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Assessing the accuracy of measuring leg length discrepancy and genu varum/valgum using a markerless motion analysis system

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ABSTRACT

Aims: Markerless motion analysis (MMA) systems are being used extensively in the area of sports medicine and physiotherapy. The purpose of this study was to compare leg length measurements (LLM) and varus/valgus knee measurements (VVM) performed clinically, radiologically and using MMA in patients being assessed for potential total knee arthroplasty (TKR).between mean LLM calculated clinically, radiologically and using MMA (all $p < 0.05$).

Discussion & conclusion: Discrepanices exist in LLM and VVM when evaluated using clinical, radiological and MMA modalities. Therefore, this study suggests that MMA alone may not be a suitable modality for assessment of patients for TKR, with a combination of two or more evaluation modalities recommended at present.

Level of evidence: IV Case Series.

1. Introduction

Analysis of gait and motion remains a changing evaluation for orthopaedic surgeons and physiotherapists. The introduction of markerless motion analysis (MMA) systems have theorectically allowed for objective analysis of a subject's gait, while also quantifying joint movement measurement into degrees and centimetres, and are therefore being used increasingly in the area of sports medicine and physiotherapy.[1] This new marker free technology has allowed for ease of assessment, and therefore is believed to be an ideal tool in clinical practice, both in diagnostics and in screening for potential arthroplasty surgery.[1]

Previous literature has attempted to validate the reproducibility of MMA,[2] as well as the accuracy of knee and hip flexion/extension while walking as compared to video analysis.[3] In the past, numerous studies have demonstrated the reliability of clinical measurement and full leg length measurement (LLM) plain film radiographs in the assessment of patients for total knee replacements (TKR).[4–7] In spite of this, there is paucity of studies reporting formal assessment by MMA systems to clinical and radiological measures in orthopaedic surgery in general, not to mention evaluation for TKRs. Additionally, to the knowledge of the authors of this study, no studies have performed formal assessment of the accuracy of MMA with respect to lower limb length, as well as genu varum/valgum angulation.

Given that little formal assessment has been reported in formally evaluating the accuracy and validity of MMA when compared to traditional clinical and radiologic measurements, study of a potential role for MMA alone in orthopaedic arthroplasty assessment is warranted. Therefore, the purpose of this study was to compare leg length measurements (LLM) and varus/valgus knee measurements (VVM) performed clinically, radiologically and using MMA in patients being assessed for potential TKR. Our hypothesis was that MMA would demonstrate non-significant differences when compared to clinical and radiological assessment of LLM and VVM in patients being evaluated for potential TKR.

2. Methods

2.1. Patient recruitment & data collection

Having gained ethical approval from our institutional review board, patients recruitment from the pre-operative assessment clinic (POAC) at our institution was carried out. Patients awaiting TKR who were attending the POAC were invited to take part in this study. Written consent was obtained from all potential participants.

Once consented, all participants were asked to invited to fill in a pre-

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determined data collection form. All data subjects received a randomized study number to which they would be referred to by the investigators for the duration of the study. Data was collected in relation to the following: (1) study number, (2) age, (3) radiological board number, (4) co-morbidities, (5) side of joint affected, (6) previous rheumatological or joint pathologies to ipsilateral knee, and (6) previous arthroplasty surgeries to ipsilateral lower limbs. Following this, clinical assessment of each patient's (1) weight in kilograms (kg) using a digit weighing scale chair, and (2) height in metres (m) using a mechanical stadiometer, were documented. Thereafter, all patient were invited for triple LLM and VVM assessments (as described below) with clinical, radiological and MMA measurements being evaluated for the purpose of this study.

2.2. Patient eligibility

The following pre-determined inclusion criteria was established by the authors of the study prior to study commencement; (1) patients awaiting unilateral primary TKR under the senior author, and (2) independent baseline. The following pre-determined exclusion criteria had also been established by the authors of the study prior to study commencement; (1) previous TKR to ipsilateral or contralateral knees, (2) unable to walk independently or unassisted, (3) any knee flexion deformity $>30^\circ$ at the knee which would limit gait analysis, (4) patient awaiting a revision TKR, and (5) patient awaiting concomittant procedure alongside TKR.

2.3. Clinical assessment

Clinical measurement was performed based on previously validated examination techniques.[8] True LLM was measured using the anterior superior iliac spine and the medial malleolus as fixed bony landmarks. The tape measure used for all patients was a standard tailor type tape measure, with graduations to 1 mm units. All clinical measurements were taken in centimetres to two decimal places. In order to maximize accuracy in clinical assessment, a total of three readings were taken for each leg, with the mean of each used as the final LLM for each lower limb.[9] No clinical assessment of knee angulation was performed.

2.4. Radiological assessment

All patients were to have bilateral full leg length plain film radiographs as part of their POAC assessment using our institutional radiological software package (AGFA Impax Version 6.0, Ilkeston, U.K.).

True LLM was for the mechanical lower limb length using the centre of femoral head and the centre of the inferior articular surface of the tibia, with measurements taken in centimetres to two decimal places. The centre of the inferior articular surface was found by dividing the talar dome in half and starting the measurement from the articular surface of the tibia just above this.

