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Title: Halo femoral traction for one week between staged anterior and posterior fusion surgeries for severe adolescent scoliosis is effective and safe

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Keywords: Spine, Scoliosis, Fusion, Deformity, Neurology

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Conclusion: Three staged deformity correction using HFT for one week only offers gradual correction of the spine over sufficient time to optimise deformity correction yet minimises neurological dysfunction.

Dear editorial team

Thank you for considering our article for publication. This study reports our experience with Halo Femoral Traction (HFT) used for one week between anterior release and definitive posterior fusion in adolescents with severe rigid scoliosis.

I, David Kieser, certify that this manuscript is a unique submission and is not being considered for publication, in part or in full, with any other source in any medium.

The authors declare no conflict of interest and that no funding was received for this research. This article is not under consideration elsewhere.

Kind regards

*Title Page

Halo femoral traction for one week between staged anterior and posterior fusion surgeries for severe adolescent scoliosis is effective and safe

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Short title: Short interval traction for scoliosis surgery

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***Abbreviations**

Abbreviations:

AIS: Adolescent Idiopathic Scoliosis

APVCR: Anterior-posterior vertebral column resection

HFT: Halo femoral traction

ICU: Intensive care unit

NMS: Neuromuscular scoliosis

NF1: Neurofibromatosis 1

PA: Posterior-anterior

PVCR: Posterior vertebral column resection

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Introduction

The surgical treatment of severe adolescent scoliosis is challenging despite the multitude of described techniques. Historically isolated posterior approaches were used, but in 1969 Dwyer first proposed an anterior approach as a method of making large, stiff thoracic curves more pliable[1]. With the advent of enhanced pedicle screw systems and the capacity of three-dimensional spinal correction, isolated posterior approaches have again regained favour. However, in severe rigid deformities the ideal approach remains debated with previous studies suggesting that there is no significant difference in the degree of spinal correction or the complication rate between anterior, posterior or combined approaches[2,3].

Furthermore, debate between more rapid single staged or more gradual deformity correction with the use of traction in severe scoliotic curves remains, with the proponents of traction suggesting that it offers greater deformity correction and lower neural complications[4,5]. Halo Femoral Traction (HFT) was first proposed half a century ago to permit gradual correction of spinal deformities and restoration of truncal balance[6-8]. At our institution we have used HFT as an adjunct to deformity correction and in severe rigid curves with an anterior release prior to HFT to maximise the correction prior to definitive posterior fusion. This approach has been reported by others and shown to offer excellent curve corrections[7,9]. However, the duration and degree of traction remains unclear.

In our institution we employ a three staged correction for stiff severe adolescent curves which involves a first stage of anterior release, followed by a second stage of HFT for seven days, obtaining a minimum of a third of body weight traction, and then culminating in the third stage of posterior instrumented fusion. In this study we assess the deformity correction and complications of consecutive adolescent patients with severe rigid scoliosis undergoing our three staged approach.

Methods

All adolescent patients who presented to our institution with severe, rigid scoliosis were offered a three staged deformity correction. The inclusion criteria for this study included; age greater than 10 years, severe scoliosis defined as a Cobb angle greater than 80°, rigid curves defined as less than 30% correction on standing bending views and/or bolster views and a minimum follow-up of two years. Patients were excluded if the pre-operative multi-disciplinary team or family felt that the patient would not tolerate one week of HFT.

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Second stage (Halo femoral traction): During the first stage the Halo frame with four pins is fixed to the skull and Steinman pins passed through distal femurs bilaterally (Figure 1). After surgery, patients are nursed on a RotoRest ™ bed (Kinetic Concepts Inc, Texas, USA) regularly rotating from side to side to improve comfort and avoid decubitus ulcers (Figure 2). All patients are admitted to the paediatric intensive care unit (ICU) for one night after the first stage procedure to optimise analgaesia and chest care, with removal of the chest drain, prior to being transferred to the ward. Flowtron boots are used for the first 24 hours after each surgery. Traction is commenced with 2-3 kg weight hung from the head and each leg. Traction force is increased gradually by adding weights in increments, depending on the patient's tolerance, over the course of seven days with the aim of providing 10-20% bodyweight on the second to third post-operative day and more than a third of the patient's body weight by the seventh day. The traction weight is defined as the cumulative weight applied to the head and both legs. Neurological function is constantly monitored, with twice daily doctor led and hourly nurse led neurological examinations, and any change in neurology leads to a reduction in traction weight. Pins around the head are cleaned daily to prevent infection and checked for tightness each day. While in traction, chest physiotherapy is performed daily, and all patients wear thromboembolic deterrent stockings and receive prophylactic heparin. All patients are catheterised, some require bowel management, and most require nasogastric or oral feeding supplementation in liaison with a dietician to ensure adequate nutrition.

