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Use of a patella marker to improve tracking of dynamic hip rotation range of motion

Tishya A.L. Wren [a,b,*], K. Patrick Do [a], Reiko Hara [a],
Susan A. Rethlefsen [a]

[a] *Childrens Orthopaedic Center, Childrens Hospital Los Angeles, Los Angeles, CA, USA*
[b] *Departments of Orthopaedics, Radiology, and Biomedical Engineering, University of Southern California, Los Angeles, CA, USA*

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Abstract

Hip rotation during gait has traditionally been measured using thigh wand markers. Hip rotation data calculated using thigh wands shows large variability between different laboratories and underestimates the rotation movement. This study investigated effectiveness of a patella marker in tracking hip rotation range of motion in comparison with traditional thigh wands. In controlled trials of isolated hip internal–external rotation, the patella marker detected 98 ± 8% of the actual range of motion, compared with 53 ± 10% for a distal thigh wand and 43 ± 13% for a proximal thigh wand. The patella marker produced the smoothest hip rotation curves and the smallest hip rotation range in walking, and results from the patella marker did not depend on walking speed. These results suggest that the patella marker is less vulnerable to wobbling, inertial effects, and soft tissue movement than traditional thigh wands. The use of patella markers with knee alignment devices may therefore allow for more accurate measurement of hip rotations during clinical gait analysis than is currently possible using traditional thigh wands.

Keywords: Kinematics; Gait analysis; Accuracy

1. Introduction

Gait analysis is a useful tool for treatment decision-making in orthopaedics. However, for gait analysis to be more widely adopted in surgical planning, improved accuracy of the kinematic data is crucial. The repeatability of kinematic data has been shown to be best for sagittal plane motions (flexion/extension), followed by coronal plane motions (ab/adduction), with the least reliable data seen in transverse plane motions (rotation) [1–3]. This is due to variability in marker placement, propagation of errors from one segment to the next, and soft tissue artifacts [2,4].

Hip rotation is a clinically important measurement that is often used in planning femoral derotation osteotomies. However, even with extreme care and skill in marker placement, kinematic measurements of hip rotation during gait cannot always be relied upon in surgical planning. Greater accuracy is critical for hip rotation kinematics to be used more widely in planning femoral derotational osteotomy surgery. With more accurate data, hip rotations could be used to decide not only whether or not an osteotomy should be done, but also how much to rotate the bone.

Hip rotations have traditionally been measured using thigh wands, which consist of a marker at the end of a stick [5,6]. The wands are taped to the lateral thigh and were originally used to extend the thigh marker away from the body to prevent colinearity with the hip and knee joint centers. Hip rotations calculated using thigh wands have large variability between different laboratories [3,7]. Thigh wands also greatly underestimate the rotation movement, recording only 40–70% of the actual hip rotation [8].

We hypothesized that a marker placed over the patella would be less affected by soft tissue movement and would

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[*] Corresponding author at: Childrens Orthopaedic Center, Childrens Hospital Los Angeles, 4650 Sunset Blvd., M.S. 69, Los Angeles, CA 90027, USA. Tel.: +1 323 361 4120; fax: +1 323 361 1310.

E-mail address: twren@chla.usc.edu (T.A.L. Wren).

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therefore produce more accurate hip rotation measurements than traditional thigh wands. If the patella marker can provide more accurate hip rotation data than thigh wands, it will enhance the clinical usefulness of gait analysis, particularly in decision-making and surgical planning for femoral derotational osteotomy. This study investigated effectiveness of the patella marker in tracking hip rotation range of motion in comparison with traditional thigh wands.

2. Methods

Eleven healthy adults (height: 165.4 ± 7.6 cm, weight: 63.2 ± 11.0 kg) participated in this study after providing written informed consent. 14-mm retro-reflective markers were placed on the lower body following the conventional gait model [5,6]. The following modifications were made to the conventional model—instead of a single thigh wand, two wands were placed on the lateral aspect of the thigh. The proximal wand (Prox) was located at 50% of the length from the anterior superior iliac spine (ASIS) marker to the knee marker, and the distal wand (Dist) was located at 80% of this length. An additional marker was placed over the center of the patella (Pat) (Fig. 1). Data were collected with all markers in place using a Vicon 612 Motion Analysis System (Vicon Oxford Metrics, Limited, Oxford, England).

The subjects performed two types of movements: controlled hip internal/external rotation and walking. The controlled hip rotations followed the protocol of Lamoreux [8]. An extra marker was placed on the fibular head for these tests. The subjects stood on the left leg with the right hip fully extended and the right knee flexed to 90° (Fig. 1). The fibular head marker and a standard marker on the lateral malleolus were used to track motion of the tibia in the transverse plane relative to the right and left ASIS markers on the pelvis (Fig. 2). This provided a ‘‘gold standard’’ measurement of the actual hip rotation, assuming motion within the knee joint was negligible.

