and steady state determination (method) occurred. Thus, it is not clear how much each factor influenced the improvement. While it is possible that the reduction in variability could be due to differences in samples, the groups appear to be well matched, except for age, where the subjects tested with the new protocol were significantly older than those tested with the old protocol (age = 8.3 years new, 10.9 years old).

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O-14

Alternative methods for measuring tibial torsion

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1. Summary/conclusions

This study introduces several new techniques for determining tibial torsion using motion analysis data. Analysis of correlations suggests that the new techniques may be more clinically valuable than the traditional bi-malleolar axis measurement.

2. Introduction

Long bone torsions are notoriously difficult to measure [1]. The most common measure of tibial torsion is the bi-malleolar axis angle. Bony landmark ambiguities combine with line-of-sight problems resulting in an angle that is hard to accurately measure. Efforts to reduce the variability in several torsion measurements within the Gillette Children's Specialty Healthcare Center for Gait and Motion Analysis have been largely unsuccessful. This study uses motion analysis data to determine estimates of knee and ankle axes and thereby estimate tibial torsion. These "technical" measurements can be compared to the bi-malleolar axis angle.

3. Statement of clinical significance

Better methods for measuring tibial torsion can lead to improved clinical decisions regarding tibial derotational osteotomies. Determination of tibial torsion using motion analysis data appears to be more useful than a bi-malleolar axis measurement.

4. Methods

Data from 20 young, able-bodied volunteers was used in this study (ages 5–14 years). Four different tibial torsion measurements were acquired; one from a physical exam and three from motion analysis data. For the physical exam measure, the bi-malleolar axis angle was used. For the motion analysis methods the locations of the medial and lateral malleoli were estimated using virtual circles [2]. The centers of those virtual circles were then used to define a bi-malleolar axis. The knee axis was estimated using three different techniques. The first used the center of a virtual circle around the medial femoral condyle and a physical knee marker (*virtual knee axis*). The second was determined *via* placement of a knee alignment device (*KAD knee axis*). The third used a functional method (*functional knee axis*) described by Schwartz and Rozumalski [3]. Note that the *functional knee axis* is defined independently from the *virtual* and *KAD knee axes*. For the tibial torsion measures calculated from the motion analysis data, the ankle and knee axes were projected onto a plane perpendicular to the long axis of the tibia. Tibial torsion was then taken to be the average of the angle between the projected knee and ankle axes during a static trial.

5. Results

The results show that there is no significant correlation ($p > 0.05$) between physical exam based tibial torsion and tibial torsion measured using the motion analysis data (Fig. 1). It is also shown that the three motion analysis based measurements are significantly correlated to each other ($p < 0.01$).

6. Discussion

The fact that physical exam based tibial torsion was uncorrelated with any of the other measures suggests one of two things: either the other three methods are wrong, or the physical exam measure is wrong. The fact that significant correlations ($p < 0.01$) existed between the *functional knee axis* and both the *virtual* and *KAD knee axes* suggests that the latter (physical exam wrong) is the case, since the mathematical definition of the *functional knee axis* is independent of the other two axis definitions. The highest correlation occurred between the *KAD* and the *virtual knee axes*, which is expected since the *KAD* and *virtual knee axes* share a common landmark (lateral femoral epicondyle).

