INFLUENCE OF THE RUNNING SHOE SOLE ON THE PRESSURE IN THE ANTERIOR TIBIAL COMPARTMENT

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The objective of the study was to evaluate the influence of a negative shoe sole on the intracompartmental pressure in the anterior tibial compartment. In 35 volunteers, the compartment pressure was documented during a 20-min. run on a treadmill with conventional running shoes and with running shoes with a negative sole. Besides the documentation of the compartment pressure we also performed a gait analysis.

The comparison of gait cycle between the conventional shoe and the shoe with a negative sole showed remarkable differences. With the conventional shoe, plantar flexion after initial contact was 16° compared to 6° with the special shoe. Duration of plantar flexion with the normal shoe was 0.17 sec. compared to 0.1 sec. with the special shoe. The intraindividual comparison of the individual pressure curves revealed evident differences in most of the subjects. The comparison of maximum pressures of each volunteer after running with the normal shoe as well as with the special shoe showed a decrease in the maximum pressure level when using the special shoe. The maximum pressures with the normal shoe (59.7 ± 9.1 mm Hg) were significantly higher than with the special shoe (36.5 ± 11.8 mm Hg) ($p < 0.001$). The comparison of the mean pressure showed similar results. With the normal shoe a mean pressure of 47.1 mm Hg (± 9.0 mm Hg) was measured compared to 29.8 mm Hg (± 11.0 mm Hg) with the special shoe ($p < 0.001$). Regarding the subjective comfort of the special shoe 18 subjects did not find any difference in comparison with the normal shoe. Five subjectively experienced the special shoe as less comfortable, 12 as more comfortable on running.

Keywords : running shoe sole ; pressure ; anterior tibial compartment.

Mots-clés : semelle des chaussures de jogging ; pression ; loge tibiale antérieure.

INTRODUCTION

Secondary muscular ischemia following muscle contraction is seen most frequently in the anterior tibial compartment. An acute and a chronic form can be distinguished. The acute type occurs during or immediately after intense stress and may lead to muscular necrosis. Originally, this type was mainly found in young individuals after forced marches, which led to the term "march gangrene" (4, 5, 23). The acute form may result in muscle necrosis and permanent late sequelae similar to those observed after traumatic compartment syndromes (13, 29, 39, 41, 48).

The chronic type, however, is much more frequent and occurs bilaterally in the majority of the cases as described by Reneman (37). This chronic exertional compartment syndrome is a widely known problem predominating in runners and walkers. According to Puranen *et al.* 0.5% of general physical symptoms and up to 60% of lower leg symptoms in athletes originate from a chronic compartment syndrome (34). Nitzschke found an anterior tibial syndrome in 6% of joggers (31). Wegner reported on 125 male and female runners participating in the German National Run in 1987 over a distance of 1000 km : 90 athletes sustained an anterior tibial syndrome that in most of the cases prevented them from going on running.

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The chronic type does not commonly lead to muscle necrosis or to persistent late sequelae, but nevertheless, it may significantly impair the athletic capability. The current conservative therapy consists of rather unspecific physical therapy (30). If these methods fail fasciotomy remains the only surgical alternative.

The results of previous studies show that the chronic exertional compartment syndrome is a dynamic problem (3, 11, 23, 27, 34, 37, 43, 44) resulting from increased intracompartmental pressure during the initial heel strike and during the phase of preswing (18, 19). The reason for the increased pressure during preswing seems to be of passive nature caused by bunching of the muscle tissue. At the same time the malleoli diverge which leads to additional tension of the surrounding fascia of the anterior tibial muscle. The extension of the ankle during running is inevitable. Increased pressure is caused by the eccentric contraction of the anterior tibial muscles after the initial ground contact. Electromyographic tests show that the anterior tibial muscle brakes the forefoot after heel strike and makes possible a smooth foot-descent during the gait cycle (15, 22). This is true in both walking and running (25, 26, 32). During walking as well as during running the highest electromyographic activity of the anterior tibial muscle is found right after the initial heel contact (15, 27, 32). Moreover, different EMG patterns are apparent in different ways of running. Higher EMG signals are, for instance, observed in heel runners than in forefoot runners (43). The question is how the eccentric action of the anterior tibial muscle can be reduced.