Third stage (Posterior instrumented fusion): After seven days in HFT, posterior instrumented fusion surgery under multimodal spinal cord neuromonitoring is performed while maintaining HFT. A standard midline posterior approach is used with exposure of the posterior elements of the spine. Following satisfactory posterior release, a hybrid fixation technique is undertaken using bilateral rods, pedicle screws throughout and hooks superiorly where appropriate. Deformity correction is then performed with a combination of global and segmental de-rotation and translation. Posterior element autograft and synthetic bone graft substitute is then applied and the wounds closed. HFT is then removed.

Posterior-anterior (PA) long-cassette radiographs were obtained pre-operatively to determine the standing coronal Cobb angle, lateral bending Cobb angle and bolster bending Cobb angle. A supine anterior-posterior spinal radiograph was obtained prior to the third stage to determine the final traction Cobb angle. Standing PA long-cassette radiographs were obtained to evaluate the post-operative Cobb angles. Analysis of the percentage curve correction was obtained, the traction weight as a percentage of body weight and complications were performed using Microsoft Excel (Microsoft Corporation, Redmond, USA).

Results

Of those patients offered a three staged deformity correction all patients consented, resulting in 23 consecutive patients of which one was lost to follow-up with a satisfactory outcome after 11 months and was therefore excluded. This left 17 female and 5 male patients with a mean age of 14.1 years (range 11-18 years) and mean follow-up of 32 months being prospectively recruited between 2009 and 2015 (Table 1). Seventeen patients had adolescent idiopathic scoliosis (AIS), four had neuromuscular scoliosis (NMS) and one had neurofibromatosis type 1 (NF1).

The mean pre-operative Cobb angle was 97° (range 80°-118°, s.d. 10), mean lateral bending Cobb angle 85° (range 70°-110°, s.d. 14) and mean bolster Cobb angle 76° (range 43°-105°, s.d. 15). The mean percentage correction was 12% on a bending view and 25% on a bolster view before surgery. Mean traction Cobb angle was 52° (range 35°- 69°, s.d. 11) after anterior release and seven days of HFT, an improvement of 49% was achieved (range 34-62%). The mean traction weight used by the end of the first day was 8.4 kg (19% of patient bodyweight). Mean final traction weight was 15.5 kg (36% of patient bodyweight). Following posterior spinal fusion surgery, the mean post-operative Cobb angle was 31° (range 16°-45°, s.d. 7) with a mean correction of 68% (range 60%-83%). At final follow-up, the deformity correction was maintained (mean Cobb angle 31°, s.d. 3.1°) (Figure 3 and 4).

Four patients experienced transient complications. These included one case of neck pain occurring on the last day of traction that resolved after removal of the HFT. One case of a left sided meralgia paraesthetica from the iliac crest bolsters during the definitive fusion that completely resolved within three months. Two cases of brachial plexopathy from traction that improved with traction weight reduction and were completely resolved by the two month clinic follow-up. No long-term complications occurred.

Discussion

Severe adolescent scoliosis remains a challenging surgical problem. Nevertheless, with the advances in spinal correction techniques and developments in instrumentation, more successful corrections can be achieved. However, surgical intervention for scoliosis aims to correct the spinal curvature to maintain and restore function and improve cosmesis without causing new deficits. We believe that interval HFT offers gradual correction of the curve to ensure maximal curve correction without causing permanent neurological dysfunction.

