

Original Articles

Salter pelvic osteotomy for the treatment of Developmental Dysplasia of the Hip: assessment of postoperative results and risk factors.

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Background

If non-surgical treatment of Developmental Dysplasia of the Hip (DDH) fails or if DDH is late-detected, surgery is necessary. Salter pelvic osteotomy (SPO) is an effective surgical option for such cases.

Objectives

To study the results after SPO; to evaluate risk factors; to reveal radiological parameters that may correlate with results.

Methods

Results analysis in 17 patients (22 hips). Risk factors included those that do not depend on the surgeon (patient's age, value of the acetabular index (AI) preoperatively, DDH Tonnis grade) and those that depend on the surgeon (amount of AI correction). To radiological parameters which may correlate with the amount of AI correction we referred distance "d" and the lateral rotation angle.

Results

SPO allows performing AI correction in ranges $24.1 \pm 6.5^\circ$. Excellent and good clinical results were obtained in 95.5% of patients; excellent and good radiological results in 86.4% of patients. Risk factors that do not depend on the surgeon were older patient's age and higher preoperative AI values ($p < 0.05$). The risk factor that depends on the surgeon was the amount of AI correction ($p < 0.05$). The distance "d" was recognized as a radiological parameter that may indicate sufficient AI correction ($p < 0.05$).

Conclusion

In older patients with a higher preoperative AI value the results will be predictably worse. The surgeon may influence the result with a greater amount of AI correction (which may also be indicated radiologically by the distance "d" values).

Level of evidence

IV, therapeutic, case series.

BACKGROUND

Developmental Dysplasia of the Hip (DDH) is the commonest hip joint pathology in neonates.¹ According to the natural history, DDH leads to early hip arthritis.² If DDH is detected in non-walking patients, non-surgical treatment (using abduction braces) is highly effective.¹ However, even after the successful femoral head concentric reduction, residual acetabular dysplasia will occur in 26% of patients.³ Moreover, in older patients (who started to walk), concentric reduction of the femoral head is difficult to achieve

with non-surgical methods due to the adaptive contracture of the surrounding muscles and hypertrophy of intra-articular structures; 66% of these patients will further require surgery.⁴ Thus, surgical treatment is mandatory for residual acetabular dysplasia after failed non-surgical treatment and for late-detected DDH.¹⁻⁴

There are different surgical options for DDH treatment: isolated femoral head open reduction, femoral varus derotational osteotomy (FVDO), different pelvic osteotomies, and the combination of all aforementioned procedures (sin-

gle-stage surgery - SSS).^{2,4} However, better results were detected after pelvic osteotomies or SSS.^{5,6}

A widely used and effective pelvic osteotomy for DDH treatment is Salter pelvic osteotomy (SPO).⁷⁻⁹ It presents itself as a complete iliac bone cut with distal fragment displacement distally, anteriorly and laterally.¹⁰ Excellent and good results may be achieved after SPO. The most common complications after SPO are avascular necrosis (AVN) of the femoral head (from 3.3%¹¹ to 43%⁸) and residual acetabular dysplasia (from 3.3%¹² to 22%¹³).

Currently, there are attempts to reveal risk factors that may lead to worse postoperative results. Different authors have referred to risk factors older patient's age,^{11,13,14} higher DDH grades (according to Tonnis classification),¹⁵ bilateral DDH,¹⁶ insufficient distal iliac fragment movement during surgery (distance "d", c/b ratio, lateral rotation angle - LRA).¹⁷⁻¹⁹

The purposes of this article were:

1. to assess the postoperative results after SPO
2. to reveal risk factors that may lead to worse results after SPO
3. to reveal radiological parameters that may correlate with results

METHODS

Institutional ethics board committee approval for patients' personal data collection, processing, and further publication was obtained (protocol No. 3, from 4.10.2021).