Additionally, Hip-Knee-Ankle was noted by measuring along the mechanical axis of the femur and tibia, with the degree of varus or valgus angulation was noted in degrees to one decimal place. A sraight line was drawn from the centre of the femoral head, to the intercondylar eminence of the tibia, and a line from the intercondylar eminence of the tibia to the centre of the inferior articular surface of the tibia.

2.5. Markerless motion analysis assessment

Measurements for the MMA were taken for all patients using the BioStage™ system (Organic Motion Inc., N.Y., USA). All patients were invited to don tensile black clothing to maximize accuracy of markerless analysis.

For MMA, LLM was measured as the sum of the thigh and the leg, using the centre of the femoral head, intercondylar mid-point of tibial and the centre of the inferior articular surface of the tibia. All clinical measurements were taken in centimetres to two decimal places. With respect to the VVM, the participants were assessed to perform their normal gait with motion sensors allowing the software calculate this in degrees, labelled as 'knee abduction'. Additionally, knee angles of $<180^\circ$ were noted to indicate valgus angulation, while $>180^\circ$ indicated varus angulation.

2.6. Data analysis

Statistical analysis was carried out using SPSS version 22 (IBM Corp. Released 2013. IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY: IBM Corp.). Based on the study by Jamaluddin et al. a difference of 0.5 cm was deemed an acceptable discrepancy for the purpose of this study in reporting LLM clinically, radiologically and using MMA.[10] Paired t-tests were performed to compare means of measurements. A p-value of <0.05 was deemed significant. Additionally, regression analysis was performed to assess whether BMI affected the system's ability to measure leg length.

3. Results

3.1. Patient demographics

Overall, a total of 25 patients were recruited, with 2 being excluded (one due to poor radiographic quality, and one due to inadequate clinical information). This left a total of 23 patients (12 females) with a mean age of 66 years (54–79) and mean body mass index of 30.5 (21.7–37.5) were assessed. A summary of patient demographics and characteristics is illustrated in Table 1.

3.2. Leg length measurements

Mean clinical measurement of LLM for all 23 patients was 87.98 cm and 87.65 cm for the left and right lower limbs respectively. In contrast, mean radiological measurement of LLM for all 23 patients was 86.28 cm and 86.03 cm for the left and right lower limbs respectively. Additonally, mean measurement of LLM using MMA for all 23 patients was 75.93 cm for both left and right lower limbs respectively. A summary of clinical, radiological and MMA LLM and VVM is further illustrated in Table 2.

Analysis using paired t-tests demonstrated that there were statistically significant differences (all $p < 0.05$) between all three LLM assesment modalities. A summary of the differences between mean clinical, radiological and MMA LLMs for Left and Right Lower Limbs are illustrated in Tables 3 and 4 respectively.

3.3. Knee angulation measurements

Mean radiological measurement of VVM for all 23 patients was 184.23° and 184.85° for the left and right knees respectively. Additonally, mean measurement of VVM using MMA for all 23 patients was 180.29° and 179.52° for the left and right knees respectively. A summary of the differences between mean clinical, radiological and MMA VVMs are illustrated in Table 5. Additionally, a summary of the differences between mean radiological and MMA VVMs for Left and Right Lower Limbs are illustrated in Table 6.

Table 1
Summary of patient demographics & characteristics.

Variable	Mean	Range
Age (Mean, range)	66	54–79
Height (metres)	1.66	1.49–1.8
Weight (Kg)	83.8	60.9–112.0
BMI (Kg/m^2)	30.5	21.7–37.3

Table 2
Summary of clinical, radiological and MMA LLM & VVM.

	Clinical leg length (cm)	Radiological leg length (cm)	MMA leg length (cm)	Radiological knee angle (deg)	MMA knee angle (deg)
Left Leg	87.98	86.28	75.93	184.23	180.89
Right Leg	87.65	86.03	75.93	184.85	179.52

Table 3
Summary of the Differences between mean Clinical, Radiological and MMA LLMs for Left lower Limb.

Left Leg (cm)	Difference of means	SD	95% CI range	P-value
Clinical Vs Radiological	1.69	2.69	0.53–2.86	0.006
Clinical Vs Organic Motion	12.05	3.33	10.61–13.49	<0.001
Radiological Vs Organic Motion	10.36	4.22	8.53–12.19	<0.001

Table 4
Summary of the Differences between mean Clinical, Radiological and MMA LLMs for Right lower Limb.

Right Leg (cm)	Difference of means	SD	95% CI range	P-value
Clinical Vs Radiological	1.62	2.83	0.39–2.83	0.01
Clinical Vs MMA	11.73	2.93	10.46–12.99	<0.001
Radiological Vs MMA	10.11	4.04	8.36–11.86	<0.001

Table 5
Summary of the Differences between mean Clinical, Radiological and MMA VVMs.

