The Role of Limited Joint Mobility in Diabetic Patients With an At-Risk Foot

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OBJECTIVE — To assess the role of limited joint mobility (LJM) in causing abnormal high plantar pressures in the forefoot of diabetic patients with an at-risk foot.

RESEARCH DESIGN AND METHODS — A total of 70 type 1 or type 2 diabetic patients and 30 control subjects participated in this cross-sectional study. Thirty-five diabetic patients with an at-risk foot, defined as a foot with neuropathy but without ulceration or previous ulceration, and 35 diabetic control subjects without neuropathy were selected for the subgroups. Joint mobility was assessed in the foot at the ankle and metatarsophalangeal I (first MTP) joints. Using the FastScan plantar pressure analyzer, the pressure-time integrals (PTIs) as dynamic variables were measured in each foot. The clinical assessment included standard measures of peripheral neuropathy.

RESULTS — The mobility at the ankle and first MTP joint were significantly reduced in the foot-at-risk group compared with the diabetic control group and the control subjects ($P < 0.0001$). The PTIs were significantly higher in the foot-at-risk group compared with the two other groups ($P < 0.0001$). There was a strong inverse correlation between the mobility of the ankle or first MTP joint and the PTI of the diabetic patients ($r = -0.67$, $P < 0.0001$, and $r = -0.71$, $P < 0.0001$, respectively). The vibration perception threshold was positively correlated with the PTI of the diabetic patients ($r = 0.44$, $P = 0.0001$).

CONCLUSIONS — Diabetic patients with an at-risk foot have reduced joint mobility and elevated PTIs on the plantar forefoot, placing them at risk for subsequent ulceration. Therefore, LJM may be a possible factor in causing high plantar pressures and may contribute to foot ulceration in the susceptible neuropathic at-risk foot.

Diabetes Care 27:942–946, 2004

Foot ulceration in diabetic patients is a major health problem, often leading to lower-limb amputations and an increased death rate (1–3). Diabetic peripheral neuropathy is the most important etiologic factor, but there is a complex interplay between a number of other contributory factors, such as limited joint mobility (LJM), altered foot pressures, glycemic control, and ethnic background (4–6). Altered foot pressures are well characterized by the determination of either maximum plantar pressure (7) or pressure-time integral (PTI). In diabetic patients, progressive stiffening of the collagen-containing tissues occurs in a number of ways, especially in LJM of both large and small joints. When fully developed, the changes comprise thickening of the skin with loss of joint mobility and, to some degree, a fixed flexion deformity in the hands described as cheiroarthropathy (8–11). This condition can be identified by the presence of a prayer's sign. It has been previously reported that LJM predisposes to foot ulceration due to elevated foot pressures in susceptible neuropathic feet (12,13).

We aimed to clarify whether LJM, PTI, and vibration perception threshold (VPT) are related to each other in diabetic patients with an at-risk foot and in diabetic and nondiabetic control subjects.

RESEARCH DESIGN AND METHODS

— Patients attending our clinic (General Internal Medicine, Endocrinology and Diabetes) were consecutively invited to take part in the study, and informed consent was obtained from patients and control subjects. The study was approved by the local ethics committee. Thirty-five diabetic patients with an at-risk foot, defined as a foot with neuropathy but without ulceration or previous ulcerations, 35 diabetic control subjects without neuropathy, and 30 nondiabetic control subjects were included in the study. Physical examination included the inspection of the foot and palpation of the peripheral pulses. Peripheral diabetic neuropathy was evaluated by VPT with the calibrated Rydell-Seiffer tuning fork and the Phywe Vibratester (Phywe System, Höchstberg, Germany) at the dorsal surface of the great toe and the external malleolus of both sides as previously described (14). A threshold <4/8 with the calibrated Rydell-Seiffer tuning fork and an age-dependent alteration of the VPT using the Phywe Vibratester indicated peripheral diabetic neuropathy. Three determinations of each method were made, and the mean values were calculated. Patients who had previous fractures or bone surgery (e.g., arthrodesis of the ankle joint) of the lower limbs or feet and patients suffering from a diabetic Charcot foot were excluded from the study. The history evaluation of the patients included age, sex, BMI, type of diabetes, and diabetes duration. HbA_{1c} was measured to assess the quality of blood glucose control within the past month.