We selected 17 patients (22 hips) with DDH, who underwent SPO during the 2015-2020 years. Among these patients, 16 were girls (21 hips - 95.5%), and 1 was a boy (1 hip - 4.5%). The left hip joint was affected in 15 cases (68.2%), the right hip joint was affected in 7 cases (31.8%); bilateral DDH was in 5 patients - 22.7% (all girls). The mean patients' age at surgery was 4.1 ± 1.3 (2-6) years old. The mean follow-up period was 5.5 ± 3.5 (2-12) years. Grade 1 DDH (according to Tonnis classification) was present in 1 case (4.5%), grade 2 - in 5 cases (22.7%), grade 3 - in 4 cases (18.2%), grade 4 - in 12 cases (54.6%). In 2 cases only SPO was performed (9.1%), in 5 cases it was a combination of SPO+ FVDO (22.7%), single-stage surgery was performed in 15 cases (68.2%).

Indications for SPO were the following: the presence of acetabular dysplasia (patients older than 2 years old with acetabular index - AI values $\geq 30^\circ$); patients' age from 2 to 6 years old. Open reduction of the FH was applied if the FH concentric position was not achieved with closed reduction and was routinely used in all patients with DDH Tonnis 3-4. Proximal femoral shortening osteotomy was applied if excessive pressure on the FH was detected during the open reduction; FVDO was added if the neck-shaft angle was $\geq 150^\circ$ and/or femoral anteversion $\geq 50^\circ$. In the case of bilateral DDH first surgery was performed on the more affected side and in 6-9 months on the other side.

All patients were examined clinically and radiologically before and after the surgery. Before the surgery, the following radiological parameters were assessed: AI, Tonnis grade, and Shenton line integrity. The next day after the

surgery AI was measured and Shenton line integrity was assessed; additionally, the amount of AI correction was calculated. At 6 months after the surgery AI was measured; also, signs of femoral head AVN were detected. At follow-up AI and Wiberg centre-edge angle (CEA) were measured; the consequences of AVN were detected and classified according to Bucholz and Ogden classification. At follow-up, radiological results were graded according to Severin classification.² We rated the I class as excellent results, II class - as good results, III class - as fair results, classes IV-VI - as poor results.

Clinical outcomes were assessed at follow-up according to McKay's criteria,⁴ where I grade represents excellent results, II grade - good results, III grade - fair results, IV grade - poor results (Table 1).

All possible risk factors we divided into those that do not depend on the surgeon's skills (patient's age, DDH Tonnis grade, acetabular deformity - preoperative AI value) and that depend on the surgeon's skills (the amount of AI correction). The amount of AI correction indirectly indicates the degree of iliac bone distal fragment displacement laterally and distally. To the radiological parameters that may correlate with the amount of AI correction, we referred the distance "d" and the lateral rotation angle (LRA) as described by others.^{18,19} The presence of bilateral DDH was not considered as a risk factor, because the postoperative results are not worse, but rather asymmetric according to Li, H. et al.¹⁶ (in fact, one side underwent surgery in a younger patient and the other side in the same patient but at an older age; thus, the patient's age is a primary risk factor).

To estimate the impact of one factor on another, the correlation (the strength of two independent factors' relationships) and linear regression (the influence of one factor on another) were calculated. Correlation may be positive with a "+" sign or negative with "-" sign; correlation is negligible if it is <0.3 , low if it is 0.3-0.5, moderate if 0.5-0.7 and strong if >0.7 .²⁰ Results with $p < 0.05$ were considered statistically significant.

For reviewing CT-scans software "Medixant. RadiAnt DICOM Viewer [Software]. Version 2020.1. Mar 9, 2020. URL: <https://www.radiantviewer.com>" was used.

Statistical analysis: to perform the abovementioned calculations JASP Team (2020). JASP (Version 0.11.1.0)[Computer software] was used.

RESULTS

The mean AI before the surgery was $39.5 \pm 6.8^\circ$ (29-56), immediately after surgery it was $24.1 \pm 6.5^\circ$ (15-39), the amount of AI correction was $15.4 \pm 6.8^\circ$ (4-32), AI value at 6 months after surgery was $20.1 \pm 7.2^\circ$ (9-36), AI value at follow-up was $14.9 \pm 8.7^\circ$ (0-37).