The subjects performed isolated internal/external rotation of the right hip through the full range of motion (approximately ±45°). Subjects were instructed to keep the right knee pointed straight down, and to minimize flexion and ab/adduction of the hip during these trials. Three cycles of internal/external rotation were performed during each trial. Data were collected from three trials, and one representative trial was selected for analysis.

Data were also collected during walking at a self-selected speed. Before the walking trials, a static trial was conducted with knee alignment devices (KADs) in place to calculate joint centers and define the limb segment coordinate systems [5]. Use of the KAD allows definition of the knee flexion-extension axis without placing the thigh or patella markers in the plane of the knee axis and hip joint center. Data were collected from two trials, and one representative gait cycle was selected for analysis.

The hip rotation range of motion (ROM) was computed using each of the three thigh segment markers (Prox, Dist, and Pat) during the controlled hip rotations and walking. Hip rotations were calculated following the conventional gait model, i.e., as the rotation component of a flexion-adduction-rotation Euler angle sequence relating the thigh coordinate system to the pelvis coordinate system [5,6]. For the controlled motions, hip rotation was also calculated as the angle between the normal to plane defining the thigh segment (i.e., the plane containing the hip and knee joint centers and the thigh or patella marker) and the vector connecting the ASIS markers. This essentially projects the rotational orientation of the thigh segment onto the inter-ASIS vector, providing a calculation analogous to that used for the gold standard (Fig. 2). The markers on the fibular head and lateral malleolus were used to calculate the gold

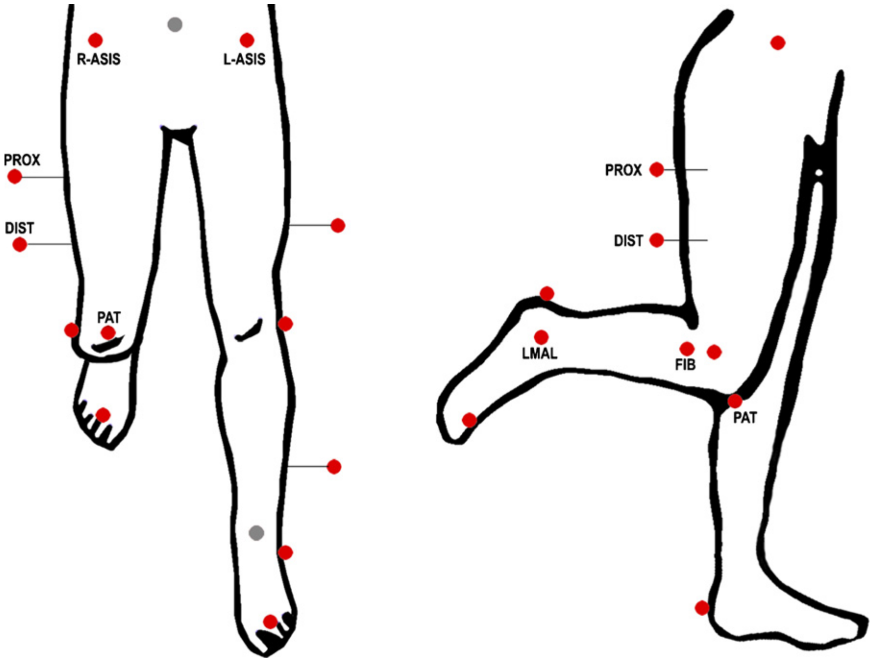

Fig. 1. Marker set including proximal thigh wand (PROX), distal thigh wand (DIST), patella marker (PAT), right and left ASIS (R-ASIS, L-ASIS), fibular head (FIB), and lateral malleolus (LMAL).

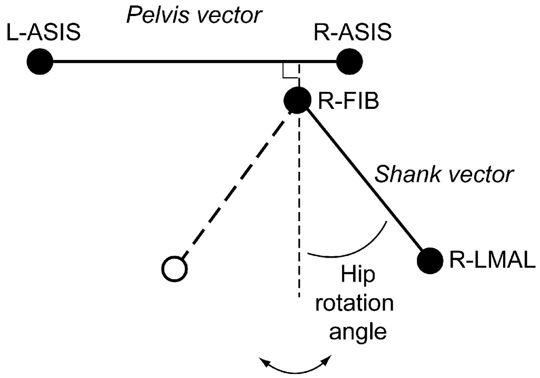

Fig. 2. Pelvis and shank markers viewed from above. Gold standard hip rotation is calculated using vectors from L-ASIS to R-ASIS (pelvis) and R-FIB to R-LMAL (right tibia).

standard (Gold) ROM for comparison during the controlled rotations. No gold standard was available for the walking trials since calculation of the gold standard requires that a 90° flexed knee posture be maintained. One-way Repeated Measures ANOVAs and Scheffe's post hoc tests were utilized to test for differences in the hip rotation ROM calculated using the different markers.