As the eccentric action lasts from initial ground contact to midsupport, the minimization of this phase must be pursued. Theoretical reflections suggest the hypothesis that a negative sole effects an earlier ground contact of the forefoot. Thus, the eccentric action of the anterior tibial muscle can be reduced and the increase of pressure within the anterior tibial compartment diminished. Hence, our study was based upon the following hypothesis :

1. A shoe with a negative sole will effect an earlier forefoot ground contact during the gait cycle.
2. The shortened action of the anterior tibial muscle will diminish the intracompartmental increase of pressure in contrast to the conditions obtained with conventional sole geometrics.

MATERIALS AND METHODS

Thirty-five healthy volunteers aged between 18 and 27 years were examined ; 5 individuals were female, 30 male. The mean age was 22 years. All of them had to run 20 minutes with 0% ascent. In a two-week interval each test person had to run a race once with the conventional shoe and once with the special shoe. The runners were randomized so that one half of them tested the special shoe first, the other half were first evaluated with the conventional shoe. Afterwards, they had to assess the subjective wearing comfort of the special shoe in comparison with the conventional shoe according to a visual analogue scale ranging from –10 to +10 (–10 : much worse, +10 : much better).

The intracompartmental measurements were performed using a compartmental pressure monitor with a slit catheter. The slit catheter was filled with 0.9% heparinized saline. After local anesthesia (Bupivacain 1.5 ml) the catheter was implanted at half the distance between the joint line of the knee and the lateral malleolus into the anterior tibial compartment by means of a lancet-needle. The lancet-needle was first introduced into the skin at a constant angle of about 40°, and after perforation of the sural fascia it was led about 2 cm cranially into the muscle at an angle of 20°. The implantation of the catheter was sonographically controlled (5-MHz linear scanner) (fig. 1) so that an intramuscular position could be verified. The pressure monitor contained an integrated electronic pressure measuring unit, which only weighed 150 g, and which did not disturb the natural pattern of locomotion (fig. 2). The slit catheter is a synthetic tube with several slits at the tip, and its intramuscular placement did not affect normal motion during the gait cycle. The accuracy of the compartmental pressure monitor was tested in previous studies by means of a Statham element which was connected parallel to the monitor. In case of exact usage the measuring error in the range of 0-200 mm Hg was limited to less than 2%. Similar values are reported by Awbery *et al.* (3). The sample rate of the pressure transformer was higher than 100 Hz so that the prerequisite for continous pressure measurement existed. In cases where the catheter did occlude during the evaluation, the slit catheter was flushed ($<$ 0.2 ml). The linear millivoltage output signal of the transformer

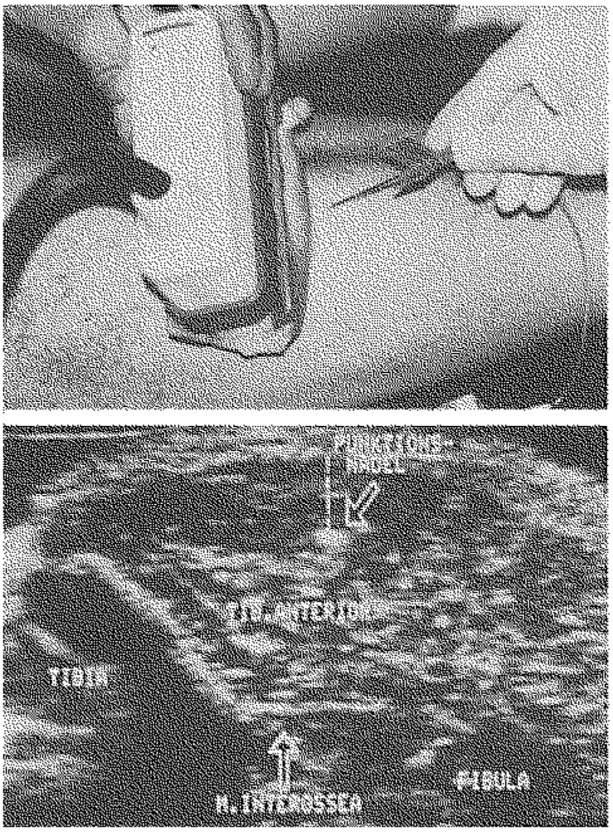

Fig. 1. — Placement of intramuscular cathether under ultrasound guidence.