Shenton line was broken in all the patients before the surgery; it was restored postoperatively in 20 cases (90.9%), and non-restored in 2 patients (9.1%) after surgery.

An average CEA at follow-up was $23.5 \pm 9.4^\circ$ (4-50).

Femoral head AVN was present in 11 cases (50%): type I according to Bucholz and Ogden classification in 7 cases

Table 1. Clinical and radiological outcomes gradation according to McKay's criteria and Severin classification.

McKay's criteria		
Grade	Rating	Description
I	Excellent	Painless, stable hip; no limp; more than 15 degrees of internal rotation
II	Good	Painless, stable hip; slight limp or decreased motion; negative Trendelenburg's sign
III	Fair	Minimum pain; moderate stiffness; positive Trendelenburg's sign
IV	Poor	Significant pain
Severin classification		
Class	Description	Center-edge angle (Degrees)
I	Normal appearance	≥ 15 (5-13 years) ≥ 20 (> 14 years)
II	Mild deformity of the femoral head and neck or the acetabulum	≥ 15 (5-13 years) ≥ 20 (> 14 years)
III	Dysplasia or moderate deformity of the femoral head and neck or the acetabulum, or both	< 15 (5-13 years) < 20 (> 14 years)
IV	Subluxation of the femoral head	-
V	Articulation of the femoral head with a false acetabulum	-
VI	Redislocation	-

(31.8%), type II - 0 cases (0%), type III - 1 case (4.5%), type IV - 3 cases (13.7%). We explained such a high incidence of femoral head AVN by the prevalence of patients with DDH grade 4 Tonnis in this study (during FH open reduction there is excessive pressure on the FH by acetabulum).

The clinical results at follow-up were excellent according to McKay's criteria in 13 cases (59.1%), good in 8 cases (36.4%), and fair in 1 case (4.5%); there were no patients with poor results.

The radiological results at follow-up were excellent according to Severin criteria in 11 cases (50%), good in 8 cases (36.4%), fair in 2 cases (9.1%) and poor in 1 case (4.5%).

Mean distance "d" was 6.6 ± 4.8 (0-23) mm. The mean LRA was $28.3 \pm 13.1^\circ$ (12-61).

The patient's preoperative characteristics and postoperative results are presented in [Table 2](#).

When investigating the impact of a patient's age on clinical and radiological results at follow-up (according to McKay's classification and Severin criteria), it was revealed that it has a moderate negative correlation with clinical results ($R = 0.541$), linear regression was statistically significant ($p = 0.009$). Similarly, it was a moderate negative correlation between the patient's age with radiological results ($R = 0.66$) and, linear regression was too statistically significant ($p < .001$). Thus, in older patients results are predictably worse.

Regarding the acetabular deformity (preoperative AI value) impact on clinical and radiological results at follow-up, it was found, that it has a weak negative correlation with clinical results ($R = 0.49$), linear regression was statis-

tically significant ($p = 0.021$). Similarly, a moderate negative correlation was found between the preoperative AI values and radiological results ($R = 0.509$), linear regression was statistically significant ($p = 0.015$). Thus, patients with larger preoperative AI values, have a higher probability of worse outcomes.

The impact of DDH Tonnis grade on clinical and radiological results at follow-up was statistically insignificant (McKay's classification - $p = 0.166$; Severin criteria - $p = 0.138$).

AI correction amount impact on clinical and radiological results at follow-up was proved. It had a moderate positive correlation with clinical results ($R = 0.5$), linear regression was statistically significant ($p = 0.018$). Similarly, a moderate positive correlation was found between the amount of AI correction and radiological results ($R = 0.523$), and linear regression was statistically significant ($p = 0.013$). Thus, patients with a lower AI correction have a higher risk of worse clinical outcomes.

