

Does Theia3D Update Improve the Agreement in Hip Joint Kinematics between Markerless and Marker-based Motion Capture?

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INTRODUCTION: Markerless motion analysis has emerged as a promising alternative to traditional marker-based motion capture. However, differences in the kinematic signals derived from the two approaches have been reported and attributed to variations in joint center definitions [1] and reference frame orientations [2]. Markerless systems, such as Theia3D, are continuously refined as new training datasets and algorithmic improvements are incorporated into their pipelines. Since these updates are meant to improve accuracy, it is critical to evaluate how successive versions perform relative to both established marker-based data and prior software releases. This will allow investigators to assess agreement, and guide end users to maintain consistency in longitudinal studies. In this study, we compared hip joint center estimation and hip kinematics during gait using two versions of Theia3D (v2023 and v2024), to determine improved agreement of the updated version with marker-based measurements.

METHODS: Ten healthy subjects (5/5 M/F, age 26.8 ± 5.6 years, 21.5 ± 1.8 kg/m²) were instrumented with reflective markers (Fig. 1) to perform five walking trials each in an IRB-approved study. Simultaneous recordings were collected with eight video cameras (Miqus, Qualisys) for the markerless system (Theia3D) and twenty-four cameras (Oqus/Arqus, Qualisys) for the marker-based system. Markerless trials were first processed with Theia3D v2023 and reprocessed with v2024. Three datasets (marker-based, markerless v2023, markerless v2024) were analyzed in Visual3D (C-Motion) to extract hip joint kinematics and hip joint centers (HJC). The marker-based HJC was estimated using pelvis width regression equations [3], while the markerless HJC was derived from Theia3D's pose matrices. Comparisons between markerless and marker-based data were performed using root mean square error (RMSE) and Statistical Parametric Mapping (SPM, $\alpha = 0.05$).

RESULTS: HJC estimates from v2023 were located posterior (2.3 ± 0.6 cm) and lateral (0.8 ± 0.7 cm) relative to the marker-based reference, v2024 estimates were also posterior but to a greater extent (3.7 ± 2.1 cm) and more medial (1.8 ± 2.0 cm). Hip kinematics differed between the two Theia3D versions and the marker-based data (Fig. 2). In the sagittal plane, RMSE was similar between versions ($5.0 \pm 3.5^\circ$ for v2023 vs. $5.1 \pm 2.7^\circ$ for v2024), with no significant differences from marker-based measurements using SPM (Fig. 2d). In the frontal plane, RMSE decreased from $4.8 \pm 1.8^\circ$ (v2023) to $3.7 \pm 1.1^\circ$ (v2024), with significant differences from the marker-based data occurring over a smaller portion of the gait cycle (18.6 - 77% for v2023 vs. 32.8 - 70% for v2024) (Fig. 2e). Conversely, in the transverse plane, RMSE increased with v2024 ($7.0 \pm 1.7^\circ$ vs. $6.2 \pm 2.1^\circ$ for v2023) (Fig. 2f), and significant differences with marker-based data extended across a wider portion of the gait cycle (14.8 - 48% for v2023 vs. 13.5 - 53% for v2024), reflecting the greater external rotation detected by v2024.

DISCUSSION: Results showed substantial shifts in joint center location. These changes likely reflect algorithm modifications, including a narrower HJC and adjusted anterior pelvic tilt, emphasizing the need for caution when comparing data across software versions. Kinematic results were inconsistent: agreement with marker-based data improved in the frontal plane, demonstrating a lower RMSE and fewer significant differences, but worsened in the transverse plane, where errors and significant differences increased. Notably, v2023 showed near-neutral rotation angles, whereas v2024 detected greater values, though still not comparable to the marker-based data. Said changes may alter segment orientation and impact knee and ankle kinematics, which should be further investigated. These findings suggest that updates to the markerless system improved agreement in some planes but increased disagreement in others; thus, caution is advised for transverse plane data, and reprocessing with updated software is recommended for longitudinal studies to preserve consistency. A limitation of our study is that marker-based data are not considered ground truth; future studies using dual-plane fluoroscopy are warranted.

SIGNIFICANCE/CLINICAL RELEVANCE: These findings are clinically and scientifically relevant for clarifying how markerless software updates affect hip kinematics, highlight potential sources of variability across versions, and inform the use of this motion capture system in longitudinal rehabilitation studies.

REFERENCES: [1] Kanko, R. M., et al. (2021). Concurrent assessment of gait kinematics using marker-based and markerless motion capture. *J Biomech.* [2] Antognini, C., Ortigas-Vásquez, A., et al. (2025). Comparison of markerless and marker-based motion analysis accounting for differences in local reference frame orientation. *J Biomech.* [3] Bell et al. (1990). A comparison of the accuracy of several hip center location prediction methods, *J Biomech.*

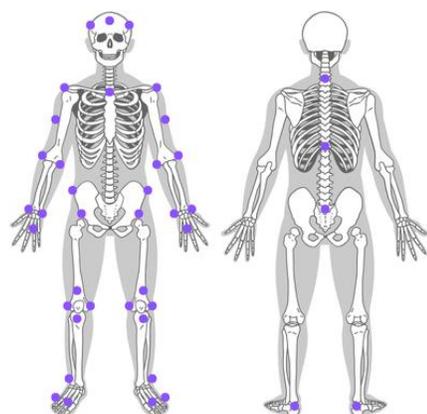


Fig. 1: Full-body Qualisys sport marker-set, consisting of 41 reflective markers for static trials. The two medial epicondyle markers were removed for dynamic trials.

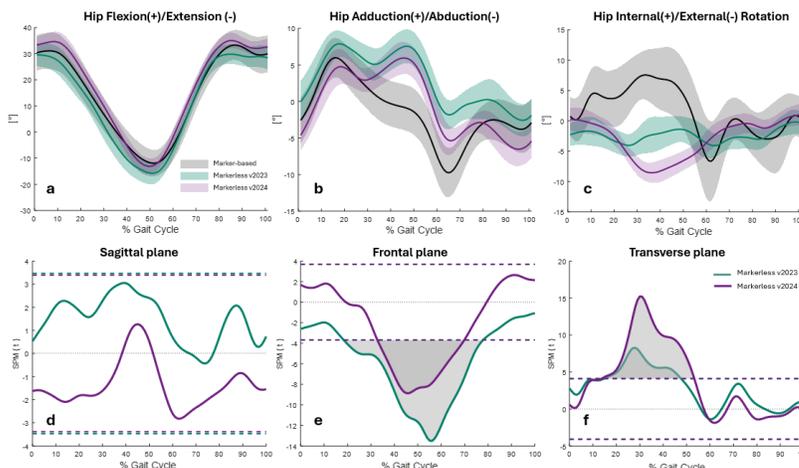


Fig. 2: Comparison of hip joint kinematics estimations between the marker-based (black), markerless v2023 (green) and markerless v2024 (purple) systems. Upper row: mean hip joint angles (solid lines) \pm standard deviation (shaded areas) across all subjects and trials. Lower row: Statistical Parametric Mapping (SPM) markerless v2023 and v2024 results, assessed against the marker-based data. All data is expressed as % percentage of gait cycle.