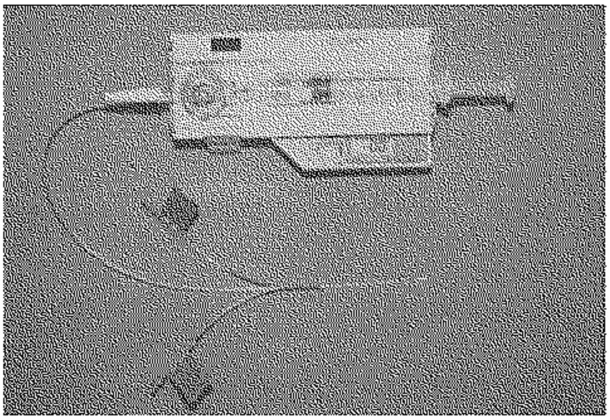

Fig. 2. — Pressure monitor with pressure transformer, catheter, and implantation devices.

Fig. 3. — Running shoe with a negative sole (right); the same with a conventional sole (left).

was directly used as an input signal for an xy-recorder. Via an AD transformer with 12-bit resolution and a sample rate up to 32 KHz the measured data (intracompartmental pressures) were transferred and stored in a data base. By means of special software the values were analyzed. All walking and running tests were done on a treadmill (Woodway, ESIV, 35-40 shore). In order to document the influence of the shoe with a negative sole (called "special shoe" in the following) on the gait cycle, motion analyses were performed. The tested shoe which was specially manufactured for the study had cushioned inserts, a molded insole and a sole of a height of 5 mm at the toes, of 25 mm at the forefoot, and of 10 mm at the heel (fig. 3). The sports shoe used in the comparative run was the same model and was also fitted with cushioned insoles and a molded insole. However, the sole measured 5 mm at the toes, 10 mm at the forefoot, and 20 mm at the heel.

The gait cycle was recorded by means of a video camera with an electronic high-speed shutter of 1/1000. The data were evaluated in a professional video studio by single-frame analysis. In 5 subjects a computer-assisted analysis was additionally performed using reflecting markers (fig. 4). The markers were placed at the anterior superior pelvic process, at the greater trochanter, the joint line of the knee joint, at the lateral malleolus, at the heel, and at the fifth toe. A video motion analysis system was used for the tests. By means of an S-VHS System with a screen resolution of 400 lines and an electronic shutter (1/1000), even rapid movements could be recorded. The sample rate of the PAL system is 50 Hz, which is combined with an electronic shutter, sufficient for the analysis of the gait cycle (7, 47). Besides full utilization of the field frequency the system offered the advantage of a better

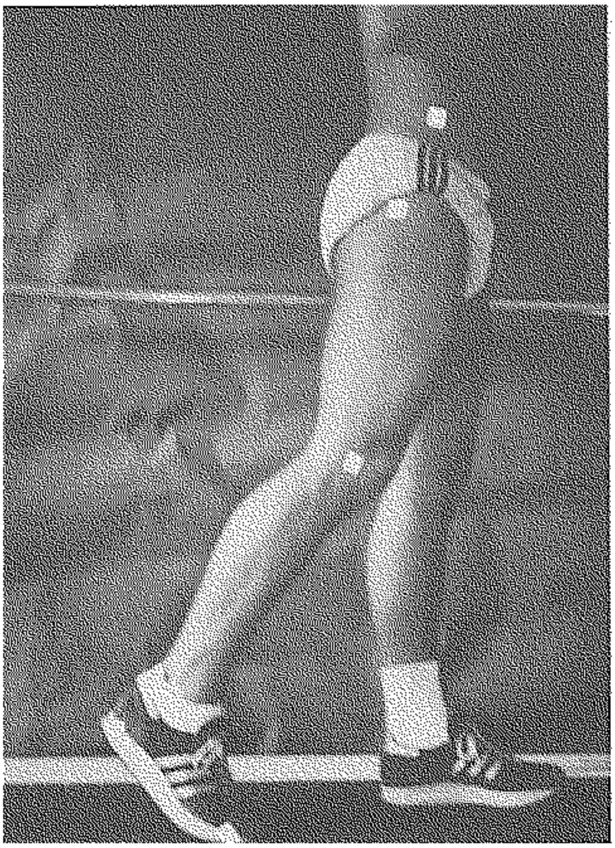

Fig. 4. — Motion analysis of the gait cycle was performed using reflecting markers.

resolution of 512 × 512 pixel, in contrast to 256 × 256 pixel usually obtained from standard monitors.