Evaluating the correlation between radiological parameters that represent distal iliac fragment displacement during surgery (distance "d", LRA) with the amount of AI correction, we've revealed that distance "d" has a weak positive statistically significant correlation with the amount of AI correction ($R = 0.45$, $p = 0.036$). Regarding the effect of LRA on the amount of AI correction - we didn't find it.

An interesting fact was revealed after the results: both patients with non-restored Shenton line postoperatively have had worse results.

Table 2. Patient's preoperative characteristics and postoperative results (S – side; A – age; f-up – follow-up; T.dr – Tonnis grade; surg – surgery; M-K – McKay's classification; Sev – Severin criteria; Sh.l – Shenton line ("–" – if non-restored, "+" – if restored); bef – before the surgery; aft – after the surgery; corr – correction; 6 m. – 6 months).

Nº	sex	S	A	f-up	T.gr	surg	M-K	Sev	Sh.l	bef	aft	AI	bef	aft	corr	6m	f-up	CEA	AVN	LRA	d
1	M	L	4	2	4	SSS	2	2		-	+		40	29	11	25	23	18	1	22	6
2	F	L	3	5	2	SPO+ FVDO	1	1		-	+		32	22	10	20	6	28	1	25	4
3	F	L	3	12	4	SSS	1	1		-	+		36	19	17	10	0	50	4	61	1
4	F	L	5	2	3	SSS	2	2		-	+		45	25	20	25	24	15		36	23
5	F	L	3	12	2	SPO+ FVDO	1	1		-	+		37	24	13	20	9	30		29	8
6	F	R	3	12	4	SSS	1	1		-	+		42	21	21	22	8	31	1	30	9
7	F	L	4	2	1	SPO+ FVDO	1	1		-	+		30	15	14	15	11	29		29	6
8	F	R	6	5	2	SPO	2	3		-	+		32	24	8	23	18	5		19	8
9	F	L	5	6	4	SSS	1	2		-	+		50	18	32	16	11	19	1	18	5
10	F	L	6	3	4	SSS	2	2		-	+		43	26	17	23	12	26	4	17	6
11	F	R	6	3	4	SSS	2	2		-	+		37	26	11	26	13	23	4	27	5
12	F	L	5	5	4	SSS	1	1		-	+		49	32	17	20	15	24		26	11
13	F	R	6	4	4	SSS	3	4		-	-		56	32	24	36	37	4	1	20	9
14	F	R	3	10	3	SSS	1	1		-	+		36	17	19	12	8	23		37	7
15	F	L	3	10	3	SSS	1	1		-	+		37	22	15	15	10	28		15	6
16	F	L	4	4	4	SSS	2	3		-	-		43	39	4	36	28	16		21	0
17	F	L	4	2	4	SSS	2	2		-	+		43	15	28	9	9	22	1	55	11
18	F	L	6	2	4	SSS	1	2		-	+		36	27	9	23	18	26		18	5
19	F	R	3	3	3	SSS	2	2		-	+		42	34	8	31	29	18	1	18	0
20	F	L	4	7	4	SSS	1	1		-	+		42	28	14	25	11	27	3	46	5
21	F	L	2	5	2	SPO+ FVDO	1	1		-	+		31	15	16	12	14	26		42	8
22	F	R	2	5	2	SPO+ FVDO	1	1		-	+		32	21	11	16	14	27		12	2
AV			4.1	5.5									39.5	24.1	15.4	20.1	14.9	23.5		28.3	6.6

DISCUSSION

DDH is a common hip pathology in neonates; without treatment, it leads to early hip arthritis. Early detected DDH may be successfully treated using abduction braces; however, in walking patients or after failed conservative management, surgery is required. Salter pelvic osteotomy (SPO) is a commonly used surgical option for this purpose. There are debates about certain risk factors that may lead to unsatisfactory outcomes after SPO. Results after SPO usually are good.

There are different proposed risk factors, that may lead to unsatisfactory results after SPO. We divided these factors into two categories: 1) those, that do not depend on the surgeon's skills - patient's age, DDH Tonnis grade, acetabular deformity degree; 2) those, that depend on the surgeon's skills (the amount of the distal iliac bone fragment displacement distally and laterally = the amount of AI correction). Radiological markers that may correlate with the amount of AI correction were distance "d" and lateral rotation angle (LRA).

