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Kinematic analysis of a multi-segment foot model for research and clinical applications: a repeatability analysis

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Abstract

An unbiased understanding of foot kinematics has been difficult to achieve due to the complexity of foot structure and motion. We have developed a protocol for evaluation of foot kinematics during barefoot walking based on a multi-segment foot model. Stereophotogrammetry was used to measure retroreflective markers on three segments of the foot plus the tibia. Repeatability was evaluated between-trial, between-day and between-tester using two subjects and two testers. Subtle patterns and ranges of motion between segments of the foot were consistently detected. We found that repeatability between different days or different testers is primarily subject to variability of marker placement more than inter-tester variability or skin movement. Differences between inter-segment angle curves primarily represent a shift in the absolute value of joint angles from one set of trials to another. In the hallux, variability was greater than desired due to vibration of the marker array used. The method permits objective foot measurement in gait analysis using skin-mounted markers. Quantitative and objective characterisation of the kinematics of the foot during activity is an important area of clinical and research evaluation. With this work we hope to have provided a firm basis for a common protocol for in vivo foot study.

Keywords: Foot kinematics; Gait analysis; Repeatability; Reliability; Stereophotogrammetry

1. Introduction

In gait analysis, the clinical biomechanical models usually represent the foot as a single rigid vector, permitting only foot progression angle and net dorsi/plantarflexion to be determined. In the research literature, there is no standard nor reliable method for dynamic in vivo measurement and it is recognised that this is very difficult to achieve due to the foot's complex structure. This paper describes a multi-segment approach to measuring foot kinematics during gait and a repeatability analysis on healthy feet.

In the last decade a few groups have presented multi-segment in vivo studies of the foot (DeLozier et al., 1991; D'Andrea et al., 1993; Kidder et al., 1996; Leardini et al., 1999), with others looking at the ankle/subtalar complex in vivo (Moseley et al., 1996; Liu et al., 1997). However, the means of marking and describing the segment fixed anatomical axes have varied between authors so that comparability of the results of these studies are limited (Leardini et al., 1999). There is a need for a standardised protocol which requires thorough testing and validation (Kidder et al., 1996). The objectives of the present study were:

(1) To develop a multi-segment foot model and measurement protocol applicable to gait analysis for clinical and research applications.
(2) To evaluate the reliability of the protocol and model.

2. Methods

2.1. Foot model

The foot model simplifies the complex anatomical structure of the 28 bones of the foot. We selected a three

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References

Altman, D.G., 1991. Practical Statistics for Medical Research, 1st Edition. Chapman and Hall, London.

American Academy of Orthopaedic Surgeons (AAOS), 1966. Joint Motion: Method of Measuring and Recording. Churchill Livingstone, Edinburgh and London.

D'Andrea, S., Tylkowski, C., Losito, J., Arguedas, W., Bushman, T., Howell, V., 1993. Three-dimensional kinematics of the foot. Proceedings of the Eighth Annual East Coast Clinical Gait Conference, Rochester, MN, USA, May 5–8, pp. 109–110.

DeLozier, G., Alexander, I., Narayanaswamy, R., 1991. A method for measurement of integrated foot kinematics. International Symposium on Three-Dimensional Analysis of Human Movement, Montreal, Canada, pp. 79–82.

Gage, J.R., DeLuca, P.A., Davis, R.B., et al., 1997. Clinical Gait Analysis, A Focus on Interpretation. Connecticut Childrens Medical Center, Hartford, Connecticut, USA.

Grood, E.S., Suntay, W.J., 1983. A joint coordinate system for the clinical description of three-dimensional motions: application to the knee. Transactions of ASME-Journal of Biomechanical Engineering 105, 136–144.

Jahss, M.H., 1991. Disorders of the Foot and Ankle. 2 Edition, 1991.

Kadaba, M.P., Ramakrishnan, H.K., Wooten, M.E., Gainey, J., Gorton, G., Cochran, G.V.B., 1989. Repeatability of kinematics, kinetic and electromyographic data in normal gait. Journal of Orthopaedic Research. 7, 849–860.

Kapandji, I.A., 1987. The Physiology of the Joints. Volume Two Lower Limb, 5th ed. Churchill-Livingstone, Edinburgh.

Kidder, S.M., Abuzzahab, A., Harris, G.F., Johnson, J.E., 1996. A system for the analysis of foot and ankle kinematics during gait. IEEE Transactions on Rehabilitation Engineering. 4, 25–32.

Leardini, A., Benedetti, M.G., Catani, F., Simoncini, L., Giannini, S., 1999. An anatomically based protocol for the description of foot segment kinematics during gait. Clinical Biomechanics 14, 528–536.

Liu, W., Siegler, S., Hillstrom, H., Whitney, K., 1997. Three-dimensional, six-degrees-of-freedom, kinematics of the human hindfoot during the stance phase of level walking. Human Movement Science. 16, 283–298.

Long, B.W., Rafert, J.A., 1995. Orthopaedic Radiology. W.B. Saunders and Co., London, 1995, pp. 388–389.

Moseley, L., Smith, R., Hunt, A., Grant, R., 1996. Three-dimensional kinematics of the rearfoot during the stance phase of walking in normal young adult males. Clinical Biomechanics. 11, 39–45.

Neter, J., Wasserman, W., Kutner, M.H., 1990. Applied Linear Statistical Models, 3rd Edition. Irwin, Homewood, IL.

Perry, J., 1992. Gait Analysis, Normal and Pathological Function. Slack Inc., Thorofare, NJ.

Rose, G.K., Welton, C.A., Marshal, T., 1986. The diagnosis of flat foot in the child. Journal of Bone and Joint Surgery 67B, 702–711.

Steinwender, G., Saraph, V., Scheiber, S., Zwick, E. B., Hacki, K., 1999. Intrasubject repeatability of kinematic and kinetic data in normal and spastic children. Proceedings of the European Society of Movement Analysis in Adults and Children, Heidelberg, Germany, Sept 23–25, pp. 57–58.

Swinscow, T.D.V., 1996. Statistics at Square One. 9th Edition. BMJ, London.

Winer, B.J., Brown, D.R., Michels, K.M., 1991. Statistical Principles in Experimental Design. 3rd Edition. McGraw-Hill Inc, New York.