The video signal was digitized by means of a VCMMS (Video Computer Measurement System, Peak Performance, Denver, USA). After digitization and calculation of the reflecting markers all articular angles and angle velocities being present at any time of the gait cycle could be demonstrated. Moreover, the whole cycle could be repeated by projection of a simulation (stick figures). The gait analysis was performed according to the nomenclature used in the Department of Pathokinesiology of the Rancho Los Amigos Hospital, California, USA (10).

All subjects underwent a thorough standardized past history particularly with regard to their athletic activity, and special questioning about symptoms in the lower leg and the foot. Exclusion criteria were posttraumatic conditions in the lower extremities, any kind of drug therapy, and hyper- or hypotensive blood pressure. Moreover, a normal range of motion of the hip, knee and ankle joints was a prerequisite.

The statistical analysis was performed using the software-packages SPSS-PC+ and Biomed Version 1.0 (Student-t-test, Wilcoxon test).

RESULTS

The motion analysis demonstrated the typical range of motion of the ankle joint. During the stance phase, the range of motion covers about 25° including a mean dorsal extension of 10° and a mean plantar flexion of 15°. During the gait cycle, the foot contacts the ground with the ankle joint in neutral position. Within the first 10% of the stance phase the ankle joint becomes plantar flexed. This is followed by a dorsiflexion lasting up to 70% of the stance phase. A rapid plantar flexion reaches the maximum during the toe-off phase. During the swing phase the ankle joint is again dorsally extended.

The gait analyses with the normal and the special shoe are evidently different during the initial stance phase (fig. 5). The average angle at heel strike is 8° steeper in the normal than in the special shoe. Subjects wearing the normal shoe show a mean plantar flexion of 16° after heel

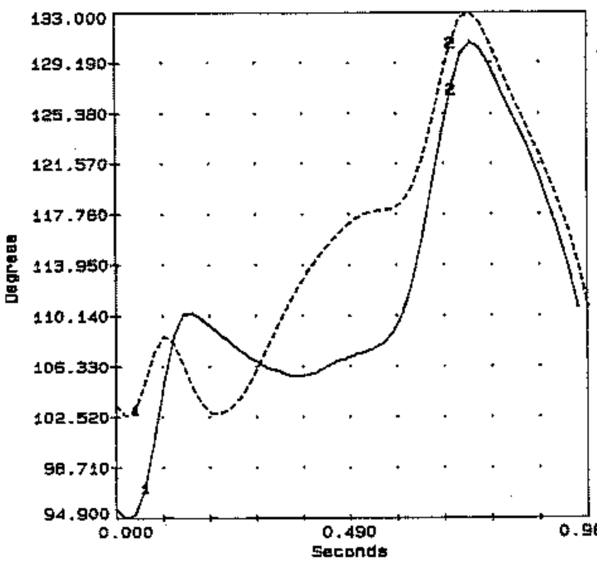

Fig. 5. — Comparison of the gait cycles with normal and special shoes (----) ; special shoe ; (——) conventional shoe ; 1 : heel strike ; 2 : toe-off).

strike, whereas subjects using the special shoe perform a mean plantar flexion of only 6° after heel contact. The duration of the plantar flexion is also different. It requires 0.10 sec. in the special shoe in comparison with 0.17 sec. in the normal shoe. In the final stance phase the curves are similar with respect to both, the time and angular deflection. In the toe-off phase the curves pass parallel showing only slight differences in the angular deflection of less than 3°.

The direct intra-individual comparison of the individual pressure curves revealed evident differences in most of the subjects. This was true for the maximum as well as for the minimum of the pressure curves (fig. 6). The direct comparison of maximum pressures of each volunteer after running with the normal as well as with the special shoe showed a decrease of the maximum pressure level when using the special shoe (fig. 7).

