of forces and moments, affecting the foot, was realized by tensiometric measurements. Preferable use of the tensiometric research is explained by small weight and sizes of strain gauges, the opportunity to carry out measurements within wide range of values, by good technologic instrumentation and development of this technique as a part of general theory and practical application of measurements.
We devided the supporting surface of the foot into areas for measuring pressure of broad and flat valgus feet, according to the tasks of our research and changes in foot anatomy caused by the deformities. For broad feet loading examination (Figure 5a) the following points were chosen:

1. - Metatarsal bones heads region,
2. - Inner and outer edges of the calcanean tuber, but for feet with flat arch- (Fig 5b)

1.- the region of the heads of the metatarsal bones,

2.- outer portion of the foot in projection of the cuboid bone;
3.- inner region of the foot in projection of the navicular bone,
4.- calcanean tuber region.

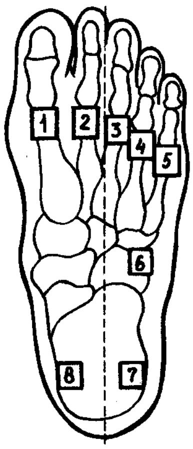

Fig.5a. Points for broad feet investigation

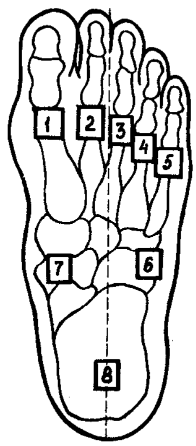

Fig.5b. Points for flat valgus feet investigation

Force and temporal parameters connected with a locomotor action were recorded simultaneously to obatain more exact information on the foot-roll-over-ground process. For this purpose, the podographic and tensiometric devices were united in a single complex, which was named electric podotensiographic complex.
The signals about temporal gait intervals and pressure in different parts of the foot were recorded simultaneously.
We can define five nosologic forms among static foot deformities: functional insufficiency, flat valgus and broad feet and osteofibrous tumors in the region of the heads of the first metatarsal bones. The kinematic function is impaired most of all by the flat valgus and broad deformities of the foot.
Our purpose was to study in detail characteristic features of gait and pressure repartition along the plantar surface of the

normal foot in the different regions during various step phases, of the flat valgus foot with the II-III deformity degree and of its broad deformity with hallux valgus of the II-IV degree. We analysed synchronous electric podotensiograms of 10 persons with normal locomotive system, 47 with static feet deformities and podograms of 67 persons with mentioned above pathologies. Digital data obtained from podo- and tensipgrams was processed for determining the differences.

To facilitate the comparison of our data with average statistic data of other authors, we united average time values for middle of the foot support (t_2) and full support of the foot (t_3), because they characterize stance phase of the foot and average temporal values of fascicular (metatarsal) support (t_4) and toe support (t_5), characterizing forefoot roll over. Comparative analysis of the average data and podographic investigations results of other authors indicated that relative values, characterizing step phases either coinside or have insignificant differences.

In the study process of patients' temporal gait features with broad feet a number of authors determined step phases dependence on the degree of deformity. They indicated, that heel support and its front region support time is shortened and time of the full support of the foot is increased with increasing of the broad foor deformity. But our investigation was the first to prove that it takes place on account of middle region support time (t_2), which coinsides with double stance step phase, while full support of the foot (t_3), being a single stance phase component, changes a little. Figuratively speaking, it resembles walking in darkness,when a man not knowing the floor relief, is walking very carefully, as if groping the foor surface; the platar time is reduced on ancount of both metatarsal (fascicular) and forefootsupport time. Temporal stance differences of heel, middle region and metatarsal support are statistically considerable in comparison with normal values.

Thus, our podographic research of patients with broad feet deformities permitted to discover subtle compensatory adaptation processes. They are aimed at pain reduction by means of smooth simultaneous loading of plantar surface of the foot and "fitting" it and shoes to the floor relief on the one hand and at floor reaction and body weight force decrease on the other hand. During investigation of gait characteristics of patients with flat valgus foot deformities it is noted that the higher deformity degree is, the shorter is support time of the heel, the forefoot and all foot, which causes shortening of single stance phase. At the same time middle region support , coinsiding with double stance phase, becomes considerably longer.

Tensiographic analysis discovered that, during normal gait, main load is applied at forefeet and it equals to 68,9% of the total load on the foot. Heels'load is 31,1%.
All the heads of the metatarsal bones are involved in support. The repartition of load among them is relatively even.
During metatarsal (fascicular) support, maximum pressure is on the heads of the II-IV metatarsal bones and equals correspondingly to 23,9; 19,8; 22,2% of the total foot load. The heads of the I-II metatarsal bones bear 44,1% of the forefoot load. It corresponds with the division of the foot by axial line (or line of load) on its axial roentgenogram and outline while locating the center of mass standing on one limb.
In broad feet deformities, morphologic impairments of the I metatarsal bone, metatarsophalangeal and clinoid joints, load registribution takes place along the plantar surface with relative increase of the load on the relatively longer II,III and the IV metatarsal bones, causing pain and callosities in the region of the heads of the bones.
Gait tensiographic analysis of patients with flat valgus deformity of the II-III degrees in comparison with normal persons' walking showed relative increase of pressure on the middle region of the foot, particularly on its outer region.
Pressure on the forefoot inner region dropped to 24,2%, but on the forefoot outer and middle regions it increased correspondingly up to 43,1% (16,9% normal) and up to 20,1%(5% normal). So, in the cases of flat valgus deformities of the II-III degrees,the roll over is realized mainly via the forefoot outer region, while normal persons gait is characterized by the forefoot inner roll over. It is necessary to underline here, that flattening of the foot arch is followed by a significant aggravation of the spring function of the foot, support reaction increase, which is reflected by the increase of dynamic forces of body weight.

Thus, normal gait is characterized by successive loading of all portions of the foot. In abnormal feet, depending upon the degree of deformity, we can observe a tendency "to grope" the support surface by the foot simultaneously. It is a protective reaction against excessive dynamic pressure on some support points and regions of the foot, which have lost considerably their support and shock absorbing properties.

The worsening of shock absorption causes double stance time increase on the one hand and simultaneous loading of the whole foot on the other hand. Such a gait is a sparing way to load the foot, It reduces dynamic shock in walking and redistributes loads with their relative reduction on the support points in comparison with normal loads. Structural abnormality of the foot brings about conciderable impairment of support, kinematic, shock absorbing and dynamic functions of the foot.

The new gait pattern requires constant control by the central nervous system and involves additional muscle work. That is why such a gait pattern results in fast fatique and makes patients consult a doctor very often.

Only pathogenetic treatment, aimed at the restoration of normal skeletal structure of the foot, blood circulation improvement, pain decrease and changes in individual working conditions can stop the process of clinical, anatomic and functional changes.

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