There are several studies reporting high correction percentages in severe adolescent scoliotic curves with varied surgical techniques. Shen and colleagues describe an anterior release and posterior hooks and pedicle screws in 24 cases and showed a final curve correction of 59%[10]. In contrast, Bullmann and colleagues used both anterior and posterior instrumentation in 33 patients achieving a 67% deformity correction[11]. Zhou and colleagues describe a staged anterior-posterior vertebral column resection (APVCR) with posterior pedicle screw instrumentation in 16 patients with a 67% correction[12]. Both Suk et al and Lenke et al have reported 60% corrections with posterior vertebral column resection (PVCR) in this patient group[13,14]. These techniques can be enhanced with the use of intra-operative traction[15,16].

However, a major concern in deformity correction is the neural elements' capacity to tolerate the change in spinal alignment[13,14,17]. One theory to reduce the risk of neural dysfunction and optimise deformity correction is to use pre-fusion traction because this gradually corrects the spinal alignment while allowing the clinician to monitor neurological complications in the awake patient[4,18]. Once the scoliotic spine is straighter, posterior instrumentation can be put in place to ensure the long-term correction. However, the value of traction remains debated[20].

In our study we performed an anterior release followed by progressive HFT over seven days with the aim of maximising the amount of traction tolerable to the patient and with the intention of the traction to exceed a third of the patient's body weight. Such loads are consistent with previous reports of the corrective effects of incremental increase in HFT[20]. Table 3 compares the published outcomes of similar three stage approaches[5,7,9,18,21]. Amongst those studies, only Mehlman et al[18] and Qiu et al[7] recorded traction weight as percentage of bodyweight as we have done here. Qiu and colleagues reported an average 45% deformity correction in patients undergoing 23 days of HFT with a mean traction weight of 38%[8]. Mehlman and colleagues describe a 71% correction, which is more similar to our results despite our shorter duration of traction (7 days versus 9 days) and lower percentage of body mass applied to the traction (36% versus 45%)[18]. This suggests that the duration and weight of HFT may offer no benefit beyond one week or a third of the patient's body weight.

HFT has well described risks including pin loosening and pin site infection[16]. In our series we experienced no pin related complications, which we attribute to diligent pin torque maintenance and a comparatively short duration of traction. Because HFT forces patients to be bed ridden during traction, patients are more susceptible to pressure sores, chest infections, and deep venous thromboses. In our series, none of these complications occurred which we attribute to the use of a RotoRest bed supervised by a scoliosis nurse specialist, thromboprophylaxis, in-dwelling urinary catheterisation, nasogastric feeding supplementation and short duration of traction. HFT also risks neurological complications[22]. In our series two patients developed brachial plexus palsies during traction that improved with HFT weight reduction and resolved within two months. No permanent neurological complications were encountered.

This study has a number of limitations. Firstly, it does not have a comparator group to determine whether HFT confers any benefit over a same day correction, which is a topic that remains intensely debated[5,10,23-24]. Secondly, it does not compare various traction amounts or durations to determine the optimal weight and duration of traction[16,18]. Thirdly, we have included patients with various causes for their scoliosis. We did this for completeness of consecutive patients and have provided raw data to allow differentiation. Fourthly, we did not assess blood loss, hospital stay or patient reported outcomes due to limitations in the retrospective accuracy of this data.

Conclusion

In adolescent patients with severe rigid scoliosis, anterior release followed by HFT for one week only and more than a third of total body weight before posterior fusion offers gradual correction of the spine over sufficient time to optimise deformity correction and minimise neurological dysfunction. ~~is an effective and safe procedure.~~

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Conflict of interest: All authors declare that they have no conflict of interest

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Figure legends

Figure 1. Pins attached to the skull via a Halo (a) and through both femora (b)

Figure 2. Patient in a tilting RotoRest Bed with halo-femoral traction applied

Figure 3. Representative radiographic example of a 14 year old with neuromuscular scoliosis with a pre-operative Cobb angle of 114^{o} and a final follow-up Cobb of 29^{o}.

Figure 4. Representative case example of 10-year-old girl with adolescent idiopathic scoliosis. Her pre-operative Cobb angle was 103^{o} and final follow-up Cobb was 29^{o}.

