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Objective functional assessment of total hip arthroplasty following two common surgical approaches: the posterior and direct lateral approaches

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Abstract: Despite the high number of total hip arthroplasty (THA) procedures performed each year, there is no common consensus on the best surgical approach. Gait is known to improve following THA although it does not return to what is typically quantified as normal, and surgical approach is believed to be a contributing factor. The current study evaluates post-operative hip function and provides an objective assessment following two common surgical approaches: the McFarland–Osborne direct lateral and the southern posterior. Faced with the common problem of providing an objective comparison from the wealth of data collected using motion analysis techniques, the current study investigates the application of an objective classification tool to provide information on the effectiveness of each surgery and to differentiate between the characteristics of hip function following the two approaches. Seven inputs for the classifier were determined through statistical analysis of the biomechanical data. The posterior approach group exhibited greater characteristics of non-pathological gait and displayed a greater range of functional ability as compared with the lateral approach cohort. The classification tool has proved to be successful in characterizing non-pathological and THA function but was insufficient in distinguishing between the two surgical cohorts.

Keywords: joint replacement, motion analysis, biomechanics, classification

1 INTRODUCTION

Total hip arthroplasty (THA) is a common procedure for the treatment of hip osteoarthritis and is successful in reducing pain and improving function and patient quality of life. Numerous surgical approaches are in routine use, the most common involving either anterolateral or posterior access to the joint. Each option compromises different muscles and static constraints surrounding the hip, resulting in varying post-operative stability and control of the new joint. For this reason, surgical technique is a potential contributing factor to the level of function achieved post-operatively. Despite this, there is currently no common consensus on the best surgical approach. This study uses motion analysis techniques to obtain biomechanical data to evaluate post-operative gait, and Trendelenburg tests following two principal surgical approaches: the McFarland–Osborne direct lateral approach (LA) [**1**] and the Moore (southern exposure) posterior approach (PA).

There are advantages and disadvantages to each procedure. The LA preserves the posterior capsule, which may reduce the rate of hip dislocation and sciatic nerve damage. The main complication to this procedure is post-operative abductor muscle dysfunction. Although the McFarland–Osborne direct LA preserves part of the insertion of gluteus medius into the greater trochanter, if migration of the abductor tendon occurs during healing, this introduces a change in the mechanical ability of the abductors, which in turn affects frontal plane stability. Abductor weakness is also reported to occur through

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denervation of the gluteus medius and minimus following damage to the superior gluteal nerve [**2**], although the role of nerve injury in the production of post-operative abductor weakness is not clear, as a study found electromyographic evidence that acute nerve injury does not correlate with clinical findings of weak abductors [**3**].

Advocates of the PA suggest that the main advantage in terms of function is the preservation of the abductor mechanism, resulting in a low-frequency incidence of post-operative limp [**4**] and improved function [**5**]. Complications associated with this approach include the potential for sciatic nerve injury and post-operative hip dislocation [**6**, **7**]. The posterior joint capsule and external rotator muscle group are compromised during this procedure, affecting the posterior and lateral stability of the hip joint. The risk of hip dislocation is reported to be higher for the PA than for the LA [**8**]. A study using finite element modelling shows that the anterolateral approach to hip joint surgery presents a sustained risk of limp compared with a posterolateral approach [**9**] when the pelvic models were subjected to a loading case representative of a Trendelenburg test [**10**]. This was due to muscle damage following surgery. Although this result is not identified by conventional clinical assessment, it is in agreement with post-surgical gait analysis [**11**].

The primary cause of gait disturbances following THA is the disruption of the abductor musculature. The abductors play a crucial role during the single-stance phase in gait by controlling hip abduction and pelvic obliquity. It is for this reason that a less stable gait is expected following the lateral approach to THA.

In a previous investigation comparing an anterolateral and posterolateral approach using motion analysis, subjects following the LA exhibited a gait pattern deviating from normal in terms of increased trunk inclination, reduced sagittal plane hip range of motion (ROM), and greater loading asymmetry, whereas a normal gait pattern was exhibited for several subjects following the posterolateral approach to surgery [**11**]. In a study of abductor strength, the PA was found to lead to a more normal hip abductor muscle strength than following an anterolateral approach [**12**]. Baker and Bitounis [**2**], using a Trendelenburg test to assess abductor strength, reported abductor weakness following the LA, indicated by a more positive Trendelenburg test as compared with the PA, whereas Downing *et al.* [**13**], in comparing the LA and PA, did not find significant differences in abductor strength.