3. Results

For the controlled hip rotation trials, the mean hip rotation ranges for Gold, Pat, Dist, and Prox were 58.0 ± 10.4°, 56.6 ± 9.4°, 31.1 ± 8.4°, and 24.3 ± 6.7°, respectively, using the conventional gait model for the latter three measurements (Fig. 3a). Results were very similar projecting the thigh segment orientation onto the inter-ASIS vector, with mean hip rotation ranges of 56.6 ± 10.3°, 31.0 ± 8.2°, and 24.5 ± 6.6° for Pat, Dist, and Prox, respectively (Fig. 3a). Expressed as a percentage of the Gold Standard, the hip rotation ranges were 98 ± 8%, 53 ± 10%, and 43 ± 13% for Pat, Dist, and Prox, respectively, using both methods (Fig. 3b). The statistical analysis revealed significant differences ($P < 0.0001$) between all conditions except Gold and Pat.

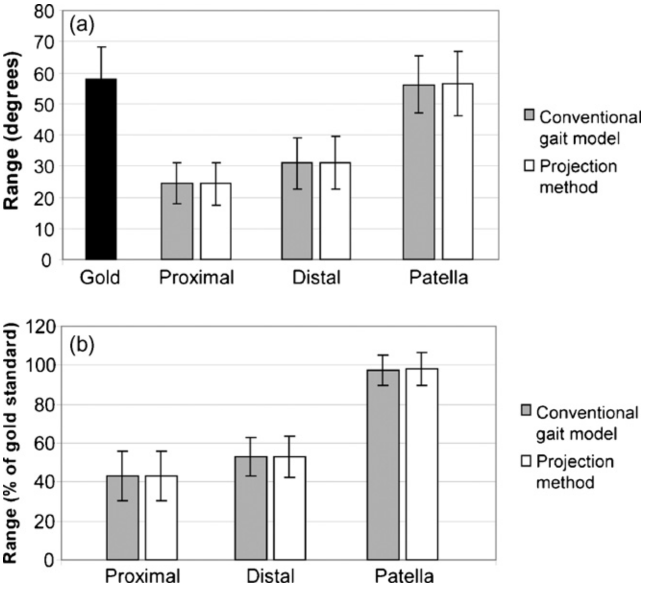

Fig. 3. Range of motion from controlled hip rotation trials expressed as (a) degrees and (b) percentage of gold standard.

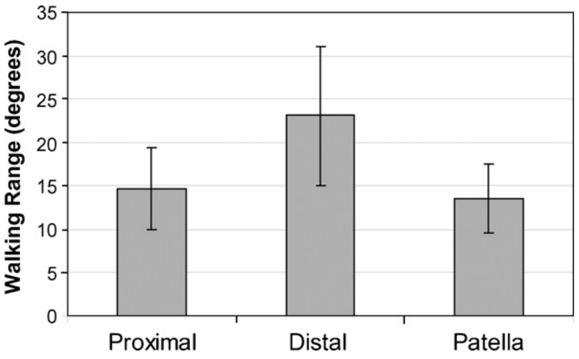

Fig. 4. Hip rotation range of motion during walking.

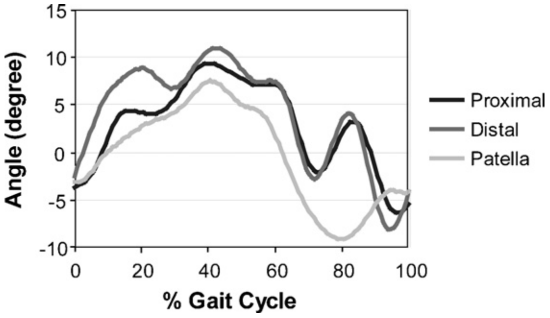

Fig. 5. Typical hip rotation curves during walking.

For walking, the mean hip rotation range was 13.5 ± 3.9° for Pat, 23.1 ± 4.7° for Dist, and 14.7 ± 8.0° for Prox (Fig. 4). The results yielded a statistically higher mean in Dist compared to others ($P = 0.0003$). The hip rotation curves tended to be smoother for Pat compared with Dist and Prox (Fig. 5). Hip rotation range tended to increase with walking speed for Dist, to a lesser extent for Prox, and not at all for Pat (Fig. 6).