Measure of Difference (cm)	Mean (cm)	Range
Radiological-MMA Left	10.36	3.19–18.19
Radiological-MMA Right	10.11	4.12–18.22

Table 6
Summary of Differences in mean VVM for Left & Right Lower Limbs.

Variables (deg)	Difference of Means (Range)	SD	95% CI range	P-value
Radiological Vs MMA Knee angle Left	3.34 (−6.30, 16.60)	4.44	1.42–5.26	0.002
Radiological Vs MMA Knee angle Right	5.33 (−0.11, 12.63)	3.81	3.69–6.98	<0.001

4. Discussion

The most important finding of this study was that significant differences were reported between results obtained for calculating LLM clinically, radiologically and using MMA. As much literature has previously validated the use of clinical and radiological in obtaining LLM, this study poses the question as to whether the results obtained using MMA for LLM can be utilized such measurements. Additionally, this study found that significant differences in VVM were calculated radiologically and using MMA. Therefore, given that significant differences exist between all three measurement modalities used, it may be proposed that no one should be used in isolation to calculate LLM or VVM, but instead multiple measurement modalities to calculate LLM and VVM of patient's lower limbs.

Motion analysis is a complicated and underutilised aspect of orthopaedic assessment, with huge potential as a clinical tool in screening, diagnostics, and rehabilitation to name but a few.[11,12] Prior to this, the most common means of assessment, diagnosis and decision-making in orthopaedics has been using clinical and radiological means alone. Clinical gait analysis remains subjective, and while obvious gait types can be broadly classified, subtle differences may be particularly difficult to observe during a short clinical consultation.[12] Furthermore, combinations of more than one gait type occurring in conjunction may potentially render clinical diagnosis by visual observation alone particularly difficult. Therefore, this suggests that subjective clinical gait analysis alone is limited, with further measurement modalities required for accurate clinical assessment.

However, to suggest that one would decide to list a patient for TKR in the absence of radiological assessment is simply not justifiable. While fundamental imaging used in combination with clinical history and exam provide insight into the degree of degenerative changes and malalignment present in a patient's joint, reported clinical symptoms remain the most commonly used indictions when listing patients for joint arthroplasty surgery.[13] Additionally, the clinical guidelines themselves in relation to listing patients for TKR at present are themselves based on limited evidence.[14] Therefore, a combination of factors play a role in patient listing for TKR, least of all patient preference in management.

As alluded to previously, the use of motion analyis in clinical medicine (as well as in animation) has gained traction in recent years.[15–17] Although this system provides clinicians a variety of gait based measurements including LLM and VVM, such systems are not without their limitations. These include a host of system factors, such as trained operator use with thorough knowledge of anatomy and biomechanics to ensure correct application of the system, great summation of time required to perform analysis, statistical and human error,[17–21] as well as patient factors, great summation of time limiting its usefulness in a busy clinical practice, as well as careful patient selection as to ensure patient compliance when being analyzed. It is possible that these aforementioned limitations in combination explain the rationale as to why motion analysis has predominantly remained a research tool, rather than a modality used routinely in clinical decision making.[22]

Motion analysis software is commercially available, with increasingly popularity of force plates, reflective skin markers, telemetry, infrared markers, and conventional or high shutter speed cameras in recent years.[23,24] However, the majority of such methods have not transcended from the research setting to the clinical setting. Despite ample evidence indicating the usefulness of gait analysis and motion analysis systems in clinical settings, it remains a rarely used method of LLM and VVM assessment.[23]

However, recent advances in motion analysis techniques, such as markerless motion capture and analysis allow further evaluation of joint and limb biomechanics when mobilizing.[25–28] This study describes how MMA can accurately estimate not only movement of limbs, but joint centres also; however discrepancies in LLM and VVM exist when compared to clinical and radiological assessments. The MMA system utilized in this study (BioStage™, Organic Motion Inc., N.Y., USA) uses a visual hull to create three-dimensional images which is combined with three dimensional mesh humanoid models that, when modelled to a human frame while in one of their systems, generate measurements in relation to length and angulation regarding joint movements. Therefore, this system overcomes the need for an operator trained in placing markers on anatomical landmarks, minimizing the risk of operator related human error. Additionally, this system ensures repeatability of testing in a standardized manner, as the location of joint centres and the 21 limb segments is reproducible to over 98%.[1]

Although this study describes a novel technique being utilized in clinical orthopaedics, it is not without its limitations. The MMA system uses in this study (BioStage™, Organic Motion Inc., N.Y., USA) was initially designed as a modality to be implemented in the animation industry, before thereafter being considered for clinical use. For this reason, incorrect medical terms are routinely utilized when performing analysis with this software, such as 'knee abduction' when describing valgus deformity at the knee. Additionally, this study only included a limited cohort of 23 patients, all of whom had a primary diagnosis of knee osteoarthritis who were subsequently listed for TKR under the senior author.

5. Conclusion

Discrepanices exist in LLM and VVM when evaluated using clinical, radiological and MMA modalities. Therefore, this study suggests that MMA alone may not be a suitable modality for assessment of patients for TKR, with a combination of two or more evaluation modalities recommended at present.

Declaration of competing interest

None.

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