The Trendelenburg test, which is a standard clinical assessment to determine the integrity of hip abductor function, is an examination of a subject's posture while they stand on one leg. The action of changing from a two-leg to a single-leg stance shifts the line of gravity of the superincumbent body, producing moments about the hip that must be balanced by a moment arising from the force of the abductor muscles. In the case of a positive test, the pelvis on the unsupported side falls below the horizontal position, indicating abductor weakness. This action moves the line of gravity towards the supporting hip, reducing the moment lever arm and consequently the moment that must be counteracted by the abductors for stability. The Trendelenburg test is used routinely in a clinic to assess hip stability and is included in the current study.

The aim of this study is to use motion analysis techniques to perform a post-operative functional analysis of the hip following two principal surgical approaches. Quantifying pelvic position during Trendelenburg tests will allow comparison of the observational measures in a clinic and would allow subtle differences to be determined for the hip in a static situation. Gait analysis was performed to determine important characteristics that are not apparent through Trendelenburg tests alone. The kinematic and kinetic variables are used to provide an indication of post-operative recovery and surgical efficacy. Madsen *et al.* [**11**] identified the importance of quantifying gait variables to identify small differences between the groups. However, a common difficulty in this method of data collection is not only the vast amount of data yielded but also its variability, which can be difficult to interpret subjectively. The current work describes a statistical analysis to determine variables that highlight significant functional differences between the two surgical approaches and also between the operated and non-pathological hip within each surgical cohort. It then explores the use of these variables as inputs for classification, using a method [**14**] based on the Dempster–Shafer theory (DST) of evidence, to characterize operated and non-pathological hip function. This method objectively analyses the mass of conflicting and corroborating data, removing the need for subjective interpretation.

2 METHODS

Hip function was evaluated during gait and Trendelenburg tests for 14 subjects following the McFarland–Osborne LA, 13 subjects following the PA and 16 hips with no pathology (NP) forming a control group. Informed consent was obtained from the subjects after the tests had been fully explained. The LA cohort had a mean age of 64.21 ($\pm$ 10.88) years, a mean height of 1.64 ($\pm$ 0.08) m, and a mean mass of 82.75 ($\pm$ 14.64) kg. The PA cohort had a mean age of 60.46 ($\pm$ 11.52) years, a mean height of 1.70 ($\pm$ 0.07) m, and a mean mass of 90.04 ($\pm$ 22.67) kg. The NP cohort had a mean age of 46.25 ($\pm$ 7.42) years, a mean height of 1.72 ($\pm$ 0.12) m, and a mean mass of 74.81 ($\pm$ 14.34) kg. The discrepancy between the ages of the healthy and THA cohorts reflects the inherent problem encountered when obtaining data for healthy age matched cohorts that are not affected by common pathologies such as osteoarthritis and osteoporosis at the hip and other lower limb joints.

Three-dimensional (3D) motion capture was performed using QTM Software (Qualisys, Sweden) and using eight Qualisys ProReflex MCU digital cameras, capturing at 60 Hz. Force data were collected using two Bertec force platforms (Bertec Corporation) with a sample rate of 1020 Hz.

During the data collection session, the subjects' height and mass were measured, and 38 retroreflective markers were positioned on their lower limbs in a modified Helen Hayes configuration. Marker positions are shown in Fig. 1 with the exception of a marker positioned centrally on each calcaneus. Surface markers were attached to anatomical landmarks; plate-mounted markers with a non-slip surface were used to reduce skin movement artefacts and were attached to the front of the thigh and shank.

A static measurement was taken for a quiet standing trial with the subject's feet placed approximately shoulder width apart. These data were subsequently used to define the bony segment and joint axes. Following this measurement the markers attached to the upper greater trochanter, femoral condyles, and malleoli were removed. Gait trials were recorded as each subject walked the length of the laboratory in bare feet and with a self-selected speed until six trials with force plate contacts were recorded for each leg. Three Trendelenburg tests were performed on the operated and non-operated legs. As there are various ways of performing a Trendelenburg test, all subjects received the same instruction to standardize the test. Each subject was asked to step on to a force plate, to raise and flex the unsupporting leg, and to return to the initial position when instructed. In cases of minimal abductor weakness, there may be a delayed positive test. For