In this study, we assessed medium- and long-term outcomes after SPO (mean follow-up period - 5.5 ± 3.5 years). The percentage of excellent and good clinical (McKay I & II) and radiological results (Severin I & II) at follow-up was 95.5% and 86.4%, respectively; the mean AI value at follow-up was 14.9 ± 8 . mean the CEA value at follow-up was $23.5 \pm 9.4^\circ$. The results of this study are similar to the results of other authors (Table 3).

Determining risk factors that don't depend on the surgeon's skills we've found that patient age and acetabular deformity degree (preoperative AI value) affect clinical and radiological outcomes (older patients with higher preoperative AI values had worse results) – Figure 1. This confirms the statement of Chen Q. et al.,¹¹ El-Sayed, M. et al.,¹² and Kotzias Neto A et al.¹⁵ who've stated better results after SPO in patients younger than 4 years old and more complications in older patients. But, our results contradict Baghdad T et al.²⁹ and Da Rocha, V. L. et al.²⁸ who found no difference in outcomes in patients younger and older than 3 years old and the same complications rate in younger and older patients.

Also, we found a statistically significant negative impact of acetabular deformity (preoperative AI value) on results, this fact wasn't described previously.

In this study, we didn't find the influence of the DDH Tonnis grade on results, which contradicts El-Sayed, M. et al.¹² and Kotzias Neto A et al.¹⁵ (who described worse results and higher complications rate in patients with higher DDH grades). We believe that the preoperative AI value gives the surgeon more objective information about acetabular deformity than the Tonnis classification and may become a better predictor of SPO result (Tonnis classification represents femoral head position according to the acetabulum rather than the acetabular deformity itself).

When assessing the risk factor that depends on the surgeon's skills (distal iliac bone fragment displacement distally and laterally = amount of AI correction) we found out, that the amount of AI correction had a statistically signifi-

cant impact on clinical and radiological results – Figure 2. Thus, larger distal iliac bone fragment displacement during surgery leads to better results. This also has not been previously described in the literature.

Trying to find the radiological parameters that may correlate with the amount of AI correction, we've found out that distance "d" may become this parameter. This confirms the results of Kitoh, H. et al.¹⁸ and Kaneko, H. et al.¹⁹ (who found better results in patients with distance "d" greater than 3.5 mm). However, we didn't find a statistically significant correlation between the LRA and the amount of AI correction, which doesn't correspond with Kitoh, H. et al.¹⁸ results.

Also, we think that the non-restored Shenton line post-operatively may lead to worse results. However, this line presents itself as a complex interplay between the proximal femur and obturator foramen. Thus, not only does SPO have an impact on Shenton line integrity, but also FVDO.

CONCLUSIONS

1. Risk factors that do not depend on the surgeon include the older patient's age and higher AI values preoperatively.
2. The risk factor that depends on the surgeon is the amount of AI correction.
3. Radiological parameter, which may indicate a sufficient amount of AI correction was revealed to be distance "d".

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Table 3. Results at follow-up after Salter pelvic osteotomy according to the literature data and this study.

