Biomechanical Analysis of Human Hip in Children with Hip Arthrodesis

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***Abstract*- The purpose of this work was to study the response of the gait of children who have had a hip arthrodesis. Nine patients (5 female - 4 male) whose average age is11 years and follow up of 2 to 6 year after the fusion, were evaluated. The gait analysis shows an increase of movement in both the sagittal and transverse plane. The 0° rotation of hip fusion is an ideal position to increase the step length of the contralateral hip as coping response, keeping the ipsilateral pelvis in external rotation.**

***Keywords*- Hip Kinetics; Hip Kinematics; Gait Biomechanics; Joints; Arthrodesis**

I. INTRODUCTION

The hip arthrodesis is still the most performed surgical procedure for active school children and teenagers with severe degenerative hip disease [10]. The total hip arthroplasty is a procedure used in patients with juvenile rheumatoid arthritis, although it is not recommended when the alteration is unilateral [5, 20]. The surgery aims at relieving pain by preventing movement while providing a supporting point (fulcrum) to the affected member. Moreover, description of the blood pressure changes on the lumbar region and ipsilateral knee [2, 4, 17] have also been made. The hip arthrodesis is indicated in:

- Young patients showing unilateral disease.
- Contralateral hip, knees and column are normal.
- Patients having no cardiovascular pathologies.

According to the functionality and wide acceptance of the series of Callaghan *et al.* [5] and Sponseller *et al.* [20]. Callaghan studied28 patients aged from 17 to 50 years (average 35) who have suffered an arthrodesis. Sixty percent of them reported backache problems twenty-five years (average) post-arthrodesis. Sixty percent reported pain in the ipsilateral knee, twenty-three years (average) after surgery. Twenty-five percent reported pain in the contralateral hip twenty years (average) post-arthrodesis, while six patients went through hip arthroplasty due to backache or knee problems. They all reported a considerable pain relief in their back but only 50% of them reported knee pain relief. Patients who had a fusion with a slight adduction showed gait improvement and reported less back and knee problems than those who had a fusion with a slight abduction. Sponseller *et al.* [20] carried out a follow-up study based on53 patients with hip arthrodesis for a 37-years-average-period. Seventy-eight percent were “satisfied” with the arthrodesis, 57% reported low to moderate pain in the lumbar region (symptoms appearance after 20 years), 45% reported pain in the ipsilateral knee, 17% reported pain in the contralateral hip and 13% required arthroplasty to relieve back or knee pains.

This paper presents the gait biomechanics study in young patients (children) with hip arthrodesis through the hip kinematic analysis to evaluate the joint ranges and time-space parameters.

II. MATERIALS AND METHODS

In this retrospective study, the medical histories of nine patients were revised (5 female, 4 male), who had been performed hip arthrodesis (6 in the left side and 3 in the right side) and aged between 7 and 16 years (average of 11 years). A post-fusion study was carried out with an average follow-up of 4 years and 3 months (2-6 years).

A. Preoperative Diagnosis

The preoperative diagnosis leading to hip osteonecrosis (see Figure 1) is described below:

- Septic arthritis
- Congenital dislocation of the hip
- Fracture of the cervical base
- Legg-Calvè-Perthes´s disease

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- Hip tuberculosis
- Proximal head epiphysiolisthesis

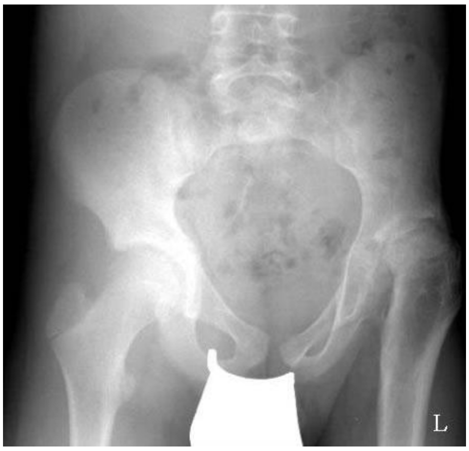

Fig. 1 Pelvis X-ray graph of a 14-years-old male with osteonecrosis in left hip

B. Surgical Technique

The surgical technique in 8 patients was performed as follows: anterior or posterior approach for hip dislocation and articular surface removal of the femur and acetabulum to obtain maximum surfaces contact [9, 13]. Hip transfixion screws were used as osteosynthesis material (Figure 2a), then they were inserted through the joint (in its back side) and at the top of the acetabular dome. Immobilization was carried out by using a plaster due to the little stability of the technique [1, 11, 20]. One case was treated by using a Cobra’s plate (Figure 2b). In other case, a contra-lateral epiphysiodesis to correct the length difference was also carried out.