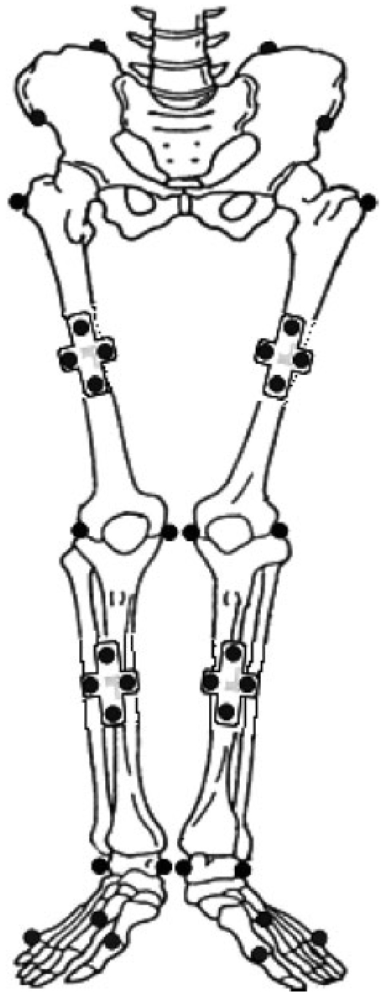

Fig. 1 Marker placement following a modified Helen Hayes marker set

this reason, the Trendelenburg test was performed for 1 min on each leg to introduce an element of fatigue into the abductor muscles. Pelvic position, frontal moment, and frontal power were calculated at 30 s into single-leg stance.

A biomechanical model of the lower limbs was created from the static measurement for each subject using Visual3D (C-Motion, USA) and subsequently used for kinematic and kinetic analysis. The pose of each rigidly defined segment in the model was determined by at least three non-collinear points using the vector method. An axis was defined at each of the segments allowing for six degrees of freedom at each joint. Joint rotations were described by a Cardan–Euler sequence. The Cardan sequence X, Y, Z, where Z is the positive vertical axis acting upwards and positive Y is acting anteriorly. A segment angle was defined as the orientation of the distal segment with respect to the proximal segment. For the calculation of the segment angle of the pelvis, a virtual laboratory segment coordinate system was created and aligned to the direction of walking; the pelvic angle was computed as the orientation of the pelvis relative to the virtual laboratory. Internal joint moments, defined as the net moments generated by muscles crossing a joint, were calculated through inverse dynamic analysis and normalized to body mass (BM). Joint power, normalized to BM, was computed as the product of proximal joint moment and segmental angular velocity.

The variables calculated were temporal parameters, hip joint ROM in three planes, pelvic tilt, obliquity, and rotation (Fig. 2). 3D moments and powers acting at the hip joint were also considered to quantify the effects of muscle contractions about the joint. Abductor muscles produce torque to control abduction and pelvic obliquity, and therefore frontal moment and power are important variables to consider. The moment and power at 50 per cent stance were calculated, as this is the point in gait when the abductor moment is at its greatest. This is due to a longer moment arm between the ground reaction force (GRF) vector and the hip joint centre [**11**]. The maximum values for moment and power experienced during the stance phase were determined in each plane.

Data from subjects satisfying strict criteria were selected for a preliminary statistical analysis to determine input parameters for the classifications. Paired and independent-sample *t* tests (SPSS 12.0.2) were applied to variables obtained from ten subjects to compare, first, the two approaches and, second, the operated and non-operated leg of five subjects from the LA group and five subjects from the PA group. This was performed to determine differences between THA function and function which is considered normal for the surgical cohorts. A significance level of 0.05 was used to reduce the amount of

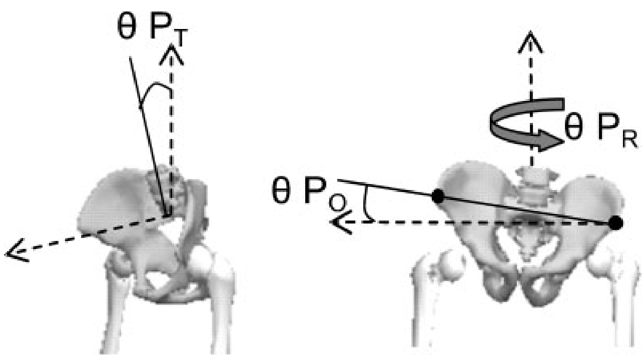

Fig. 2 Pelvic angles: pelvic tilt θ_{P_T}, pelvic obliquity θ_{P_O}, and pelvic rotation θ_{P_R}