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Received for publication 1 September 2003 and accepted in revised 23 December 2003.

Abbreviations: LJM, limited joint mobility; MTP, metatarsophalangeal; PTI, pressure-time integral; ROC, receiver operating characteristic; VPT, vibration perception threshold.

Table 1—*Characteristics of 70 diabetic patients and 30 nondiabetic control subjects*

	Foot-at-risk group	Diabetic control group	Nondiabetic control group
n	35	35	30
Age (years)	62.0 ± 9.5	63.7 ± 11.2	62.1 ± 10.8
BMI (kg/m^2)	27.6 ± 4.1	27.9 ± 4.0	28.5 ± 4.3
Sex (men/women)	20/15	22/13	17/13
Type of diabetes (type 1/type 2)	11/24	7/28	—
Diabetes duration (years)	14.7 ± 8.6	17.6 ± 7.9	—
HbA_{1c} (%)	7.4 ± 1.1	7.8 ± 0.7	5.0 ± 0.3

Data are means ± SD unless noted otherwise. Age, BMI, sex, type of diabetes, diabetes duration, and HbA_{1c} did not differ between the diabetic groups. Age, BMI, and sex distribution did not differ between all groups.

Determination of joint mobility and PTI

Joint mobility was measured at the ankle joint and first MTP. With the patient supine and the ankle joint in neutral position, a vertical line was marked on the patient's skin from heel to midcalf, and the maximum range of talar flexion and extension in passive motion was measured with a goniometer. Regarding the first MTP joint, the patient was also in the supine position and a horizontal line was drawn from the first toe to the heel. The maximum range of passive extension to plantar flexion was recorded. The mean of three readings was calculated and reported as the mean range of passive motion. The clinical examinations of joints were performed routinely by the same observer. The coefficient of variation of the LJM was 0.06 (6%) for the passive motion of the first MTP and 0.074 (7.4%) for the passive motion of the ankle joint. Foot pressure measurements were performed using the FastScan system (Megascan, Hannover, Germany). This system uses an ultra-thin, pressure-sensitive insole sensor, which has been well evaluated (15). The PTIs were measured by selecting the area of interest under the forefoot after removal of callus when necessary. The size of the area of interest was accordingly adjusted to 40 × 40 mm, and the box was placed centrally on the same location on the image of the forefoot, which corresponded to the same anatomical site of the foot. The pressure is directly proportional to the force and inversely proportional to the area. PTI was measured in Newton-seconds per square centimeter, which represents the amount of force (in newtons) maintained through a defined area (in centimeters squared), multiplied by the amount of time (in seconds) taken to complete the propulsion phase of a gait. The mean of all PTIs in each walk (three steps per walk and two walks per test) was calculated for each patient. For the PTI measurement, the coefficient of variation was 0.052 (5.2%).

Statistical analyses

Statistical analyses included descriptive statistics, SE, and ANOVA. Differences between the groups regarding the patients' sex and type of diabetes were calculated using Fisher's exact test. The correlations between the LJM, PTI, and VPT were calculated with linear regression analysis. To evaluate LJM and VPT as a screening test for elevated stresses of the forefoot, a receiver operating characteristic (ROC) analysis using the PTI for the diagnosis of time-dependent pressure load was done. The ROC is the relation between sensitivity and specificity for a cutoff value used as a criterion to detect the disease. The statistical analyses were done using JMP version 4.0 for Windows (SAS, Cary, NC).

RESULTS — Thirty-five diabetic patients (20 men and 15 women, mean age 62 years) with reduced VPT were included in the foot-at-risk group. Thirty-five diabetic patients (22 men and 13 women, mean age 63.7 years) without alteration of the VPT neuropathy and without foot ulcerations were included in the diabetic control group. Thirty nondiabetic subjects (17 men and 13 women, mean age 62.1 years) were included in the nondiabetic control group. The detailed clinical characteristics of the patients and control subjects are given in Table 1. There was no significant difference in age, sex, BMI, HbA_{1c}, and diabetes duration between the three groups, except diabetes duration and glycated HbA_{1c} (Table 1).