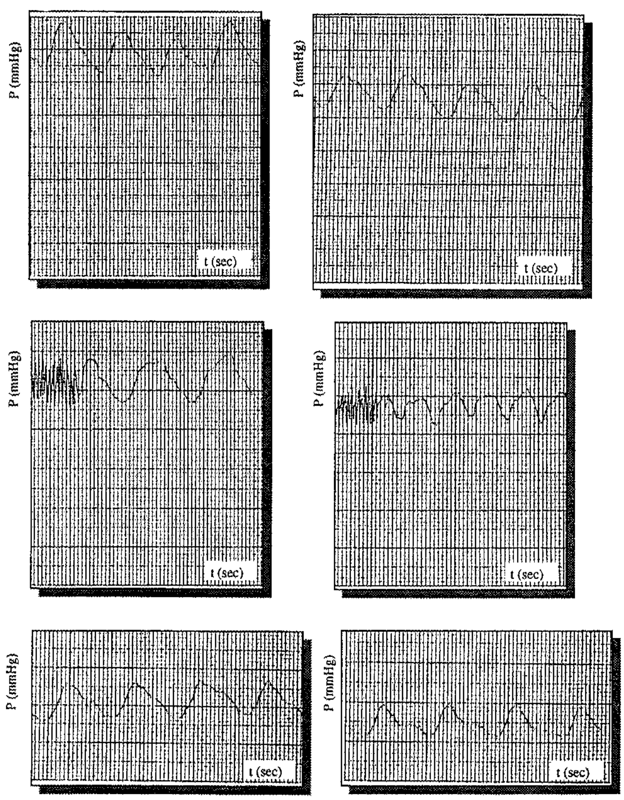

Fig. 6. — Pressure curves of several subjects using both the conventional (left) and the special shoe (right), x-axis : 10 mm/1 sec ; y-axis : 10 mm/mm Hg.

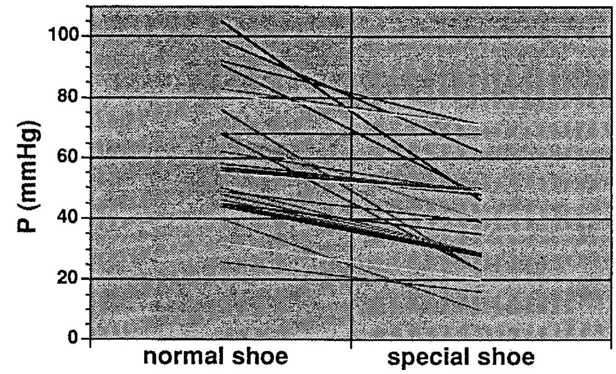

Fig. 7. — Comparison of maximum pressures during running with the conventional and the special shoe.

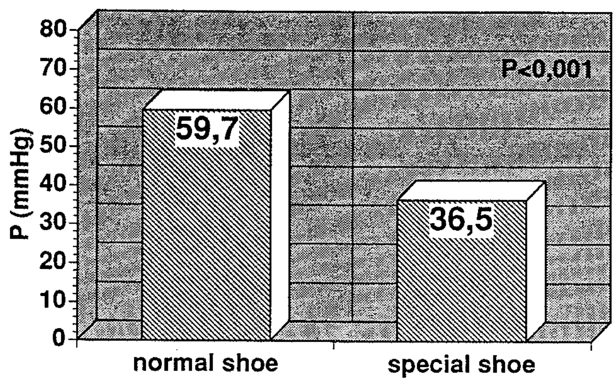

Fig. 8. — Comparison of maximum pressures of all subjects.

The statistical analysis of the maximum pressures of all individuals resulted in values of 59.7 mm Hg (± 9.1 mm Hg) in the normal shoe and 36.5 mm Hg (± 11.8 mm Hg) in the special shoe (fig. 8). This difference is highly significant ($p < 0.001$).

The comparison of the mean pressure showed similar results. The statistical evaluation of the mean pressures of all subjects reveals a difference of 17.3 mm Hg (36.7%). In the normal shoe a mean pressure of 47.1 mm Hg (± 9.0 mm Hg) was measured compared to 29.8 mm Hg (± 11.0 mm Hg) in the special shoe (fig. 9). This difference is highly significant ($p < 0.001$).

Regarding the comfort of the special shoe, 18 subjects did not find any difference in comparison with the normal shoe. Five subjectively experienced the special shoe as less, 12 as more comfortable on running (fig. 10).

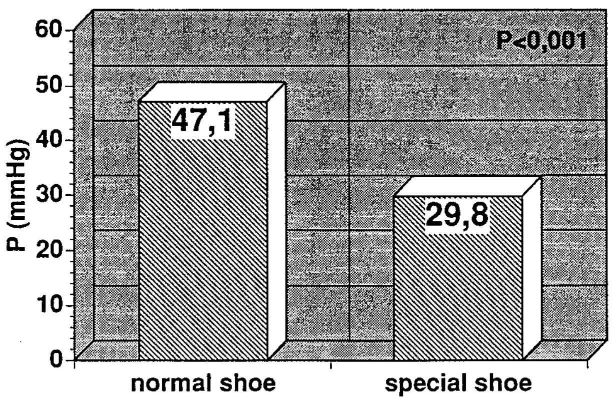

Fig. 9. — Comparison of mean pressures.