data to a small subset of variables that were considered important in the comparison of function from the two cohorts. The subjects selected for this preliminary analysis performed walking trials without the use of aids. One subject from the LA group and five from the PA group felt unable to complete the Trendelenburg tests without an aid. These satisfied a selection criterion where 0.8 BM or greater registered on the force plate during the Trendelenburg tests to ensure that considerable effort was required from the abductors for pelvic control. The remaining subjects included when exploring the use of the classifier registered at least 0.8 BM or greater on the force plate during gait trials (where five subjects from the LA group and one subject from the PA group used aids) and 0.7 BM during Trendelenburg tests (where nine subjects from the LA group and 13 from the PA group used aids).

Variables with a statistical significance less than 0.05 were used as inputs to the DST classifier. A series of four classifications were performed to provide an objective and visual indicator of post-operative THA function:

(a) NP and LA;
(b) NP and PA;
(c) PA and LA;
(d) NP and surgical group containing PA and LA.

To describe the method briefly, the classification of NP and LA subjects are used as an example. The DST classifier transforms the functional hip data from each subject into a set of three belief values: a belief that the subject's hip function is non-pathological, $m(\{NP\})$; a belief that the subject has hip function characteristic of an LA to surgery, $m(\{LA\})$; and an associated level of uncertainty $m(\Theta)$. These are represented as a single point on a simplex plot to give a visual representation of hip function (Fig. 3(a)). The distance of the point from each side of the equilateral triangle is in proportion to the belief values. For example, the closer the point is situated to the vertex labelled {NP}, the greater is the belief that the subject has NP hip function. The simplex plot can be split into four regions (Fig. 3(b)) with a central decision boundary illustrated by the dashed line along which $m(\{NP\}) = m(\{LA\})$. Region 1 highlights the area of dominant NP function in which $m(\{NP\}) > 0.5$, region 2 highlights the area of dominant LA function where $m(\{LA\}) > 0.5$, region 3 highlights the area of non-dominant NP function where $m(\{LA\}) < m(\{NP\}) < 0.5$, and region 4 shows non-dominant LA function where $m(\{NP\}) < m(\{LA\}) < 0.5$.

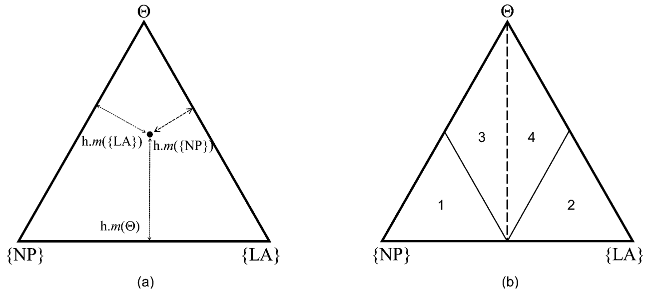

Fig. 3 (a) Relationship between the belief values and position of the point on the simplex plot, where h is the height of the triangle; (b) regions of dominant (1 and 2) and non-dominant (3 and 4) classification

3 RESULTS

Following data collection, kinematic, kinetic, and temporal parameters were computed. Statistical analysis was performed on the data from five subjects from each surgical cohort to determine a subset of signals with a statistical difference, first, between the two cohorts and, second, between the operated and non-operated hip within each cohort. Variables with a statistical significance less than 0.05 were used as inputs to the DST classifier. Once the variables highlighting differences between the two surgical groups were determined, the remaining subjects were included in the analysis using the classifier.

3.1 Comparison between the surgical cohorts

An independent t test was performed on the variables displayed in Table 1. Through the comparison of the two surgical cohorts, the LA group was generally found to produce lower hip and pelvic ROM during gait, with the exception of hip frontal and pelvic sagittal ROM. The difference in pelvic obliquity ROM, i.e. the movement in the frontal plane for the LA group ($3.92^\circ \pm 0.92^\circ$) and PA group ($6.13^\circ \pm 1.74^\circ$), was found to be significant. The LA patients may compensate for this by adopting a greater pelvic ROM in the sagittal plane ($4.47^\circ \pm 2.09^\circ$) as compared with the PA group ($3.08^\circ \pm 1.11^\circ$).