Table legends

Table 1. Summary of outcomes. Note (R) – Right convex, (L) – Left convex; AIS – Adolescent Idiopathic Scoliosis, NMS – Neuromuscular scoliosis, NF1 – Neurofibromatosis 1

Table 2. Results of three staged correction using HFT in other studies. Note the two rows in Qui et al are results comparing the use of HFT in congenital and neuromuscular scoliosis (top row) versus idiopathic scoliosis (bottom row).

Abstract

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There are several studies reporting high correction percentages in severe adolescent scoliotic curves with varied surgical techniques. Shen and colleagues describe an anterior release and posterior hooks and pedicle screws in 24 cases and showed a final curve correction of 59%[10]. In contrast, Bullmann and colleagues used both anterior and posterior instrumentation in 33 patients achieving a 67% deformity correction[11]. Zhou and colleagues describe a staged anterior-posterior vertebral column resection (APVCR) with posterior pedicle screw instrumentation in 16 patients with a 67% correction[12]. Both Suk et al and Lenke et al have reported 60% corrections with posterior vertebral column resection (PVCR) in this patient group[13,14]. These techniques can be enhanced with the use of intra-operative traction[15,16].

However, a major concern in deformity correction is the neural elements' capacity to tolerate the change in spinal alignment[13,14,17]. One theory to reduce the risk of neural dysfunction and optimise deformity correction is to use pre-fusion traction because this gradually corrects the spinal alignment while allowing the clinician to monitor neurological complications in the awake patient[4,18]. Once the scoliotic spine is straighter, posterior instrumentation can be put in place to ensure the long-term correction. However, the value of traction remains debated[20].

In our study we performed an anterior release followed by progressive HFT over seven days with the aim of maximising the amount of traction tolerable to the patient and with the intention of the traction to exceed a third of the patient's body weight. Such loads are consistent with previous reports of the corrective effects of incremental increase in HFT[20]. Table 3 compares the published outcomes of similar three stage approaches[5,7,9,18,21]. Amongst those studies, only Mehlman et al[18] and Qiu et al[7] recorded traction weight as percentage of bodyweight as we have done here. Qiu and colleagues reported an average 45% deformity correction in patients undergoing 23 days of HFT with a mean traction weight of 38%[8]. Mehlman and colleagues describe a 71% correction, which is more similar to our results despite our shorter duration of traction (7 days versus 9 days) and lower percentage of body mass applied to the traction (36% versus 45%)[18]. This suggests that the duration and weight of HFT may offer no benefit beyond one week or a third of the patient's body weight.

HFT has well described risks including pin loosening and pin site infection[16]. In our series we experienced no pin related complications, which we attribute to diligent pin torque maintenance and a comparatively short duration of traction. Because HFT forces patients to be bed ridden during traction, patients are more susceptible to pressure sores, chest infections, and deep venous thromboses. In our series, none of these complications occurred which we attribute to the use of a RotoRest bed supervised by a scoliosis nurse specialist, thromboprophylaxis, in-dwelling urinary catheterisation, nasogastric feeding supplementation and short duration of traction. HFT also risks neurological complications[22]. In our series two patients developed brachial plexus palsies during traction that improved with HFT weight reduction and resolved within two months. No permanent neurological complications were encountered.

This study has a number of limitations. Firstly, it does not have a comparator group to determine whether HFT confers any benefit over a same day correction, which is a topic that remains intensely debated[5,10,23-24]. Secondly, it does not compare various traction amounts or durations to determine the optimal weight and duration of traction[16,18]. Thirdly, we have included patients with various causes for their scoliosis. We did this for completeness of consecutive patients and have provided raw data to allow differentiation. Fourthly, we did not assess blood loss, hospital stay or patient reported outcomes due to limitations in the retrospective accuracy of this data.

Conclusion

In adolescent patients with severe rigid scoliosis, anterior release followed by HFT for one week only and more than a third of total body weight before posterior fusion offers gradual correction of the spine over sufficient time to optimise deformity correction and minimise neurological dysfunction.