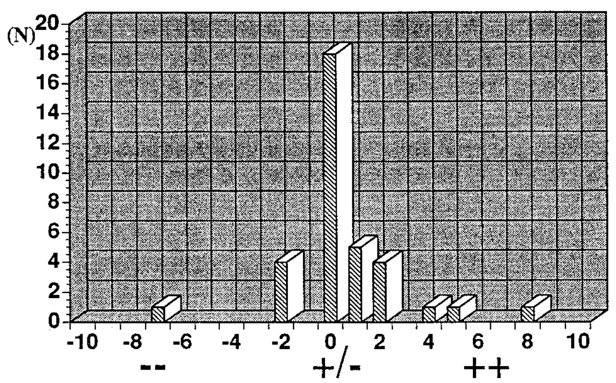

Fig. 10. — Subjective judgement regarding the comfort of the special shoe.

DISCUSSION

Related to the increase in leisure time in the general population acute and chronic sports injuries are becoming more and more frequent. According to Steinbrueck (40) the lower extremity is involved in 69% of the cases. A syndrome rarely mentioned in the literature is the chronic exertional compartment syndrome. Styf (42) detected a chronic compartment syndrome in 26 out of 89 patients suffering from lower leg symptoms of unknown origin. Our own experiences also suggest that probably more people than generally supposed are predisposed to develop an exertional compartment syndrome (20) : 12.8% of 164 recreational athletes examined had an average intracompartmental pressure over 70 mm Hg. These results correspond to those of Puranen *et al.* who consider the chronic compartment syndrome to be the reason for 9.5% of all physical symptoms and for up to 60% of all lower leg symptoms in an athletic patient population (34). The data from Qvarfordt *et al.* are also similar to our findings. They detected a chronic compartment syndrome in 14% of unselected patients affected with lower leg symptoms of unknown origin (35).

Regarding our findings a negative shoe sole seems to influence the intracompartmental pressure in the anterior tibial compartment. The question arises as to the reasons for these pressure changes. Electromyographic studies show (1, 6, 14, 22, 47) that during initial heel contact and during load response the anterior tibial muscle is activated. This contraction is eccentric in nature. By this contraction, the kinetic energy of the foot is intercepted and the ankle is stabilized for the subsequent stance phase.

Harrison *et al.* showed that the torque (Nm) in the ankle region reaches the maximum within the first 0.1 sec. of the gait cycle, and that the absolute value of the ankle is evidently higher than that of the hip and as high as the values obtained in the knee region (14). Ounpuu (33) found on walking as well as on running absolute peak torques in the ankle joint comparable to the hip and knee joint. These peak torques must be eccentrically intercepted by the anterior tibial muscle after the initial heel contact.

Some of our previous studies revealed that heel running is exceptionally unfavorable and significantly increases the intracompartmental pressure (18, 19, 20). This is shown by a diminished pressure amplitude and a resulting increase of the mean pressure. In toe runners, on the other hand, we documented a significant reduction of the mean pressure compared with heel runners. The duration of muscle contraction is shortened by about 40%. This also results in a clearly lower intracompartmental pressure. Although the stabilization phase of the ankle is diminished, the joint angles at the knee and hip joints seem not to be significantly influenced during running. These objective findings were confirmed by the subjective feeling of the volunteers, some of whom considered the special running shoe even more comfortable than the conventional shoe.

In the literature, successful conservative therapy for chronic compartment syndromes is rarely mentioned. Methods described are the use of anti-inflammatory drugs, isotonic and isometric exercises, diuretics, Xylocaine injections, cryotherapy, stretching and ultrasound treatment (2, 8, 9, 11, 16, 24, 29). As all of these conservative procedures have, at best, a symptomatic effect, the athlete is usually forced to reduce his athletic activity. Even 12 months of conservative treatment do not improve the symptoms of a chronic compartment syndrome (36). If the athletic activity should be continued or had to be maintained in professional athletes, fasciotomy was the only recommended therapy. Surgery is said to be sucessful in 60% to 100% of the cases (34, 38, 44). The operative treatment represents, however, an invasive procedure with its typical complications. Beyond that, Garfin *et al.* (12) found a 15% loss of muscular strength after fasciotomy in animal experiments. Mozan and Keagy also demonstrated a loss of strength after this treatment (28). Nevertheless, to what extent these results can be transferred to human subjects is not known, especially since Matsen (27) and Reneman (36) did not see any indication of decreased physical ability in the operated athletes.