The ankle and first MTP joint mobility was significantly reduced in the foot-at-risk group compared with both the diabetic control group and the control subjects ($P < 0.0001$) (Table 2). As expected, the PTI was significantly higher in the foot-at-risk group compared with the two other groups ($P < 0.0001$) (Table 2). There was a strong inverse correlation (Fig. 1) between the ankle joint mobility and the PTI of the diabetic patients ($r = -0.67$, $P < 0.0001$). In the analyses of the LJM of the first MTP joint, there was also a strong inverse correlation ($r = -0.71$, $P < 0.0001$) between the first MTP joint mobility and the PTI (Fig. 2). The VPT was positively correlated (Fig. 3)

Table 2—*Characteristics of neuropathy, passive ankle, and first MTP joint mobility and plantar pressure in 70 diabetic patients and 30 nondiabetic control subjects*

	Foot-at-risk group	Diabetic control group	Nondiabetic control group
n	35	35	30
VPT (μm)	11.4 ± 1.4*	2.3 ± 0.2	2.3 ± 0.3
	(8.6–14.3)	(1.9–2.7)	(1.8–2.8)
Ankle joint mobility (°)	17.9 ± 0.7†	28.4 ± 0.8	31.0 ± 1.6
	(16.5–19.3)	(26.7–30.1)	(27.8–34.1)
1st MTP joint mobility (°)	35.3 ± 1.1†	62.0 ± 0.8	59.4 ± 1.0
	(33.0–37.5)	(60.3–63.7)	(57.3–61.5)
PTI (N · s/cm^2)	27.4 ± 0.8‡	16.1 ± 0.7	16.4 ± 0.6
	(25.7–28.9)	(14.6–17.6)	(15.1–17.7)

Data are means ± SE (95% CI). VPT has been used as an inclusion criterion in the study. *$P < 0.0001$ for the VPT comparing the foot-at-risk group and the diabetic and nondiabetic control groups; †$P < 0.0001$ for the ankle joint and 1st MTP joint mobility comparing the foot-at-risk group and the diabetic and the nondiabetic control groups; ‡$P < 0.0001$ for the PTI comparing the foot-at-risk group and the diabetic and nondiabetic control groups.

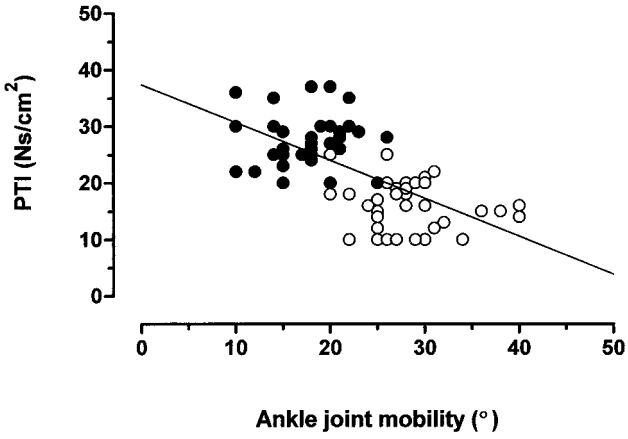

Figure 1—*Correlation of the passive ankle joint mobility and PTI in 35 diabetic patients with an at-risk foot (●) and in 35 diabetic control subjects without an at-risk foot (○). R = −0.67, P < 0.0001. The solid line denotes the linear regression curve.*

with the PTI in both feet of the diabetic patients ($r = 0.44$, $P = 0.0001$).

To evaluate LJM and VPT as a screening parameter for time-dependent elevated plantar forefoot loads, we performed an ROC analysis (Fig. 4) using the PTI as a result of time-dependent plantar pressure of the forefoot because the time-dependent load in the forefoot region seems to play an important role as a cofactor for plantar ulceration (7). Using a PTI of 20 N · s/cm^2 as the cutoff value, the ROC for the LMJ showed a better sensitivity and specificity for detecting an impaired forefoot plantar load compared with the ROC analysis of the VPT in diabetic patients with an at-risk foot. Ankle joint mobility reduced to an angle of 20–25° appears to be an ideal cutoff value that indicates elevated time-dependent pressure to the forefoot in diabetic patients with an at-risk foot.