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Figure legends

Figure 1. Pins attached to the skull via a Halo (a) and through both femora (b)

Figure 2. Patient in a tilting RotoRest Bed with halo-femoral traction applied

Figure 3. Representative radiographic example of a 14 year old with neuromuscular scoliosis with a pre-operative Cobb angle of 114^{o} and a final follow-up Cobb of 29^{o}.

Figure 4. Representative case example of 10-year-old girl with adolescent idiopathic scoliosis. Her pre-operative Cobb angle was 103^{o} and final follow-up Cobb was 29^{o}.

Table legends

Table 1. Summary of outcomes. Note (R) – Right convex, (L) – Left convex; AIS – Adolescent Idiopathic Scoliosis, NMS – Neuromuscular scoliosis, NF1 – Neurofibromatosis 1

Table 2. Results of three staged correction using HFT in other studies. Note the two rows in Qui et al are results comparing the use of HFT in congenital and neuromuscular scoliosis (top row) versus idiopathic scoliosis (bottom row).

Table 1

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Patient Number	Age at Operation	Diagnosis	Risser Grade	Pre-op Cobb angles (degrees)	Pre-op bolster bending angle (degrees)	Levels	Lenke classification	Post-op Cobb	Final Correction (%)	Follow up Cobb	Follow up correction (%)
1	11.4	AIS	0	97	77	T4-T12	1BN	35	64	33	66
2	10.5	AIS	1	103	73	T4-T12	1BN	32	69	29	72
3	15.4	NMS	1	92	51	T5-L1	1A+	18	80	14	85
4	12.3	AIS	0	118	85	T5-L1	1C+	35	70	32	73
5	15.7	AS	4	93	56	T5-L4	1BN	16	83	20	78
6	15.5	AIS	3	117	105	T5-L5	1AN	45	62	44	62
7	14.7	NMS	0	114	75	T8-L2	3C+	32	72	29	75
8	18.2	AIS	4	96	74	T5-L4	3C+	36	63	36	63
9	14.5	AIS	4	104	78	T5-L4	1BN	26	75	26	75
10	14.8	NMS	2	93	43	T5-L3	1BN	23	72	24	74
11	14.7	AIS	5	93	80	T5-T11	1CN	27	71	27	71
12	16.1	AIS	3	95	73	T6-L5	1BN	28	71	24	75
13	11.6	AIS	0	100	86	T2-T11	2A+	32	68	33	67
14	14.3	AIS	2	96	79	T6-T12	1B+	37	61	45	44
15	13.2	NF1	4	100	90	L2-L5	5CN	35	65	38	62
16	15.7	AIS	5	85	77	T6-T12	1A+	34	60	33	61
17	14.9	AIS	4	98	89	T12-L4	3C+	32	67	26	73
18	13.3	AIS	2	94	86	T3-L5	3CN	33	65	33	65
19	12.2	NMS	3	104	90	T3-L4	3C+	40	62	41	61
20	13.7	AIS	5	80	67	T3-L1	3C+	27	66	25	69
21	13.5	AIS	1	83	63	T2-L1	3AN	37	55	37	55
22	13.8	AIS	5	82	67	T2-L1	4AN	20	72	22	73
MEAN	14.1			97	76			31	68	31	68

Table 1. Summary of outcomes. Note (R) – Right convex, (L) – Left convex; AIS – Adolescent Idiopathic Scoliosis, NMS – Neuromuscular scoliosis, NF1 – Neurofibromatosis

Table 2
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Table 2. Results of three staged correction using HFT in other studies. Note the two rows in Qui et al are results comparing the use of HFT in congenital and neuromuscular scoliosis (top row) versus idiopathic scoliosis (bottom row).