(a) (b)

Figure 2 (a) Arthrodesis with transfixion screws,(b) Arthrodesis with Cobra ́s plate

C. Clinical Analysis of the Gait

A clinical gait analysis was performed on each patient, following the Gait Lab Protocol of the Children’s Orthopedic Hospital. The equipment used was a Vicon 370E System (Oxford Metrics LTD), with five infrared cameras (60 Hz) and three force plates AMTI OR-600 (Advanced Mechanical Technologies, Inc.).

Kinetic and kinematic variables were recorded for three walks with clean footprints, left and right over the force plates. The marker’s model used was the proposed by Kadaba*et al.* [11]that uses a knee alignment device (KAD) to determine the joint axis.

The clinical evaluation and markers placement were carried out by the physiotherapist, while the device calibrations and data recordings were performed by the biomedical engineer. The clinical guide, observations and interpretations were done by the orthopedists team. The study included a two dimensional video, physical test and biometric measurements of the patient and recordings of the kinetic and kinematic variables. The graphs were generated by the Vicon Clinical Manager (VCM, Oxford Metrics LTD) including the consistency analysis of the kinematics and kinetics for each member and also compared to the normal pattern of the sagittal, coronal and transverse planes. The normal pattern was compared to the one reported in technical literature, giving special attention to the movements of the pelvis [1,6,8].

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Measurements of pelvic inclination angles were carried out for maximum and minimum fusion angles and pelvic-movements ranges in the three planes. The data were used to obtain the corresponding statistics needed to get the correlation coefficient (ρ) between the flexion angles of hip fusion and the pelvic-inclination angles.

III. RESULTS

The obtained results are included in this section. Some figures have been added for helping in their interpretation. For the results reported in Table I, a correlation coefficient between the maximum pelvic inclination and the fusion angle of the hip was r=0.71 (p<<1).

TABLE I ANTERIOR MAXIMUM PELVIC TILT DURING THE GAIT CYCLE

Patient	**Side**	**Maximum anterior tilt (°)**	**% of the gait cycle**
1	R	33	47.36
2	R	25	51.70
3	R	30	44.00
4	L	34	50.00
5	L	23	46.00
6	L	25	51.70
7	L	29	48.30
8	L	22	44.00
9	L	20	48.30
	Average	26.78 ± 4.94	47.93 ± 2.91
	Maximum	34	51.70
	Minimum	20	44.00

For the results reported in Table II, a correlation coefficient between the minimum pelvictilt and the fusion angle of the hip was r=0.57 (p<<1).

TABLE II POSTERIOR MINIMUM PELVIC TILT DURING THE GAIT CYCLE

Patient	**Side**	**Minimum posterior tilt (°)**	**% of the gait cycle**
1	R	18	75.90
2	R	13	82.80
3	R	24	81.00
4	L	18	89.70
5	L	9	89.70
6	L	10	86.20
7	L	12	82.80
8	L	5	70.70
9	L	5	79.30
	Average	12.67 ± 6.36	82.01 ± 6.23
	Maximum	24	89.70
	Minimum	5	70.70

Other registered parameters such as the pelvic range of movements are collected in Table III. Table IV reports the results for the hip fusion, while the gait velocity and single support phase are shown in Table V.

