ACCURACY OF CALCULATED KNEE JOINT MOVEMENTS DEPENDING ON MARKER SETS AND LEG POSITION

Frank Lindner, Karen Roemer, and Thomas L. Milani

Institute of Sports Science, Chemnitz University of Technology, Germany

This study investigated the influence of different marker sets and different leg positions on time histories of skeletal kinematics of the lower limb. Surface markers were attached to the thigh and the shank to reproduce their kinematics during a knee movement cycle. Certain selections of posture and marker sets minimised the expected measurement errors without further optimisation procedures. However, the results showed an approximation to skeletal movement, only. The results lead to recommendations for the use of skin based marker systems.

KEY WORDS: knee movement cycle, surface markers, rigid body modelling, bone position

INTRODUCTION:

To analyse whole body movements surface markers are adequate regarding accuracy of the data (Schache et al., 2002).The analysis of single joints or skeletal kinematics require higher accuracy. Measurement errors have to be expected when surface markers were used to estimate skeletal kinematics (Fisk, 2004; Cerveri et al., 2005). Movements of soft tissues around the bone are the main reason for measurement errors. Skin movements relative to the bones caused by muscular activity, skin elasticity, or soft tissue movements due to impacts increase with higher magnitudes of movement amplitude and velocity. The amount of sub-skin fat tissue, associated with the water content, influences the vibration by natural frequency. These non-rigid parts are characterised as wobbling masses (Günther et al., 2003). Muscle movements also lead to skin deformations in particular where they directly underlie the skin. Skin thickness and strain can also effect marker movements. These aspects constrain the application of skin based marker systems and the accuracy of the data. The errors may be minimized by using special fixtures, e.g. orthoses, marker clusters or mathematical algorithms as used for rigid body modelling (Cappozzo et al., 1996; Cappello et al., 1997; Andriacchi et al., 1998; Alexander and Andriacchi, 2000; Fisk, 2004). The marker cluster technique was used to estimate the bone position by the geometrical centre of the marker cluster. Therefore, the geometry of the marker cluster and the number of markers influence the accuracy level of the calculated bone position. In this context the purpose of this study is to investigate three strategies to minimise the influence of skin based markers on the accuracy of the kinematic data. Strategy I was to use different postures of the leg in order to minimize additional skin deformations or vibrations during a knee movement cycle (KMC). Strategy II reduced the number of markers in a controlled procedure. Strategy III allocated markers to marker cluster in a controlled marker selection.

METHOD:

Right leg kinematics were captured in one subject, using a 6 camera (MX3, 240 Hz) Vicon system. The right knee was free of pain, trauma and able to work under load as well as to perform full range of motion (ROM). 44 markers on the right thigh and 37 markers on the right shank were placed non-collinear and in randomized order around the segments to desensitise the geometrical centre of mass against random marker movements. Markers were fixed with a distance of 2 cm to each other. The kinematics were captured for a full extension-flexion motion in the knee joint (knee movement cycle) and skeletal motion was calculated with MATLAB™. The method to calculate the skeletal kinematics was derived from point cluster techniques by Andriacchi et al. (1998). Lindner et al. (2007) elaborated some method steps on this calculation. To minimize the effect of measurement errors and the influence of specific marker positions on the geometrical centre of mass, three different strategies were evaluated. Strategy I: Three different postures, e.g. standing, leaning and seating were defined to analyse their effect on the marker movement. The postures are graphically described in Figure 1. The starting position for the right knee joint was always defined as an angle of 90° (grey marked leg, Figure 1). The starting position of each posture was defined as follows:

1. Standing position: 90° flexion in the hip joint
2. Leaning position: The subject was standing on the left leg with slight hip flexion so that the right leg did not touch the floor during knee extension. The hip angle was 180°.
3. Seating position: 90° flexion in the hip.