Author (reference)	Results	
	Radiological	Clinical
Esmailnejad-Ganji, S. M. ¹	Severin I\II - 96.7%; AI - 11.24; CEA - 39.1	Mac-kay I\II - 94.5%
Bhuyan BK ²	Severin I\II - 83.4%; AI - 21°; CEA - 23.5°	Mac-kay I\II - 90%
Gurger, M. ³	Severin I\II - 100%; AI - 18.0; CEA - 39.0	Mac-kay I\II - 100%
Ahmed, E. ⁴	Severin I\II - 76.8%; AI - 19°; CEA - 26°	Mac-kay I\II - 80.8%
Spence, G. ⁵	AI - 11.55 ± 1.3°	
Da Rocha, V. L. ⁷	Severin I\II - 69.2%; AI - 18.5°	Dutoit (excellent +good) - 92.3%
Kobayashi, D ⁸	CEA - 27 ± 10°	Harris hip score - 99 ± 3
Morita, M. ⁹	AI - 16.4 ± 4.9°; CEA - 23.7 ± 5.1°	
Chen Q ¹¹	Severin I\II - 83.3%; AI - 21±2°; CEA - 23.5°	Mac-kay I\II - 90%
Liu TJ ¹⁴	Severin I\II - 84%; AI - 14°; CEA - 26°	
Kotzias N A ¹⁵	Severin I\II - 66.7% ; AI - 18.2±6.3°	
Agus, H ¹⁶	AI - 10.25±2°	Mac-kay I\II - 83.8%
Chang, C.-H. ¹⁷	Severin I\II - 85.7%; AI - 12.6°; CEA - 29.4°	
Kitoh, H. ¹⁸	Severin I\II - 91.7%; AI - 20.7°; CEA - 20.7°	
Kaneko, H. ¹⁹	Severin I\II - 87%	
Xie X ²¹	Severin I\II - 97.6%	Mac-kay I\II - 98.3%
Ahmed K ²²	Severin I\II - 90%	Mac-kay I\II - 89.5%
Hedelin H ²³	AI - 12.2°; CEA - 29°	
Ertürk, C. ²⁴	AI - 19.71°; CEA - 28.51°	
Wang, C.-W. ²⁵	AI - 12°; CEA - 44°	
Bayhan, I. A. ²⁶	Severin I\II - 92%; AI - 12 ± 8°; CEA - 30 ± 9°	Mac-kay I\II - 92%
Morin, C. ²⁷	Severin I\II - 96.3%; AI - 12 ± 8°; CEA - 29°	Harris hip score - 94.5
Da Rocha, V. L. ²⁸	Severin I\II - 88.9%; CEA - 20.7± 5.02°	Dutoit (excellent+good) - 83.3%
This study	Severin I\II - 86.4%; AI - 14.9 ± 9°; CEA - 23.5± 9°	Mac-kay I\II - 95.5%

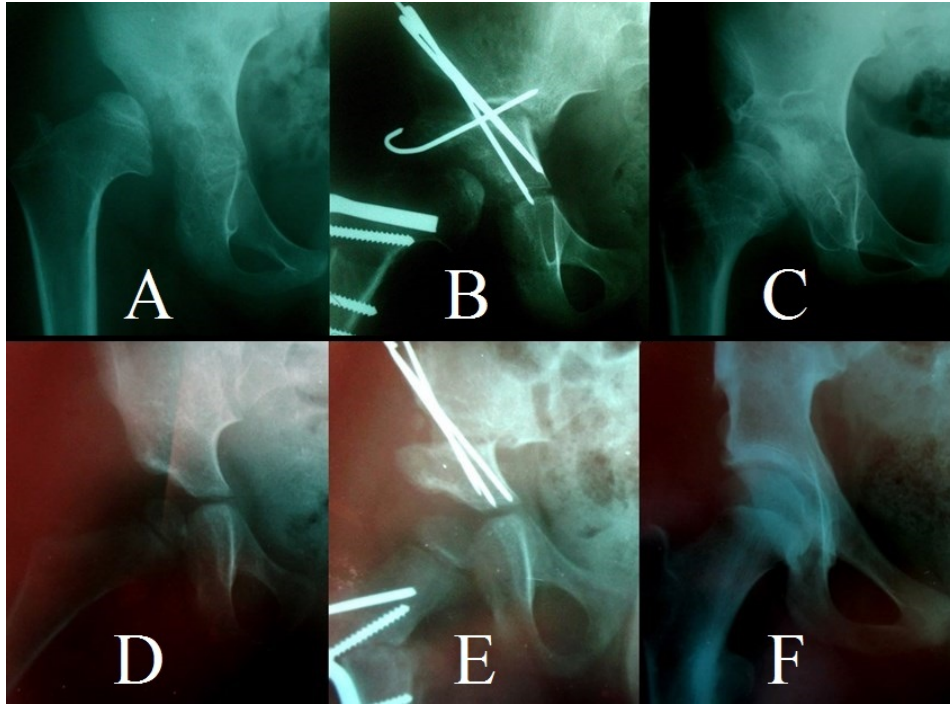


Figure 1. Impact of factors that do not depend on the surgeon's skills (patient's age, acetabular deformity) on the radiological result.