CONCLUSIONS — LJM, with its common manifestation as cheiroarthropathy, is more frequently seen in diabetic patients than in the general population and occurs in as many as 30% of diabetic patients. LJM is often overlooked because it causes little disability and is therefore thought to be of little clinical consequence. The exact pathogenesis of LJM is unclear. It is thought to be a manifestation of the diffuse collagen abnormalities found in diabetic patients. The association between LJM and neuropathic foot ulceration was demonstrated by Delbridge et al. (13) in 1988. It was suggested that LJM at the ankle joint contributes to the development of tissue damage by causing abnormal pressures at susceptible sites (13). However, this group did not study this putative association between LJM and elevated foot pressures. The movements of the ankle joint are of special interest in the diabetic foot because any reduction in mobility of this joint may cause an increase in plantar pressure during walking. In the presence of LJM, the foot is unable to provide a shock-absorbing mechanism (pronation from heelstrike to midsupport and supination in the propulsion phase of the forefoot in the ankle joint) and may lose its ability to maintain normal plantar pressures. It was demonstrated by Fernando et al. (16) that, with increasing severity of changes in the hand, there is a progressive decline in the mobility of the ankle region, indicating that LJM is a widespread phenomenon. The elevated plantar foot pressures seen in patients with LJM in the hands may also reflect this generalized LJM in the foot. However, it has not yet been clarified whether the determination of LJM is also useful in identifying diabetic patients with an at-risk foot.

We aimed to assess the relationships between LJM, PTI, and VPT in diabetic patients with an at-risk foot. The main finding of our study is that both the LJM of the ankle and first MTP joints and the VPT are significantly correlated with the PTI of the forefoot in diabetic patients with an at-risk foot. The ankle joint and first MTP joint mobility showed a strong inverse correlation with the PTI of the forefoot, and there was a clear cutoff in the PTI between the foot-at-risk group and diabetic control group around 20 N · s/cm^2 (Figs. 1 and 2). The elevated PTI in the foot-at-risk group was predominantly evoked by the reduced joint mobility of the ankle and first MTP joints and would result in an elevated time-dependent load of the forefoot as described by Stess et al. (7). Therefore, it is conceivable that LJM is a major factor in the pathogenesis of diabetic foot ulcers and that patients with impaired ankle joint or first MTP joint mobility are preferentially at risk for foot ulceration. Interestingly, it has recently been shown that the lengthening of the Achilles tendon increases the dorsiflexion of the foot and reduces the recurrence of neuropathic plantar ulcers of the forefoot by 52%, compared with total contact cast therapy (17). In diabetic patients, the VPT is a useful indicator for peripheral neuropathy of the foot. In this study, we ob-

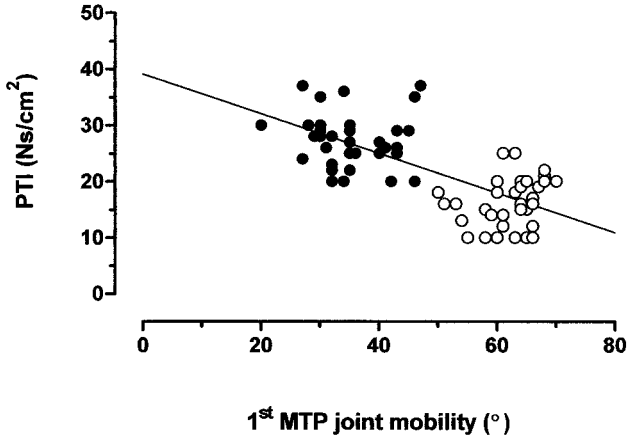

Figure 2—*Correlation of the passive first MTP joint mobility and PTI in 35 diabetic patients with an at-risk foot (●) and in 35 diabetic control subjects without an at-risk foot (○). R = −0.71, P < 0.0001. The solid line denotes the linear regression curve.*

