A new measurement system for determining bending moments at the human foot during footwear conditions

Thomas Stief, Klaus Peikenkamp; Biomechanics Research Laboratory, University of Applied Sciences, Münster, Germany

Summary

Stress on the feet during foot wear conditions is determined by pressure measurements. Multidimensional loads can't be analyzed so far in daily practice. At the University of Applied Sciences Münster an insole measurement system was developed to detect reliable, mobile and easy bending and torsional loads at the foot.

Introduction

Shoes protect and support feet during daily and sports activities. At various orthopedic and systemic diseases such as diabetic foot ulcers, reduction of the stress at the feet is indicated to avoid damage from overstressing. Till today the stress occurring at the foot in the shoe is determined with plantar pressure measurements across different systems with insoles or individual sensors. Other forms of stress such as bending, torsional moments and shear loadings can't be detected yet, although this strain in various forms could be of great interest at different orthopedic disorders at the lower extremities. The development objective of the presented, new measurement system (betois; bending torsion insole system) was the reliable and mobile determination of bending and torsional stress on the foot during wearing shoes or using different orthopedic devices.

Methods

On a flexible special shaped base layer proximal to the metatarsal heads I (MTP I) and V (MTP V) strain gauge rosettes (Vishay GmbH) were applied on the top and bottom side. The shape of the base has been designed so that, in a forefoot medial and lateral cantilever beam deflection could be realized. The sensors were integrated into Wheatstone bridges to determine bending moments (Mb). Finally, the insole was cable connected with an A/D device (125 Hz, ME Systems) with Bluetooth interface. During calibrations, each forefoot cantilever of the insole were clamped horizontally and loaded with standard masses. Afterwards measured and applied Mb were compared.

The dynamic determination Mb at the foot with betois during footwear condition (samba, adidas) was executed on one subject (m, 27 yrs., 75 kg). The tests consisted of treadmill and overground walking and running at self-selected speed and walking up- and downstairs. 20 consecutive cycles were analyzed per condition.

Results

The determined calibration Mb proximal to the MTP I provide a coefficient of determination of $R^2 > 0.999$ on a regression line of y=1.00+0.26x (see Figure left: MTP I). The crosstalk to other sensors is less than 0.5 % (see Figure 1, left: CT_MTP V). In Figure 1 right, the results of the dynamic Mb measurements of the individual applications are shown. Positive values represent the averaged maximum dorsal extension moments (DEM) and negative values the averaged maximum plantar flexion moments (PFM). In all conditions both DEM and PFM occur.

Conclusion

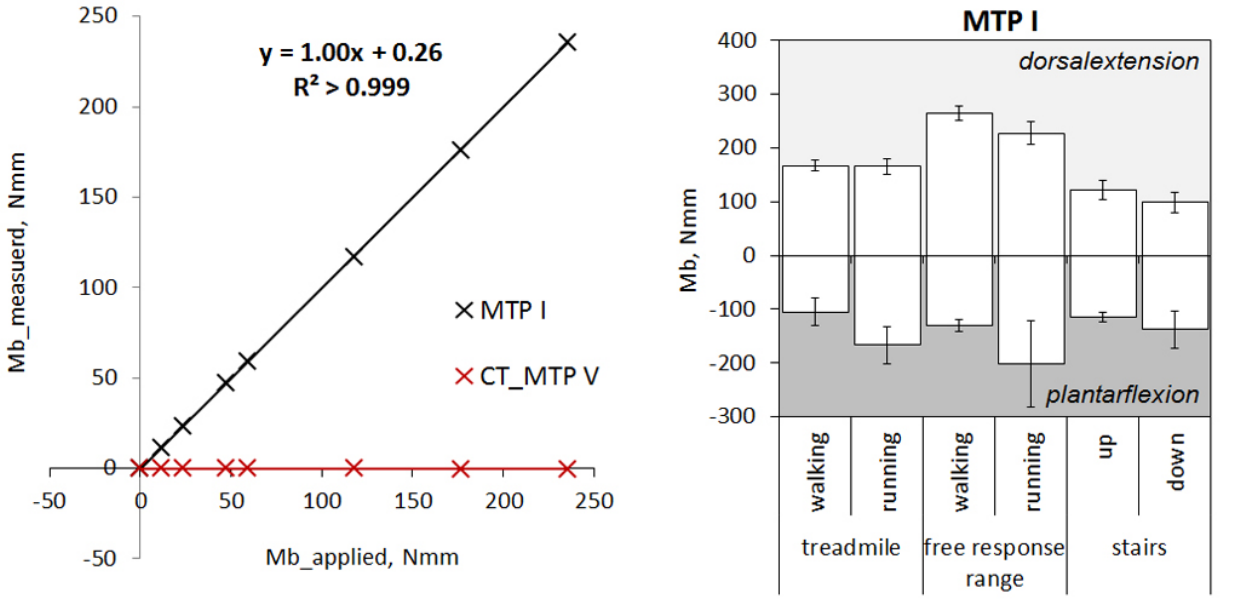
The calibration with a linearity factor of almost 1 and a coefficient of determination of $R^2 > 0.999$ shows that the developed measurement system is a reliable method to detect Mb.

In the case study alternating bending loads with specific characteristics can be detected for all test conditions. The greatest DEM occur during overground walking whereas largest PFM are generated while overground running at optimal speed. Minimum DEM can be determined during walking downstairs.

In conclusion, the proposed measurement system allows the mobile, reliable and easy detection of Mb proximal to MTP I. Additionally, both Mb proximal to MTP V and torsional moments proximal to MTP I and MTP V can be detected with the system. A German and international patent application is pending.

References

1. Collins, N., et al. (2007). Foot orthoses in lower limb overuse conditions: a systematic review and meta-analysis. Foot Ankle Int., 28, S. 396–412.
2. Janisse, D. (1995). Prescription insoles and footwear. Clin. Paediatr. Med. Surg., 12, S. 44–61.
3. Long, J. T. (2007). Biomechanics of the double rocker sole shoe: Gait kinematics and kinetics. Journal of Biomechanics, 40, S. 2882–2890.
4. Stefanyshyn D. J. & Nigg B.M. (1997). Mechanical Energy Contribution of the Metatarsophalangeal Joint of Running and Sprinting. Journal of Biomechanics, 30, S.1081–1085.



Figure; left: calibration results for Mb at MTP I (black crosses and black line) and crosstalk at the unloaded sensor at MTP V (red crosses and red line); **right:** maximal dorsal extension (positive values) and plantar flexion moments (negative values) proximal to MTP I detected under different dynamic conditions