The frontal power and moment acting about the hip are indicative of abductor muscle function. In addition to the maximum values measured during gait, values at 50 per cent stance phase, when the abductor moment is at its greatest [**11**], were also considered. In comparing the surgical cohorts, lower frontal moments and powers were found for the LA group, indicating abductor muscle weakness. These differences are statistically significant, with the exception of frontal moment at 50 per cent stance due to a large standard deviation in the LA subject group. Analysis of the measurements for the operated leg taken 30 s into the Trendelenburg tests indicated significantly lower frontal moments acting about the hip for the LA group as compared with the PA group. This may indicate abductor weakness or the use of compensatory mechanisms to maintain a

Table 1 Variables (mean ± standard deviation) used for the independent-sample t test for LA and PA groups

Variable (unit)	Value	
	LA group ($n = 5$)	PA group ($n = 5$)
Height (m)	1.67 ± 0.11	1.68 ± 0.07
Weight (kg)	86.90 ± 14.66	86.5 ± 28.91
Speed (m/s)	0.98 ± 0.28	1.03 ± 0.13
Stride length (m)	1.09 ± 0.20	1.14 ± 0.14
Cycle time (s)	1.14 ± 0.15	1.10 ± 0.05
Double limb support time (s)	0.25 ± 0.08	0.23 ± 0.04
Peak GRF in stance (N)	1.11 ± 0.10	1.15 ± 0.05
Symmetry index	1.01 ± 0.02	1.04 ± 0.04
Stance time (s)	0.69 ± 0.10	0.67 ± 0.04
Hip sagittal ROM during gait (deg)	29.7 ± 4.71	32.55 ± 7.82
Hip frontal ROM during gait (deg)	9.62 ± 2.78	9.51 ± 2.58
Hip transverse ROM during gait (deg)	11.41 ± 2.67	13.53 ± 3.79
Pelvic sagittal ROM during gait (deg)	4.47 ± 2.09	3.08 ± 1.11
Pelvic frontal ROM during gait (deg)*	3.92 ± 0.92	6.13 ± 1.74
Pelvic transverse ROM during gait (deg)	13.44 ± 7.34	16.10 ± 5.00
Hip frontal moment at 50% stance phase (N m/kg)	0.61 ± 0.22	0.79 ± 0.08
Hip frontal power at 50% stance phase (W/kg)*	0.08 ± 0.04	0.25 ± 0.14
Peak hip frontal moment in stance (N m/kg)*	0.75 ± 0.15	1.02 ± 0.13
Peak hip frontal power in stance (W/kg)*	0.34 ± 0.10	0.82 ± 0.08
Pelvic obliquity 30 s into the Trendelenburg test (deg)	3.86 ± 2.34	1.87 ± 1.77
Hip frontal moment 30 s into the Trendelenburg test (N m/kg)*	0.52 ± 0.19	0.95 ± 0.12
Hip frontal power 30 s into the Trendelenburg test (W/kg)	0.02 ± 0.02	0.01 ± 0.00

*Indicates a statistical significance between the LA and PA groups ($p < 0.05$).

Table 2 Variables (mean ± standard deviation) used for the paired-samples t test to compare operated and non-operated hip functions within the surgical groups

Variable (unit)	Value			
	LA ($n = 5$)		PA ($n = 5$)	
	Operated hip	Non-operated hip	Operated hip	Non-operated hip
Hip sagittal ROM during gait (deg)	29.70 ± 4.71	39.89 ± 3.21*	32.55 ± 7.82	32.75 ± 14.14
Hip frontal ROM during gait (deg)	9.62 ± 2.78	11.73 ± 0.81	9.51 ± 2.58	9.55 ± 2.91
Hip transverse ROM during gait (deg)	11.41 ± 2.67	11.36 ± 3.34	13.53 ± 3.79	11.72 ± 3.15
Peak GRF in stance (N)	1.11 ± 0.10	1.10 ± 0.09	1.15 ± 0.05	1.10 ± 0.07
Stance time (s)	0.69 ± 0.10	0.71 ± 0.12	0.67 ± 0.04	0.67 ± 0.05
Hip frontal moment at 50% stance phase (N m/kg)	0.61 ± 0.22	0.67 ± 0.14	0.79 ± 0.08	0.82 ± 0.16
Hip frontal power at 50% stance phase (W/kg)	0.08 ± 0.04	0.09 ± 0.13	0.25 ± 0.14	0.17 ± 0.11
Peak hip frontal moment during stance (N m/kg)	0.75 ± 0.15	0.85 ± 0.23	1.02 ± 0.13	1.00 ± 0.16
Peak hip frontal power during stance (W/kg)	0.34 ± 0.09	0.60 ± 0.43	0.82 ± 0.08	0.79 ± 0.32
Pelvic obliquity 30 s through the Trendelenburg test (deg)	3.86 ± 2.34	4.65 ± 2.49	1.87 ± 1.77	5.56 ± 3.07*
Hip frontal moment 30 s into the Trendelenburg test (N m/kg)	0.52 ± 0.19	0.86 ± 0.36	0.95 ± 0.12	1.00 ± 0.39
Hip frontal power 30 s into the Trendelenburg test (W/kg)	0.02 ± 0.02	0.02 ± 0.02	0.01 ± 0.00	0.01 ± 0.01