TABLE III RANGE OF MOVEMENTS OF THE HIP

Patient	**Side**	**Sagittal (°)**	**Coronal (°)**	**Transverse (°)**
1	R	13	12	15
2	R	10	9	12
3	R	10	8	20
4	L	16	16	8
5	L	14	4	7
6	L	12	6	10
7	L	18	6	14
8	L	18	10	15
9	L	15	5	15
	Average	14.00±3.04	8.44±3.81	12.89±4.08
	Maximum	18	16	20
	Minimum	10	4	7
	Normal	3 ± 2	7 ± 3	10 ± 4

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TABLE IV HIP FUSION LOCATION

Patient	Side	Flexion (°)	Internal rotation (°)	External rotation (°)	Abduction (°)	Adduct. (°)
1	R	15	10	-	5	-
2	R	20	-	35	5	-
3	R	27	-	10	20	-
4	L	50	-	10	20	-
5	L	10	-	20	-	4
6	L	15	-	35	-	5
7	L	30	-	10	5	-
* 8	L	10	0	-	5	-
* 9	L	15	-	20	5	-
	Average	21.33 ± 12.79	5.00 ± 7.07	20.00 ± 11.18	9.29 ± 7.32	4.50 ± 0.71
	Maximum	50	10	35	20	5
	Minimum	10	0	10	5	4

* external tibial torsion detected.

TABLE V GAIT VELOCITY AND SINGLE SUPPORT PHASE

Patient	Side	GAIT VELOCITY (m/sec)		CONTRALATERAL SINGLE SUPPORT (sec)
		Fused side	Contralateral	Simple support
		0.94	0.94	0.42
1	R	1.04	1.05	0.38
		0.87	0.89	0.43
2	R	0.83	0.85	0.48
		0.84	0.82	0.52
		1.11	1.11	0.38
3	R	1.19	1.19	0.40
		1.24	1.24	0.45
		0.78	0.79	0.53
4	L	0.72	0.75	0.57
		0.83	0.78	0.55
		0.84	0.83	0.50
5	L	0.85	0.83	0.45
		0.80	0.79	0.55
		0.83	0.83	0.42
6	L	0.87	0.87	0.42
		0.91	0.91	0.43
		0.68	0.75	0.38
7	L	0.63	0.65	0.48
		0.81	0.82	0.04
		1.22	1.20	0.35
8	L	1.14	1.09	0.40
		1.39	1.30	0.32
		1.22	0.96	0.52
9	L	1.14	0.92	0.52
		0.89	0.99	0.48
	Average	0.95 ± 0.20	0.93 ± 0.17	0.44 ± 0.10
	max	1.39	1.3	0.57
	min	0.63	0.65	0.04
	Normal	1.21	1.21	0.34
	% with respect to normal	78.23	76.76	128.62
	Difference	21.77	23.24	-28.62

Figures 3 to 5 show the Pelvic Tilt, the Pelvic Obliquity and the Pelvic Rotation, respectively. Figures 3, 4 and 5 (top) display the evolution of the variable, while Figures 3, 4 and 5 (bottom) are the consistency graphs. In all figures vertical lines are as follows: dashed-line represents the right limb toe-off while continuous-line represents the left limb toe-off. The thin-continuous line at 62% of the gait cycle stands for normal toe-off.

PELVIC TILT

An increment of 10° to 15° in hip movements in the sagittal plane can be observed in the graphs below. Two effects can also be detected: a pelvic maximum anterior tilt immediately after toe-off and a maximum simultaneous posterior tilt during the swing of the fused hip [15], as shown in Figure 3:

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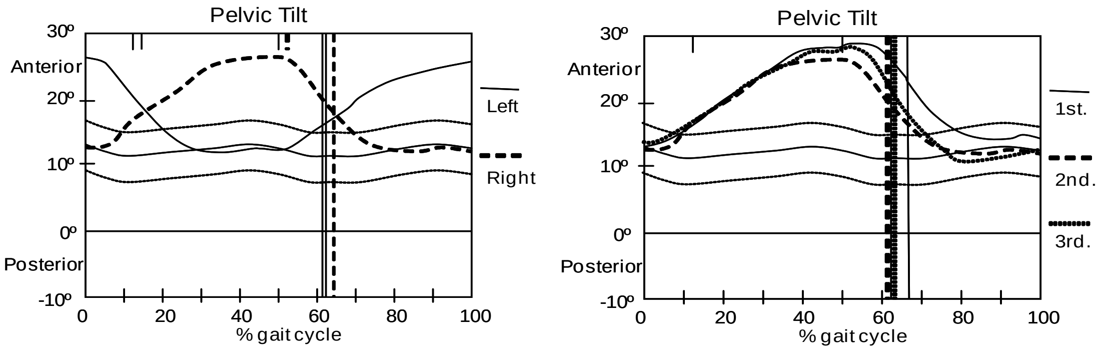