A rational graduation from conservative to invasive therapy for the chronic exertional compartment syndrome is not yet known. Our results show that the running shoe presented seems to be an option for a causal conservative therapy of this entity. To what extent the negative sole adversely influences other locomotion parameters will have to be clarified by further studies.

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SAMENVATTING

J. JEROSCH, W. H. M. CASTRO, H. HALM, H. BORK. Invloed van de jogging schoen zool op de intrakompartimentale druk van het anterieure tibiale kompartiment.

Doel van de studie was om te evalueren welke invloed een negatieve zool van een jogging schoen op de intrakompartimentale druk van het anterior tibiale kompartiment had. Bij 35 vrijwilligers met normale joggingschoenen en met joggingschoenen met een negatieve zool werd de intrakompartimentale druk gedurende 20 minuten rennen op een tredmolen gemeten. Naast de meting van de intrakompartimentale druk werd ook een ganganalyse verricht.

De vergelijking tussen het looppatroon met normale schoenen en met speciale schoenen vertoonde duidelijke verschillen. Met de normale schoen was de plantaire flexie na initieel kontakt 16 graden ; met de speciale schoen 6 graden. De duur van de plantaire flexie met de normale schoen was 0,17 seconden vergeleken met 0,1 seconden bij de speciale schoen. De

intraindividuele vergelijking van de drukcurves vertoonden duidelijke verschillen tussen de meeste proefpersonen. De maximale druk van elke vrijwilliger na het rennen met de normale als ook met de speciale schoen vertoonde een afname van het maximale drukniveau bij gebruik van de speciale schoen. De maximale drukken van de normale schoen (59,7 ± 9,1 mm Hg) waren significant hoger vergeleken met de speciale schoen (36,5 ± 11,8 mm Hg) ($p < 0,001$). De gemiddelde druk toonde soortgelijke verschillen. In de normale schoen werd een gemiddelde druk van 47,1 mm Hg (± 9,0 mm Hg) gemeten i.t.t. 29,8 mm Hg (± 11,0 mm Hg) met de speciale schoen ($p < 0,001$). Met betrekking tot het pasgemak van de speciale schoen vonden 51% van de proefpersonen geen verschil met de normale schoen ; 14,3% vonden de schoen minder comfortabel en 34,3% meer comfortabel tijdens het rennen.

RÉSUMÉ

J. JEROSCH, W. H. M. CASTRO, H. HALM, H. BORK. Influence de la semelle des chaussures de jogging sur la pression dans la loge tibiale antérieure.

Le but de l'étude est d'évaluer l'influence d'une semelle négative de chaussures de jogging sur la pression intracompartimentale de la loge tibiale antérieure. Trente cinq volontaires ont couru pendant 20 minutes sur un tapis de marche, d'abord avec des chaussures de jogging normales et ensuite avec des chaussures avec semelle négative. Les auteurs ont pratiqué une mesure de la pression intracompartimentale et une analyse de la marche.

La comparaison de la marche avec chaussure normale et avec chaussure spéciale met en évidence des différences manifestes. Avec des chaussures normales, la flexion plantaire était de 16° après le contact initial ; de 6° avec les chaussures spéciales. La durée de la flexion plantaire avec chaussure normale était de 0,17 seconde, comparée au 0,1 seconde avec chaussure spéciale. La comparaison des courbes de pression entre les individus montre des différences nettes. La pression maximale de chaque volontaire après la course avec chaussure normale ou avec chaussure spéciale montrait une diminution du niveau maximal de pression, lors de l'emploi de chaussures spéciales. Les pressions maximales avec chaussure normale (59,7 ± 9,1 mm Hg) étaient nettement plus élevées qu'avec la chaussure spéciale (36,5 ± 11,8 mm Hg) ($p < 0,001$). La pression moyenne montrait des différences similaires avec chaussure normale, la pression moyenne comportait 47,1 mm Hg (± 9,9 mm Hg) contre 29,8 mm Hg (± 11,0 mm Hg) avec la chaussure spéciale ($P < 0,001$). En ce qui concerne la facilité de la marche avec chaussure spéciale 51% des sujets ne notaient aucune différence par rapport à une chaussure normale ; 14,3% trouvait les chaussures moins confortables ; 33,3% plus confortables lors de la course.