*Indicates a statistical significance between the operated and non-operated hip functions within a surgical group ($p < 0.05$).

stable pelvic position. Although no significant difference between the orientations of the pelvis (defined as the angle of the pelvis above the horizontal in the frontal plane) was determined 30 s into the Trendelenburg, some variation was observed during the tests and between patients. Two patterns deviating from normal were observed, indicating abductor weakness. First, although a negative test was noted initially, the pelvis then dropped towards the horizontal because of diminishing abductor strength. Second, a subject began with a positive Trendelenburg test and then, as their abductors became more influential, they corrected their position by raising their pelvis until nearing the end of the test when their pelvis dropped below the horizontal position.

3.2 Comparison between the operated limb and non-operated limb within each surgical cohort

The variables used in the comparison of the operated and non-operated hip within each surgical group are displayed in Table 2.

The ROMs for the operated and non-operated hip within the PA cohort are similar, although a large variation is evident for the operated leg for sagittal ROM. A significantly lower ROM was found in the sagittal plane for the operated ($29.7^\circ \pm 4.71^\circ$) compared with the non-operated ($39.89^\circ \pm 3.21^\circ$) hip for the LA cohort. This suggests that, following the LA, subjects have both insufficient control of the stabilizing mechanisms that would normally allow them to utilize the full ROM of their operated hip during gait, and a lack of confidence on their operated limb. In the comparison of the operated and non-operated legs, pelvic obliquity was significantly less for the operated hip ($1.87^\circ \pm 1.77^\circ$) than the non-operated hip ($5.56^\circ \pm 3.07^\circ$) for the PA group. This suggests that the abductors are weaker for the LA group as compared with the PA group and that abductor strength for the PA group has also not returned to normal.

From the statistical analysis the variables selected as inputs to the classifier were as follows: pelvic obliquity and hip sagittal ROM during gait; hip frontal power at 50 per cent stance phase during gait; peak frontal power and moment during gait; and frontal hip moment and pelvic obliquity 30 s into the Trendelenburg test.

3.3 Outputs from classification

The outputs from the classifications are shown in Figs 4(a) to (d). The classification in Fig. 4(a) has an out-of-sample accuracy of 93.3 per cent. There is a distinction between the subjects exhibiting NP and LA function, as the subjects are situated within their respective dominant regions of the simplex plot. A distinction between the groups is also evident for the classification in Fig. 4(b). The out-of-sample accuracy is 86.2 per cent with four misclassified subjects; two subjects from the PA group are situated in the dominant NP region. For the classification in Fig. 4(c), between the PA and LA cohorts, not all the subjects are positioned within their respective sides of the simplex plot, indicating that no objective functional difference was found between them. This is supported by an out-of-sample accuracy of 55.6 per cent. However, all but one of the LA and NP subjects are positioned in their respective dominant regions of the simplex plot for the classification in Fig. 4(d), indicating differences in function, while