Upper row – 6-years old patient, AI preoperatively - 56° - A. Despite the good AI correction (24°) and sufficient displacement of the distal iliac fragment during surgery (distance "d" - 9 mm) - B, radiological results at follow-up are poor according to Severin classification (class IV) - C. Lower row – 3-years old patient, AI preoperatively - 37° (D). With a lesser AI correction (13°) and almost the same lateralization of the distal iliac fragment (distance "d" - 8 mm) - E, radiological results at follow-up are excellent according to Severin classification (class I) - F.

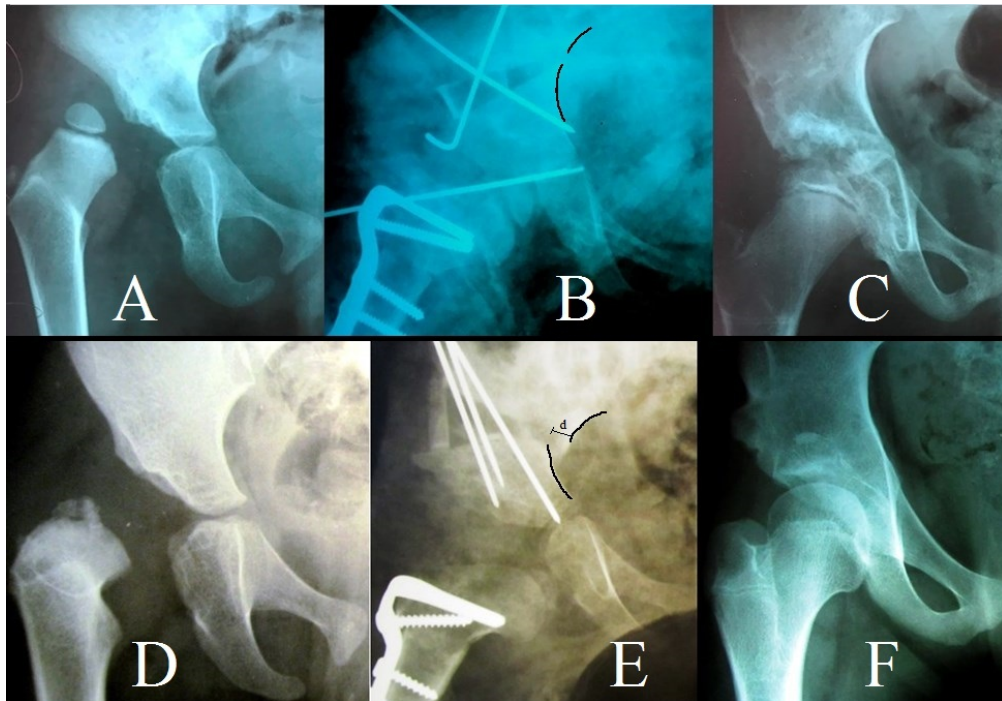


Figure 2. Impact of factor that depends on the surgeon's skills (amount of AI correction) on the radiological result.

Upper row – 3-years old patient, AI preoperatively - 42° - A. After the surgery - the amount of AI correction is low (8°) and absent distal iliac fragment lateralization (distance "d" - 0 mm) - B; radiological results at follow-up are fair according to Severin classification (class III) - C. Lower row – 3-years old patient, AI preoperatively - 42° - D. After the surgery - the amount of AI correction is good (21°), lateralization of a distal iliac fragment is satisfactory (distance "d" - 9 mm) - E; radiological results at follow-up are excellent according to Severin classification (class I) - F.

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