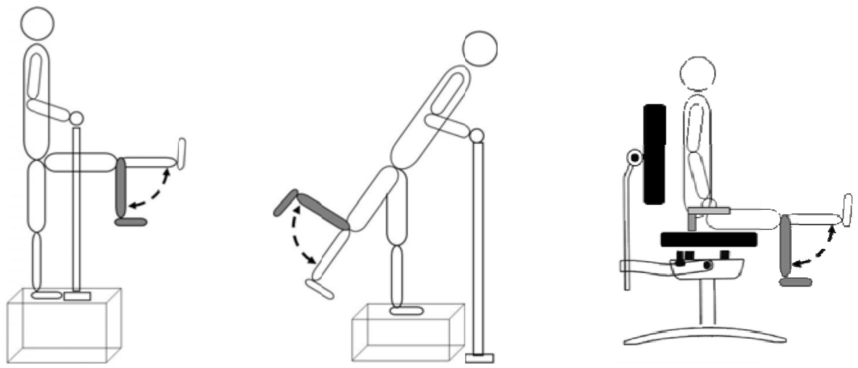

Figure 3: Conducting of the KMC from different posture

Strategy II: To analyse the effect of the cluster size, the number of markers was reduced to the same amount for all leg sides. The first derivation of eigenvalue was used to parameterize the rigid body behaviour of the segment. To compare the results the data were given by percent with respect to the maximum normalised data using all markers. Strategy III: Different areas of a segment have different skin properties and anatomical characteristics. The selection of specific segment areas was made to find the marker cluster representing the rigid body behaviour best. In consideration of the results of Lindner et al. (2007), medial-lateral (MLC) and ventral-lateral marker cluster (VLC) were analysed regarding error minimisation. Both clusters consisted of 10 markers each, attached to the lateral-ventral, and the medial-lateral side of the thigh, respectively.

RESULTS AND DISCUSSION:

Not all time histories of the captured markers could be reproduced without gaps. Therefore, 28 markers on the thigh and 19 markers on the shank could be used without any interpolation. Results of the first strategy are shown in Table 1 and 2. The comparison between postures indicates that the standing position provides the best results with respect to the thigh and the shank. In particular the ventral, medial and lateral markers of this position point out differences between other postures. The influence of muscle activity in the knee movement cycle on marker movement may decrease in standing position, due to the isometric hip flexion. The connecting tissue around the thigh could be more stretched in the leaning position than in standing position. For this reason the skin tension has more influence on the marker movement in leaning position than muscle activity. During the initial phase of the knee movement cycle the increasing muscle activity in seated position results in larger marker movement due to low initial tension of *m. rectus femoris*, *m. gracilis* and *m. sartorius.* Referring to the maximum eigenvalue change in seated position, the standing position shows better representation of the rigid body behaviour.

Table 1 Maximum of the local marker displacement on the thigh

	DORSAL 7 MARKERS [cm]	VENTRAL 5 MARKERS [cm]	MEDIAL 6 MARKERS [cm]	LATERAL 10 MARKERS [cm]
STANDING	1.99	1.36	1.69	1.54
LEANING	3.86	3.41	3.87	2.79
SEATING	2.73	2.65	2.23	2.20

Table 2: Maximum of the local marker displacement on the shank

	DORSAL 5 MARKERS [cm]	VENTRAL 6 MARKERS [cm]	MEDIAL 3 MARKERS [cm]	LATERAL 5 MARKERS [cm]
STANDING	1.82	1.42	1.32	0.87
LEANING	1.15	1.50	2.19	1.68
SEATING	5.10	1.54	3.56	2.36

The difference in eigenvalue change in standing position is 82 % lower than in seated position and 2% lower than in leaning position (Figure 2). This finding leads to the assumption that the standing position provides the best results. Results of strategy II represent a positive dependency of the rigid body behavior and the number of markers (Figure 3).