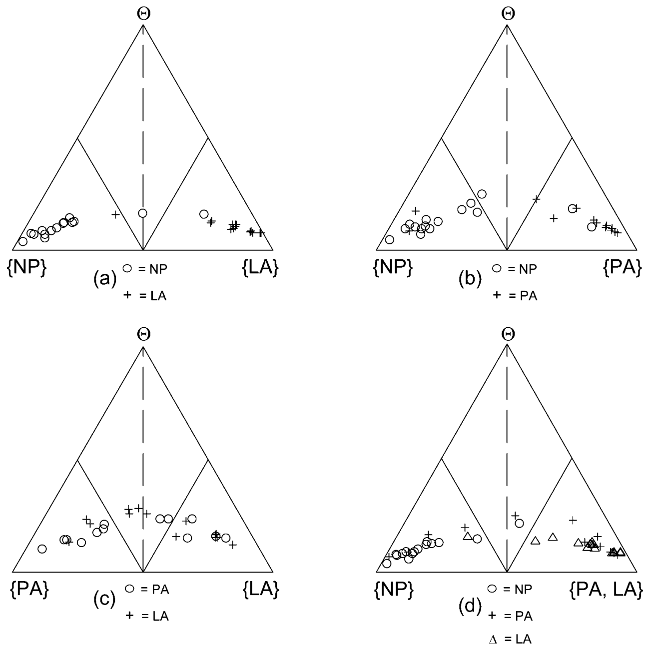

Fig. 4 Simplex plots for the classification of (a) NP and LA, (b) NP and PA, (c) PA and LA, and (d) NP and the surgical group containing both PA and LA

four subjects from the PA group are positioned in the dominant NP region, which indicates a greater range of NP functional ability within the PA group; the out-of-sample accuracy is 86.0 per cent.

Independent-sample *t* tests (SPSS 12.0.2) were applied to the variables used in the four classifications to clarify the classification outputs. The results from the *t* tests comparing NP and surgical function are displayed in Table 3. From a *t* test on the variables to compare the LA and PA functions, a statistical difference was determined between the two approaches for peak hip frontal power in stance (LA, 0.39 ± 0.20 W/kg; PA, 0.56 ± 0.23 W/kg), and peak hip frontal moment in stance (LA, 0.70 ± 0.24 N m/kg; PA, 0.89 ± 0.20 N m/kg).

4 DISCUSSION

From this initial study, seven clinically relevant variables have been found to be important in characterizing THA function. Six of the seven input variables relate to hip function in the frontal plane, indicating a difference between the abductor strength and stabilities of the surgical groups.

Pelvic obliquity and frontal moment acting at the hip measured 30 s into the Trendelenburg test were significant in the comparison of the two cohorts. This is to be expected, as it is a standard clinical test to assess pelvic position, hip stability, and abductor strength. The pelvis was held at a slightly lower position when standing on the operated leg compared with the non-operated leg within the PA group. A difference between the abductor strengths of the operated hips and non-operated hip is expected, although a significant difference within the LA group was not found. This is due to a larger variability within the group. The angles computed for pelvic obliquity – angle of unsupported side measured above a horizontal position – are small. This highlights the benefits of the motion analysis system in detecting subtle differences but also raises the question of the reliability of using the Trendelenburg tests in a clinic for the assessment of THA patients where small differences may not be observed.

During the Trendelenburg test, hip frontal moment is significantly lower for the LA, indicating a lower net torque generated by the muscles surrounding the joint. As the pelvic position is not significantly different between the two groups, this suggests that an alternative compensatory action is acting to reduce the loading on the abductor muscles. Possible mechanisms include trunk inclination over the supporting leg or the use of alternative stabilizing structures surrounding the hip. Through video analysis, slight trunk inclination over the supporting leg was observed for several of the subjects. Trunk inclination occurred more frequently

Table 3 Variables (mean $\pm$ standard deviation) used for the independent-sample *t* test to compare the NP group with the LA group, PA group, and surgical group containing LA and PA

	Value			
Variable (unit)	NP group ($n = 16$)	LA group ($n = 14$)	PA group ($n = 13$)	Surgical group LA and PA ($n = 27$)
Hip sagittal ROM during gait (deg)	46.94 ± 5.73	28.72 ± 6.67*	33.88 ± 7.12*	31.21 ± 7.25*
Pelvic frontal ROM during gait (deg)	6.88 ± 3.29	4.32 ± 1.08*	5.03 ± 1.64	4.66 ± 1.40*
Hip frontal power at 50% stance phase (W/kg)	0.20 ± 0.12	0.83 ± 0.71*	0.16 ± 0.12	0.12 ± 0.10*
Peak hip frontal moment in stance (N m/kg)	0.97 ± 0.15	0.70 ± 0.24*	0.89 ± 0.20	0.79 ± 0.24*
Peak hip frontal power in stance (W/kg)	0.75 ± 0.31	0.39 ± 0.20*	0.56 ± 0.23	0.47 ± 0.23*
Pelvic obliquity 30 s into the Trendelenburg test (deg)	2.32 ± 3.08	1.18 ± 3.06	1.01 ± 2.78	1.10 ± 2.87
Hip frontal moment 30 s into the Trendelenburg test (N m/kg)	0.74 ± 0.18	0.49 ± 0.22*	0.59 ± 0.34	0.53 ± 0.28*