Figure 3 Pelvic tilt
Top: Left (continuous line), Right (dashed line)
Bottom: consistency

PELVIC OBLIQUITY

There seems to be no increments in the frontal plane (except for 2 cases). A slight pelvic obliquity and a prolongation of the stance phase in the contralateral side is observed (around 5 º to 15 º), as displayed in Figure 4 (top) by the vertical dashed line, near to 10 º after the fingers normal toe-off (62% of the gait cycle).

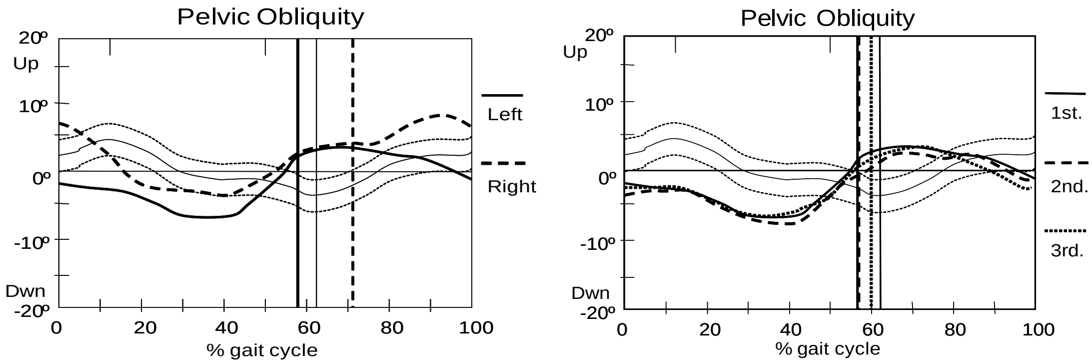

Figure 4 Pelvic obliquity
Top: Left (fused, continuous line), Right (dashed line)
Bottom: consistency

PELVIC ROTATION

An increment over 10 º to 15 º in the transverse plane was observed near 50% of the gait cycle, as shown in Figure 5 (top). Also, a reduction of the stance phase of the affected side can be noted, as shown in Figure 5 (top) by the vertical dashed line near 10 º before the fingers normal toe-off (62% of the gait cycle).

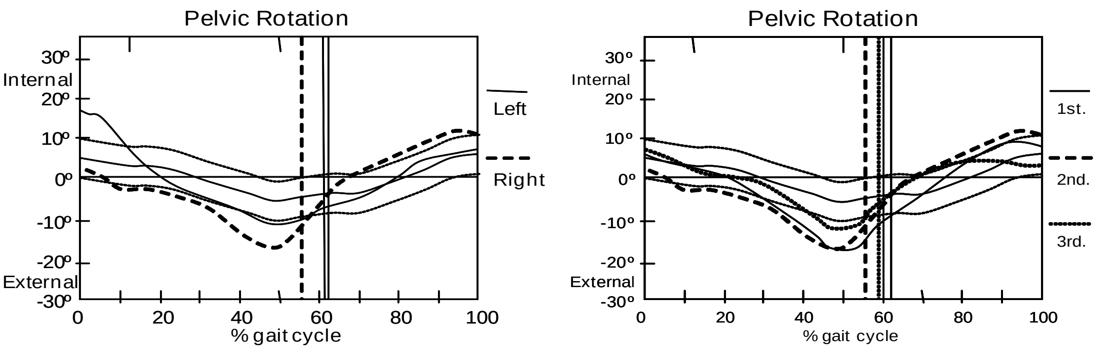

Figure 5 Pelvic rotation
Top: Left (continuous line), Right (fused, dashed line)
Bottom: consistency

Some problems in the swing can be observed in those cases where the fusion was less than 20 º. An increment of the pelvic obliquity was observed as well. This effect has also been described by Perry [16].

