Investigating the effects of surgical approach on total hip arthroplasty recovery using 3D gait analysis

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Abstract—Postoperative gait analysis data was collected for 38 total hip arthroplasty (THA) subjects. In this preliminary study, the data for 10 THA subjects was used to determine significant kinematic and kinetic variables highlighting the differences between (i) lateral and posterior approach to surgery (ii) difference between operated and non-operated leg for each subject. The variables presented include frontal hip moments, sagittal range of motion of the hip and pelvis measured during gait, and pelvic obliquity measured from a Trendelenburg test. Moments acting in the frontal plane about the hip joint were found to be lower for the lateral approach group indicating abductor muscle weakness. Sagittal range of motion was found to be significant in the comparison between the operative and non-operative leg for the lateral approach. From this preliminary analysis the lateral approach group exhibited lower stability of their affected hip than the posterior group. The posterior group exhibited range of motion similar to their non–operative leg. This study is not conclusive and analysis of the remaining gait data is required. Although statistically significant results were not determined through the comparison of the two approaches, the findings are similar to those of other studies. Since this is a multivariate problem, a more sophisticated analysis using objective classification techniques may reveal further differences.

Keywords-Total Hip Arthroplasty; Gait Analysis; Surgical approach; Kinematics; Kinetics

I. INTRODUCTION

Total Hip Arthroplasty (THA) is a common surgical procedure for the treatment of osteoarthritis and disease of the hip, to improve quality of life by restoring hip motion and reducing pain. Gait is known to improve following THA, however studies have shown that gait is not returned to a normal level for several years [1]. It is thought that surgical approach may contribute to the extent to which normal gait is achieved. The merits of each technique are debated and since quantitative data comparing surgical techniques is lacking it is not apparent which surgical approach produces a more advantageous postoperative hip function.

The two most common surgical options are to access the joint through a posterior or lateral incision. The two approaches compared in this study are the Hardinge direct lateral [2] and the posterior (Southern) approach. These surgical options affect different muscular structures to access the joint, resulting in differing stability and control of the new joint. Each approach has its benefits. The lateral approach facilitates cup positioning which may reduce the rate of hip dislocation and reduce the risk of sciatic nerve damage. The posterior approach has a reduced operative time reducing blood loss and is believed to lead to a more normal gait pattern, [3] and improved function [4]. However a drawback is the increased risk of hip dislocation [5].

A complication of the lateral approach is postoperative abductor weakness. This may occur through the denervation of the abductors following damage to the superior gluteal nerve, or by failure to reattach the muscle mass to the greater trochanter [6]. The primary cause of gait disturbances following THA is the disruption of the abductor musculature and it is for this reason that the lateral approach is thought to have a disadvantage to the posterior approach.

In a previous investigation of the two techniques using motion analysis Madsen et al [7] found that the lateral approach to surgery lead to a gait pattern deviating from normal in terms of increased trunk inclination, reduced sagittal plane range of motion and greater loading asymmetry, whereas a normal gait pattern was exhibited for several subjects following the posterior approach to surgery. In a study of abductor strength following the two surgical approaches, Baker and Bitounis report abductor weakness following the lateral approach with the production of a more positive Trendelenburg test compared with the posterior approach, [6] whereas Downing et al did not find a significant difference in abductor strength between the approaches [8].

The abductor muscles play a crucial role during the single stance phase and are responsible for the torque required for hip abduction and the control of pelvic obliquity. Since these are incised during the procedure it is expected that the lateral approach to surgery produces a less stable gait. A Trendelenburg test is a standard clinical assessment of hip stability. A positive test indicates gluteus medius weakness and is observed when weight is supported by the affected limb and the pelvis on the healthy side falls instead of rises. This test was used in this study to compare the two approaches. In cases of minimal abductor weakness there may be a delayed positive test. It is for this reason that an element of muscle fatigue was taken into account by considering the pelvic position at 30 seconds of single leg stance. Since gait analysis allows subtle differences to be detected compared to clinical analysis, it was hoped this test would be an effective measure to compare the two approaches.