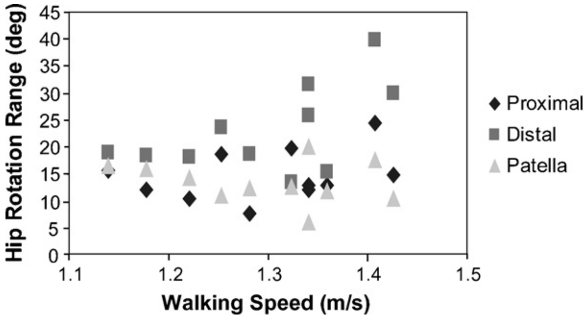

Fig. 6. Dependence of hip rotation ROM on walking speed.

4. Discussion

In the controlled trials, the patella marker demonstrated a much greater potential in accurately detecting hip rotation movement (97% of gold standard range) compared to the distal and proximal thigh wands (59% and 41% of gold standard range, respectively). The results for the thigh wands are similar to those reported previously by Lamoreux (70% for distal wand and 40% for proximal wand) [8]. Less soft tissue lying between the patella marker and the bone might have allowed the patella marker to track more direct movement of bone while the thick layer of soft tissues hindered this ability in the wands.

During walking, the thigh wands produced relatively higher ranges of motion than the patellar marker despite their poor rotation tracking capacity in the controlled tests. The rotation ranges of the wands, especially the distal wand, displayed sensitivity to walking speed. Their augmented ranges in walking, therefore, could possibly be explained by artifacts that are magnified with increased walking speed. The patella marker, on the other hand, was insensitive to walking speed and also produced the smoothest hip rotation curves. These results suggest that the patella marker is less vulnerable to wobbling, inertial effects, and soft tissue movement than traditional thigh wands. It appears that for the thigh wands, particularly the proximal wand, decreased motion due to movement of soft tissue relative to bone may be offset by increased motion due to inertial effects. The net result of these two errors makes the walking results more similar to the patella marker results, and it is unclear whether the differences would affect clinical decision-making aside from reducing confidence in the accuracy of the results.

The difference between the controlled tests and walking was not due to the smaller ROM during walking. To examine this possibility, we analyzed the results of the controlled hip rotations using only the range of angles observed during the walking trial. The results were similar to those using the entire ROM (96%, 54%, and 35% of the gold standard for Pat, Dist, and Prox, respectively). The results of the controlled trials also were not significantly affected by the possibility of the knee angle deviating from 90°. Sensitivity testing showed that the gold standard angle changed by less than ±5° for knee angles between 65° and 105°.

While the patella marker was clearly superior in the controlled tests, no gold standard measurement was available for the walking trials. Therefore, it can only be inferred that the patella marker is superior during walking based on the results of the controlled tests and the smoother, velocity-independent results of the patella marker during walking. In addition, this study only examined range of motion. Absolute angles were not evaluated because of the lack of a gold standard reference angle. However, a marker that more accurately tracks hip ROM should also provide more accurate tracking of absolute hip rotation angles.

An additional limitation of this study is that soft tissue artifacts and internal motion at the knee were not directly examined. If motion occurred within the knee joint during the controlled tests, the markers on the shank would reflect this motion in addition to rotation of the hip. Perhaps more importantly, previous studies have shown significant soft tissue artifacts in the vicinity of the knee [9,10] although a marker directly over the patella was not studied. It is likely that movement occurs between the femur and patella and also between the patella and the overlying skin. These sources of potential error may be most noticeable during full extension or hyperextension of the knee and may be especially important in pathological conditions that affect patellar tracking. Future studies may examine these effects further to determine if the patella marker is indeed better than thigh wands as it currently appears.

A final limitation of this study is that only adults without disability were studied. We have not formally studied behavior of the patella marker in children or pathological gait. Our laboratory has used the patella marker in clinical studies of children, including children with cerebral palsy, with a variety of gait patterns such as crouch and internally rotated gait. However, caution should be advised in collecting and interpreting patella marker data until additional validation studies are completed.

It should be noted that the patella marker can only be used in conjunction with knee alignment devices. The wand markers can be placed in the plane of the hip joint center and knee axis to define the coordinate system of the thigh. Since the patella marker must be placed anteriorly, it cannot be positioned in this plane. Use of the KAD allows definition of the thigh coordinate system relative to the anteriorly located patella marker.

In conclusion, the patella marker was clearly superior to the thigh wands in tracking hip rotation ROM during controlled tests in healthy adults. The patella marker also appeared to give better results during walking. The patella marker may therefore provide an opportunity to minimize soft tissue artifacts and improve the accuracy of hip rotation measurements. This may improve the clinical utility of gait analysis, particularly in planning femoral derotation osteotomies.

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Conflict of interest statement

There are no conflicts of interest for this study.

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