The ideal position for fusion is a flexion of 20 º to 25 º, external rotation of 0 º to 5 º and 0 º to 5 º in adduction, due to biomechanical advantages during the gait [5,12]. Such location looks forward the minimization of the excessive movement of

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the lumbar spine and of the knee. More than 10 º in abduction/adduction of the hip could lead to knee instability in varus/valgus respectively.

Other relevant aspects are: a) an average gait velocity around 80% of the normal gait velocity(see Table V)and b) a shortening of the step-length in the fused side which ranges from 0.5 to 0.6 cm. All patients presented muscle atrophy and according to clinical examination, three of the nine cases reported medial-side laxity and upper-anterior instability of the ipsilateral knee[15].

IV. DISCUSSION AND CONCLUDING REMARKS

Hip arthrodesis remains as a valid alternative for the treatment of either children or young adolescents. However, advances in endoprostheses usually lead to variations in the functional criteria used in arthroplasty. The main drawback of this technique lies on its weak fixation due to the large lever arm and the resulting torque. This requires the immobilization using plasters to avoid the fracture consolidation at undesired positions [1,11,20]. Some authors recommend either acetabular or subtrochanteric osteotomy to improve the position [21]. However, these procedures were not carried out in any of the cases considered herein. In this work, some complications observed were the bad position (the most frequent), lower-extremities length differences (all cases), lack of fusion (one case), column and knee pain (three cases).

Large flexion arthrodesis may cause an excessive lumbar lordosis to compensate this last effect, increasing the movements into the sagittal plane. The correlation results (Tables I and II) show that the larger the flexion in the fusion is, the larger the anterior pelvic inclination gets. The value of r=0.71 (anterior maximum pelvic tilt) is in reasonable agreement with the value of r=0.75of Õunpuu*et al.* [15]and may be the cause of back's pain. It is important to emphasize that among the time-space variables, the gait velocity stands out representing in average 78.2% of the regular value, also in good agreement to the 84% reportedby Õunpuu*et al.* [15].

The revision shows that the hip-fusion location suggested by other authors in 0 º rotation [5,12,15,20]allows the patient to increment the step length of the healthy side in order to compensate the inability to extend the fused member, then holding the pelvis of this side at an external position regarding the progression line. All the cases presented an exaggerated external-fusion rotation, greater than 10 º and/or they presented an external tibial torsion, as occurred in the series used in this research. The pelvic pattern behaved in the contrary sense, which determine the position of the ipsilateral pelvis to be internal, thus increasing the movements into the transverse plane from 10 º to 15 º (see Figure 5).

The increment of the movements of the pelvis and the lumbar spine into both the sagittal and transverse planes are also responses to the lack of movement of the hip. The use of the abdominals, combined with the mobility of the back, determines the range of movements forward the member during the initial swing. The knee and ankle adaptation hide the difference in length and the lack of movement of the hip [15].

This increment of movement of lumbar spine seems to be positively related with pain, such as reported by previous studies [5,20]. The difference in length yielded by the interruption of the proximal femoral epiphysis has negative effects on the gait biomechanics. The epiphysiodesis of the distal epiphysis of the contralateral femur must be considered at a suitable age, in order to minimize the discrepancy between the lower limbs. The reduction in the leg-length difference allows the free swing of the foot without the need to raise the ipsilateral half-pelvis. This is in good agreement with findings reported in technical literature [3,5,12,14,15,18,20].

Movements of 9 º in the fused hip were accepted as artifacts (Bennett *et al.* [4]), possibly due to a)the vibration of upper-anterior iliac spines and the sacrum markers and b) to the movement of both soft tissue and lumbar spine. The authors suggest to recalculate the hip rotation-center by using alternative methods (for instance, using the length between the upper-anterior iliac spines in correlation with the distance from the main trochanter to the upper-anterior iliac spine and the length of the lower members, in agreement to that discussed by Davis *et al.* [7]). Because of the hip reconfigurations produced by the pathologies [22] and the arthrodesis itself, it is possible that this rotation center will be located before its effective position, thus giving unrealistic hip extensions (2 º-3 º).

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