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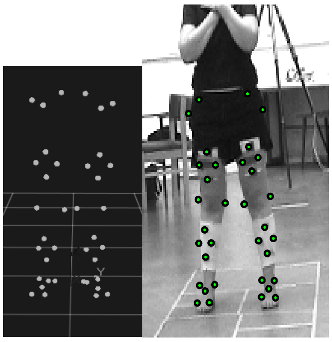

Figure 1. Marker placement for the static measurement

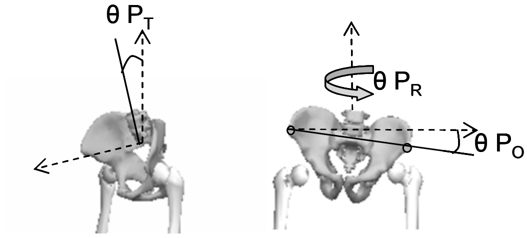

Figure 2. The Pelvic angles under consideration are Pelvic Tilt (θP_T), Pelvic Obliquity (θP_o) and Pelvic Rotation (θP_R)

The aim of this preliminary study is to examine kinematic and kinetic variables to compare the two approaches and provide an indication of postoperative recovery and surgical efficacy. This was achieved using Qualisys motion capture (Qualisys, Sweden) and a 6 Degree of Freedom (DOF) Cardan/Euler model developed using Visual3D (C-Motion Inc).

II. Materials and Methods

Motion and force data was collected postoperatively for 38 subjects forming two subject groups; those following a (i) lateral and (ii) posterior approach to THA. During data collection, height and weight was recorded and a total of 38 reflective markers were positioned on each subject. Arrays of markers were positioned on rigid surfaces attached to the thigh and shank and individual markers placed on anatomical landmarks, in a modified Helen Hayes configuration, see Fig.1.

A static measurement was taken of a standing trial, following which the anatomical calibration markers on the upper greater trochanter, medial and lateral epicondyles and malleoli were removed. The tracking markers remained in position for the dynamic measurements. Dynamic trials were recorded where each subject walked with a self selected speed of progression over a walkway. Trials were recorded for each subject until six force plate contacts were obtained from each foot. Trendelenburg tests were performed where the subjects were asked to stand unassisted on a force plate for 1 min on each leg. This allowed for an element of muscle fatigue. Many of the subjects felt they were unable to stand unassisted. Data obtained from subjects using walking aids during the dynamic trials are not considered in this preliminary study. 3D motion capture was performed using QTM Software, (Qualisys, Sweden) and using 8 Qualisys Proreflex MCU 120Hz digital cameras, capturing at 60Hz. Force data was collected using 2 Bertec force platforms (Bertec Corporation) with a sample rate of 1020Hz.

The collected data was analysed in Visual3D 3.34 (C-Motion Inc) using a biomechanical model of the lower limbs created using the static measurement. The pose of each rigidly defined segment in the model was determined by 3 non-collinear points using the vector method and using the marker clusters for greater accuracy by reducing inertial skin movement artifact. An axis was defined at each of the segments allowing for 6DOF at each joint. Joint rotations were defined using a Cardan/Euler sequence. Inverse dynamic analysis was used to calculate internal joint moments which were normalized to body weight. This model was subsequently used for 3D kinematic and kinetic analysis. The variables considered were temporal parameters, hip joint range of motion in 3 planes, pelvic tilt, obliquity and rotation, defined in Fig. 2 and moments and powers at the hip joint.

Movement is produced by muscle contractions. Considering kinetic variables gives a quantitative measure of the forces and moments produced during muscle contractions about the hip joint. Moments were investigated indicating the net torque generated by muscles crossing a joint. Segmental power gives an indication of the muscles influence on a segment and was determined as the product of the proximal joint moment and the segment angular velocity. Maximum moment and power during stance were calculated. Moment and power were also calculated during the point in stance when the ankle joint centre of the swinging leg passes along side that of the stance leg, as recommended in [7]. An average and standard deviation of these variables was calculated for each subject group.

Paired and independent-sample t-tests (SPSS 12.0.2) were applied to the results obtained for 10 subjects who performed walking trials without the use of walking aids, to compare: (i) the two approaches and (ii) the operated and non-operated leg, using a significance level of 0.05.

Only 3 of the subjects used for this preliminary study performed the Trendelenburg tests without walking sticks for balance. The data from those registering 0.85 BW or greater on the force plate were used to compare the groups and to consider the efficacy of a Trendelenburg test to assess hip stability. Nine out of the 10 subjects passed this criterion.

III. Results

The main variables considered in the analysis were hip and pelvis range of motion, frontal moment and power acting at the hip, and temporal parameters.