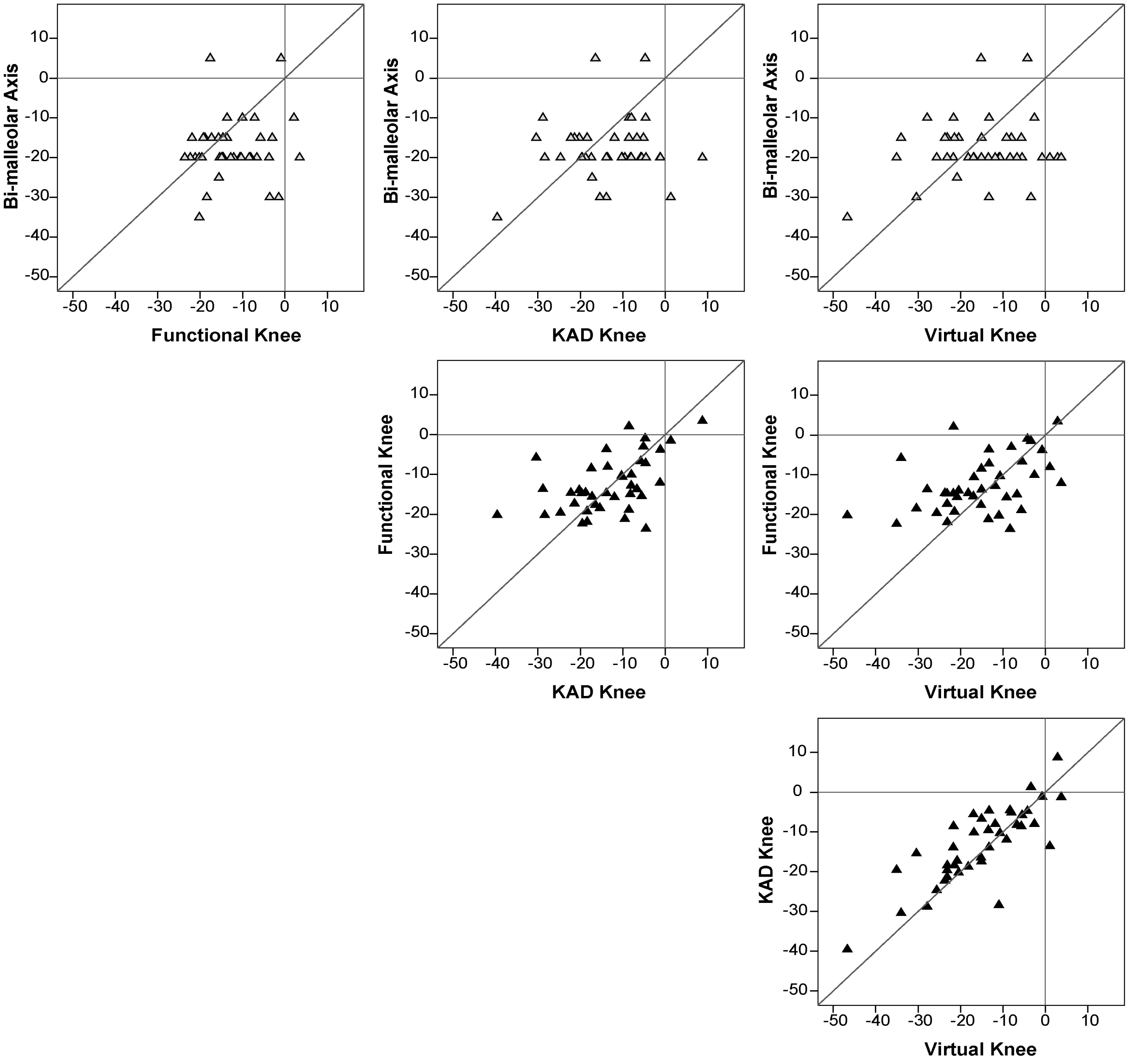

Fig. 1. These scatter plots show comparisons between four different methods of measuring tibial torsion. All measurements are in degrees, with positive indicating an external tibial torsion. The diagonal lines have a slope of 1.

The measurements in the plots with grey symbols *are not* significantly correlated ($p > 0.05$), while measurements the plots with the black symbols *are* significantly correlated ($p < 0.01$). The significant correlations (r) are as follows: *functional* versus *KAD* = 0.512, *functional* versus *virtual* = 0.451, and *KAD* versus *virtual* = 0.807.

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O-15

Overlay projection of 3D gait data on calibrated 2D video

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1. Summary/conclusions

A straightforward technique for the calibration of an arbitrarily placed video camera in the same laboratory coordinate system as motion capture cameras and force plates is described. Captured 3D data and derived data can then be projected onto recorded 2D video.

2. Introduction

Systems for video overlay of graphical analog data (e.g. EMG) or ground reaction force vectors (planar projections) have been developed in the past. However, despite the potential power of overlaying 3D information on video, projection of 3D data on 2D video recorded by an arbitrarily placed video camera has not been readily available. The straightforward calibration of a video camera in the same laboratory coordinate system as motion capture cameras and force plates in Matlab (Mathworks Inc., Massachusetts, USA) is described here. Captured 3D data is then projected onto recorded 2D video.

3. Statement of clinical significance

Overlay of 3D data on 2D video has many potential applications in clinical gait analysis for visualization/quality control of 3D reconstruction, labelling, virtual markers (e.g. joint centres), and muscle/joint modelling.

4. Methods

Fig. 1. Unibrain Fire-i camera.

Video of gait trials is captured via Firewire to AVI file by Vicon Workstation (Vicon Peak, Oxford, UK) using a Fire-i camera (Unibrain SA, Athens, Greece), with 640 × 480 pixel resolution at 30 frames/s (Fig. 1). Eight Vicon M2 cameras (1280 × 940 at 120 frames/s) are used for motion capture of the reflective markers. A fixed 'frame offset' is empirically determined to time-match the 30 fps video frames to the 120 fps motion capture data. To calibrate the Firewire video camera, multiple still images of a planar, 'checker-board' are separately captured in different orientations (Fig. 2). The only information required about the planar board is the standard size of the squares. A second planar object is subsequently placed over one of the force plates (Fig. 3) to establish the video camera position and orientation in relation to the laboratory coordinate system for motion capture.

The still images are processed in the public domain Camera Calibration Toolbox for Matlab developed by Bouguet [1], based on methods exploiting the unique characteristics of planar calibration objects [2,3]. The intrinsic camera parameters (focal length, principal point, radial and tangential distortion) are initially determined from the multiple board views, followed by the extrinsic parameters (position and rotation matrix) from the board over the force platform. No information about the video camera characteristics needs to be supplied for its calibration. The intrinsic and extrinsic param-

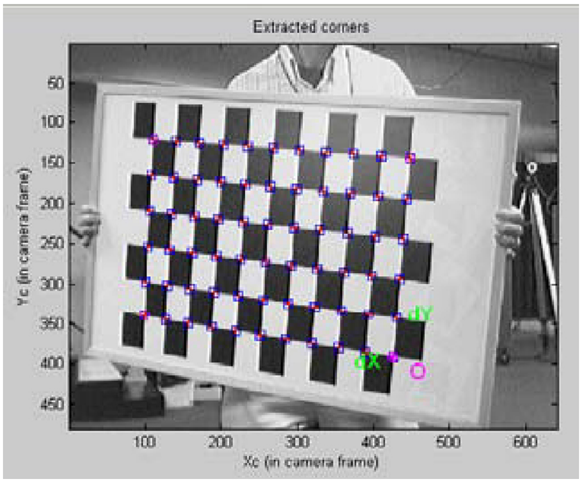

Fig. 2. Planar calibration board.