*Indicates a statistical significance ($p < 0.05$) between NP and the LA group, PA group, or LA and PA subjects.

and was more pronounced when the subjects stood on their operated limb. For this reason, it would be beneficial to position markers on the trunk and to make electromyographic recordings during the tests.

Values were taken 30 s into the Trendelenburg test to allow for muscle fatigue; however, it is apparent that, owing to the variability in the data, there is a danger of losing important information as the subject acts to stabilize their position. Further investigation is required to analyse these waveforms in order to produce a definitive point at which the data can be used satisfactorily for comparative studies.

During gait trials, the LA group exhibited a reduced ROM of their operated hips. Significantly lower sagittal hip ROM and pelvic obliquity ROM were measured for the LA group compared with the PA group. These subjects may have limited control or strength in the stabilizing mechanisms that would allow them to use the full ROM of their operated hip. The posterior group showed a greater variation in ability and showed greater characteristics of non-pathological gait. Unfortunately, for the current study, patients were referred for post-operative gait analysis only; thus there are no comparisons with pre-operative gait analysis data. On exploring the outcomes of this study it is evident that for similar studies in the future, pre-operative gait will also be analysed since, first, it would provide individual patient comparative data sets and, second, surgeons note that, via the LA, it is common to see chronic abductor tears at the time of surgery which obviously preceded the surgery.

Frontal moments during gait were significantly lower for the LA group owing to abductor weakness and subsequent reduced torque generation. Frontal moment measured at 50 per cent stance was found to be an important variable. This is when the abductor moment is at its greatest because of the greatest moment arm between the GRF vector and hip joint centre. Frontal power was also found to be a salient variable in the comparison of the two surgical groups. The maximum value and value at 50 per cent stance were considerably lower for the LA group, indicating a reduced rate of change in energy.

The clinical measures determined through statistical analysis were applied to the classifier for further analysis to determine their ability to characterize NP, PA, and LA functions. The variables were successful in classifying non-pathological and surgical function but were unable to distinguish between surgical groups.

The classification outputs display several interesting results. First, from the classification of LA and NP functions, generally all the subjects are situated within their respective dominant positions on the simplex plot, whereas the PA group displays a variation in functional ability. In the classification of the NP and PA functions, there is less clustering of the subjects, and two PA subjects exhibit characteristics of the NP hip function. The spread of PA subjects across the simplex plot suggest that the difference in function is not as clearly defined as for the NP and LA classification. This is supported by the results of the independent t tests displayed in Table 3. Six of the functional variables were significant in the comparison of the LA and NP groups, resulting in a clear divide in functional abilities, whereas only one significant result was produced in the comparison of NP and PA functions, indicating some similarities between the functions of the groups. The variables were unable to distinguish between LA and PA subjects. Although the t tests comparing LA and PA function determined the maximum frontal power and maximum frontal moment during the stance phase to be significant, the body of evidence responsible for the classification did not have sufficient positive or negative support to classify each subject correctly. Interestingly, when both surgical groups were classified against the NP function, a pattern emerged. For this classification, the NP and LA subjects were predominantly situated within their dominant regions, whereas the PA subjects were spread across the simplex plot with several subjects situated within the NP dominant region. This confirms that a difference between the post-operative functions of the two groups existed. The PA cohort exhibits patterns more characteristic of the NP function than the LA group did. Further work involving a larger cohort is required to determine whether these initial results are clinically relevant.

Initial results have determined clinically relevant measures that highlight a difference in functions following the two approaches. The posterior approach to THA appears to lead to a more stable function and greater ROM than does the LA. A classification method has been implemented to characterize functions. A visual output allows a straightforward comparison of subject functions. With further investigation of the input variables using a larger cohort, the classifier could be used to improve patient care by predicting surgical outcomes and monitoring post-operative function.

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