TABLE I. RANG E OF MOTION OF THE HIP AND PELVIS FOR LATERAL AND POSTERIOR SURGICAL APPROACH GROUP

Range of Motion	Surgical Approach	
	Lateral	Posterior
Hip Flexion/Extension (°)	29.82 ± 4.8	33.31 ± 6.22
Hip Abduction/Adduction (°)	9.36 ± 2.73	7.35 ± 2.93
Hip Internal/External Rotation (°)	11.58 ± 2.98	11.79 ± 3.83
Pelvic Tilt (°)	5.22 ± 1.17	3.15 ± 1.21
Pelvic Obliquity (°)	4.28 ± 1.26	5.08 ± 1.98
Pelvic Rotation (°)	13.43 ± 7.63	13.04 ± 2.97

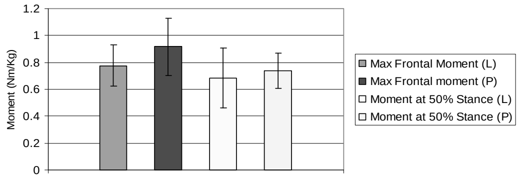

Figure 3. Hip frontal moments for lateral (L) and Posterior (P) approaches.

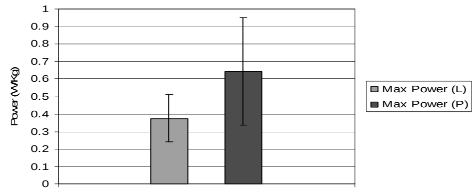

Figure 4. Hip frontal power for Lateral (L) and Posterior (P) approaches.

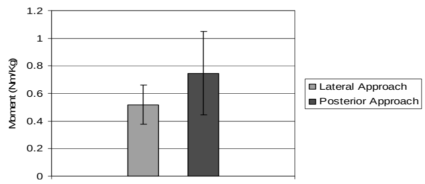

Figure 5. Hip frontal moment 50% through Trendelenburg tests.

A. Range of motion

The means and standard deviation of the range of motion of the hip joint and pelvis during one gait cycle are presented in table 1 for each surgical approach. Hip range of motion was lower in the sagittal and transverse plane for the lateral approach and was larger in the frontal plane. Although this is not statistically significant this may be indicative of abductor weakness reducing the control and stability at the joint in this plane of movement.

In the comparison of the mean range of motion of the affected and non affected hip within each surgical group, the difference between the range in the sagittal plane of the operated ($29.82^o \pm 4.80$) and non-operated hip ($41.58^o \pm 4.91$) for the lateral subject group was found to be significant. This indicates that the lateral approach group does not appear to be using their full range of motion of their operative leg. A lower stance time was recorded for the operative leg compared with the non-operative leg for the lateral approach group which, along with the reduced range of motion may indicate a lack of confidence on their operative limb.

The mean range of motion at the hip joint was found to be similar when comparing the operative and non-operative leg for the posterior approach group. The maximum difference was a 1.34^o.

Pelvic obliquity angle was recorded at 50% through the Trendelenburg test with the subject standing on their affected leg. A positive Trendelenburg test was present for 2 subjects from the lateral approach group where 1.76^o and 1.34^o pelvic obliquity was measured below the horizontal. One subject from the posterior group exhibited a positive Trendelenburg test with an obliquity angle of 0.57^o. One subject from each approach performed a positive test on their non-operative leg, although smaller angles of 0.42^o and 0.44^o were measured. Much variation existed in pelvic obliquity for the duration of the Trendelenburg tests. For some, although a negative test was noted initially, the pelvis then dropped towards the horizontal due to diminishing abductor strength. During a test one of the lateral approach subjects began showing a positive Trendelenburg test, then as their abductors became more influential, they then corrected their position by raising the pelvis until nearing the end of the test when their pelvis dropped below the horizontal. In a comparison of pelvic obliquity between the operative and non-operative leg, both groups exhibited reduced abductor function on their operative side as the pelvis did not rise to the same degree above the horizontal. Within the lateral approach a statistically significant difference in pelvic obliquity was determined between the operative ($-1.46^o \pm 4.38$) and non-operative leg ($-3.74^o \pm 3.6$).

B. Moment and Power

Maximum frontal moment and the moment at 50% Stance during the walking trials were consistently lower for the lateral approach group than the posterior group (Fig. 3) indicating weakness in the abductor muscles.

The maximum frontal moment exhibited in the lateral approach is 15.3% lower than the posterior approach. A lower moment measured at 50% through stance is also evident for the lateral approach group. Frontal power was 41.9% lower for the lateral approach than the posterior approach but was not found to be statistically significant due to the large standard deviation, (Fig. 4).