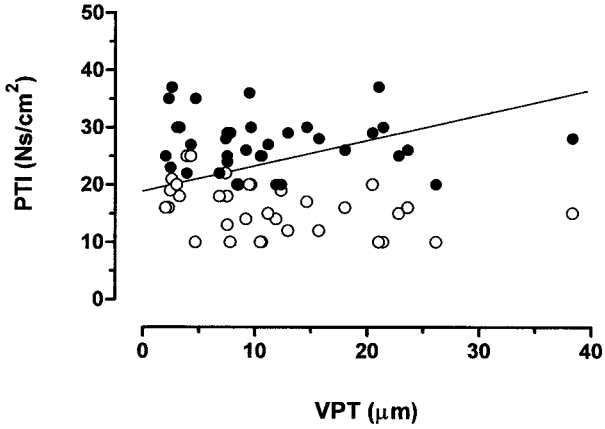

Figure 3—*Correlation of the VPT and PTI in 35 diabetic patients with an at-risk foot (●) and in 35 diabetic control subjects (○). R = 0.44, P = 0.0001. The solid line denotes the linear regression curve.*

served a positive correlation between the VPT and the PTI of the forefoot. However, compared with the correlation of LJM and PTI (Figs. 1 and 2), there was no clear cutoff in the PTI when related to the VPT in diabetic patients with an at-risk foot (Fig. 3). This yields the impression that the VPT is much less able to distinguish between normal and elevated PTIs of the forefoot in diabetic patients with an at-risk foot. This was also clearly reflected in the ROC analysis, which revealed a sensitivity of 90% with a specificity of 90% to identify diabetic patients with an at-risk foot testing for LJM and time-dependent elevated plantar forefoot loads using the range of motion of the first MTP joint. For testing the LJM and raised plantar forefoot pressures using the ankle joint, the sensitivity was 80% and the specificity was 90%. In contrast, when using the VPT, the sensitivity was only 55% and the specificity 80% (Fig. 4).

A limitation of these observations may be the cross-sectional study design because, for ethical reasons, we are not able to provide prospective data for foot ulceration in diabetic patients with elevated PTI due to reduced LJM of the ankle and first MTP joints without intervention. In case of elevated PTIs and plantar pressures in the forefoot of diabetic patients that will lead to callus formation and subsequent ulcer formation, we advise patients to wear custom-made insoles in cushioned therapeutic shoes to prevent ulceration of the feet (18).

In conclusion, our data indicate that the determination of the ankle joint mobility or first MTP joint mobility is a simple and rather exact test to identify diabetic patients with an at-risk foot. The method is simpler and less costly than measuring the plantar pressure loading of the foot itself and might therefore be useful as a screening tool in diabetic patients to identify those with an at-risk foot.

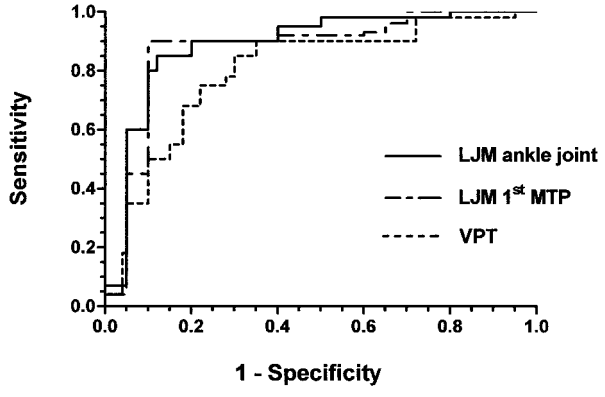

Figure 4—*ROC analysis of the LJM of the ankle joint (solid line), first MTP joint (dashed line), and VPT (dotted line) for the elevated PTI. Determination of a cutoff point of 20 N · s/cm² of the PTI showed the true positive rates (sensitivity) for the three different criteria, which are plotted against false-positive rates (1-specificity).*

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