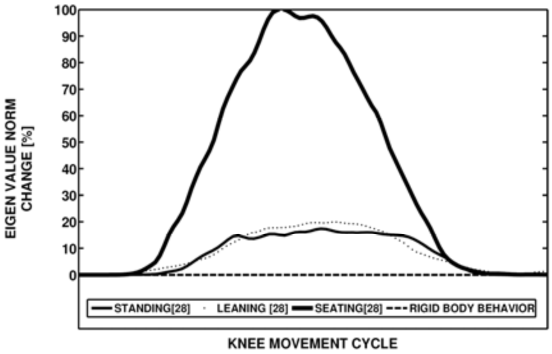

Figure 2: Deviation from the rigid body behavior on the thigh with respect to three postures

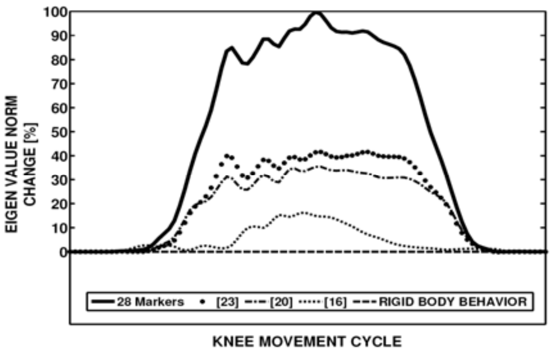

Figure 3: Deviation from the rigid body behavior in consideration of marker sets on the thigh

The reduction of 28 to 20 markers improved the results by 65 %. The reduction of 20 markers to 16 markers gained once more a minimisation of 20 %. One could assume that the rigid body behaviour could be improved with fewer markers. This reduction may lead to an increasing deviation between locations of the segmental centre of mass and the geometrical centre of mass defined by the marker cluster. The same results were found for the shank when reducing the markers from 19 to 6. Consequently, the eigenvalue change could be minimised up to 96 %. Strategy III leads to the assumption, that MLC may be more suitable for reconstructing the rigid body kinematics of the thigh. The eigenvalue change of the VLC deviated with 55 % more from rigid body behaviour than the MLC. On the other hand, using this cluster leads to the problem that medial markers may be hidden by other body parts during gait analysis. To estimate the skeletal kinematics of the tibia, the front face of the tibia (*margo anterior* and *facies medialis* and *lateralis*) was selected. Figure 4 (A, B, C, D) shows few soft tissues are located only between skin and underlying bone. Due to these anatomical bases, markers can be approximately placed on the tibia. Anatomical and functional aspects have a considerable effect on the error minimisation.

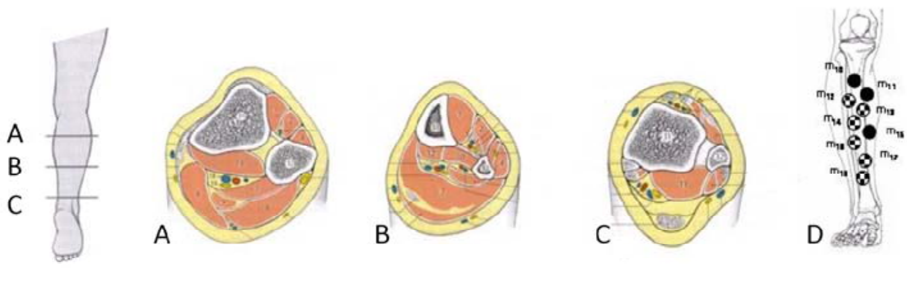

Figure 4: Section view by the proximal third (A), the middle third (B), the distal third of the shank(C, Platzer, 1997, p.257) and six placed markers (chequered) on the ventral side of the shank (D, Lindner et al. 2007).

CONCLUSION:

It is not possible to separate between errors due to measurement problems while capturing markers with a camera system properly, due to the influence of soft tissues. This has to be considered during the description of movement characteristics of the lower extremity. It is recommended to analyse a full knee extension and flexion movement in standing position to estimate the skeletal kinematics. Three to five markers should be used for each area of the thigh to reconstruct the skeletal kinematics. To avoid further errors in the data three to six markers may be placed on the front face of the shank to model the tibial kinematics. It is easier to determine the rigid body behaviour for the shank than for the thigh. This could be stated, because the ratio between bone and soft tissue regarding the shank was supposed to be smaller.

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