The moment calculated at 50% through the Trendelenburg tests, (Fig. 5) was 30.7% less for the lateral approach (0.52Nm/Kg ± 0.14) compared to the posterior approach (0.75Nm/Kg ± 0.3).

C. Temporal Parameters

Several parameters were examined. It was found that the lateral approach subject group had a decrease of 4.1% stance time for their operative leg (0.71s ± 0.087) compared to their non-operative leg (0.74s ± 0.11). This result was not statistically significant due to a large standard deviation.

IV. Discussion

From this initial study, although few variables have been found to be statistically significant due to a large variation between the groups, several variables may be important in the comparison of the two surgical approaches:

A. Range of Motion:

Hip range of motion in each of the three planes was not found to be significant in the comparison between the two groups in this preliminary study, due to large standard deviations within each group. It is likely however, that these may become important when the remainder of the cohort is analysed. Range of motion in the sagittal and transverse plane was greater for the posterior group. However, in the frontal plane the range of motion was 27.3% greater for the lateral group compared to the posterior group. This is indicative of lack of abductor muscle control during gait.

Range of motion for the operative leg for the lateral approach was consistently lower than the non-operative leg, indicating joint instability. The reduced range of motion of the operative leg in the sagittal plane was found to be statistically significant. The range of motion at the hip for the posterior approach group was found to have similar values to the non-operative hip range of motion.

Pelvic obliquity angle was believed to be important in the comparison as an indicator of Trendelenburg gait and abductor weakness. However, a significant difference was not found between the groups.

B. Fontal Moment and Frontal Power:

Frontal moment and muscle power around the hip are indicative of the abductor muscle function. The frontal moments were lower for the lateral approach group indicating abductor weakness, thus generating less torque. The frontal moment measured at 50% stance was lower in the lateral group by 7.3%. This is an important variable for comparison since the measurement is taken at the instant in gait when the abductor moment is at its greatest, due to a longer moment arm between the ground reaction force vector and the hip joint centre.

C. Pelvic Obliquity:

Pelvic drop on the unsupported side during a Trendelenburg test is a compensatory action to shorten the moment arm between the hip and centre of mass, thus reducing the torque required from the abductor muscles for control. A positive Trendelenburg test was more common within the lateral group. The obliquity angles measured were small and therefore may have been affected by a number of factors including marker misplacement and the use of a support. Pelvic drop may also be affected by trunk inclination over the affected leg which elevates the contralateral side of the pelvis. This may be a compensation mechanism performed out of habit. Also, loss in elasticity following surgery may affect this test and the quantification of muscle weakness. These results from the Trendelenburg tests raise the question of the reliability of this test for the observation of abductor weakness. A number of the subjects in the study insisted on the use of aids for the test which lowers the effort required by the abductor muscles. The large standard deviation within each group indicates a large range of ability between the subjects in each group which would also affect the results.

D. Temporal Parameters

Stance time gives an insight into the confidence of a subject to take equal load distribution over both their affected and non affected leg during gait. Within the lateral group the non-operative leg was in stance for a longer duration than the operative leg. This indicates postoperative limp and a lack of confidence on the operative leg.

E. Limitations

Whether out of necessity or habit, a number of subjects required the use of walking aids for some of the tests which may affect their gait and trunk inclination. Subjects chosen for this initial analysis did not use aids during the walking trials. Although seven subjects used aids during the Trendelenburg tests, six exerted less than 15% BW through the aid and therefore it was assumed that a considerable amount of effort was still required from the abductors for pelvic control. Markers were not positioned to record trunk inclination which did not enable a measurement of trunk inclination as a possible compensatory action.

V. Conclusion

The results suggest that gait patterns following the posterior approach to surgery show greater characteristics of normal gait than those following the lateral approach. However, further work must be undertaken before a firm conclusion can be drawn. Although they are not statistically significant, frontal moment along with hip and pelvis range of motion present themselves as potentially important variables when considering the stability of the joint and its effect on gait. It is expected that once the remaining cohort are used in the analysis, the standard deviation within the groups will change and statistically important variables may be revealed. Due to the variability of the results from the Trendelenburg tests, it may also be found that gait is more indicative of postoperative function and abductor strength than a static Trendelenburg test. A more sophisticated analysis will be applied to variables from this study and possible feature selection performed using an objective classifier based around the Dempster-Shafer Theory [9].

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