Study	No. of patients	Mean age (Years)	Pre-op Cobb (Degrees)	Cobb Traction (Degrees)	Post-op Cobb (Degrees)	Follow-up Cobb (Degrees)	Final Correction (%)	No. of days in traction
Tokunga et al [21]	21	17	107	59	56	58	46	28
Mehlman et al [18]	24	14	95	95	32		71	9
Qiu et al [7]	30 (AIS)	16	92	58	40	43	58	23
	30 (NM)	15	96	68	57	59	45	
Zhang et al [9]	12	15	106	Not recorded	51	57	49	14
Koptan et al [5]	21	18	107	59	44	Not recorded	59	14
This study	22	14	97	52	31	31	68	7

Figure 1a
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Figure 1b
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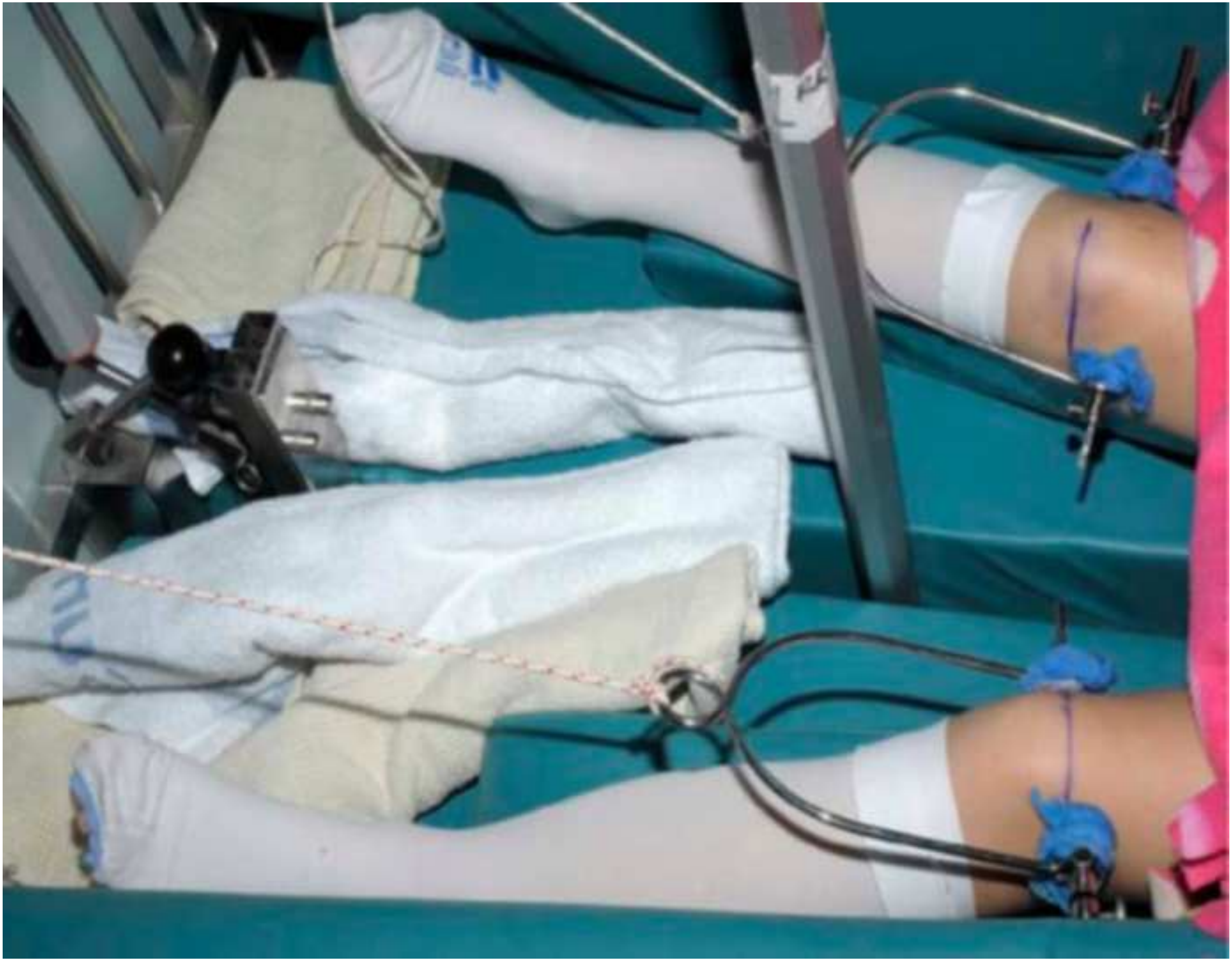

Figure 2
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Figure 3
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Figure 4

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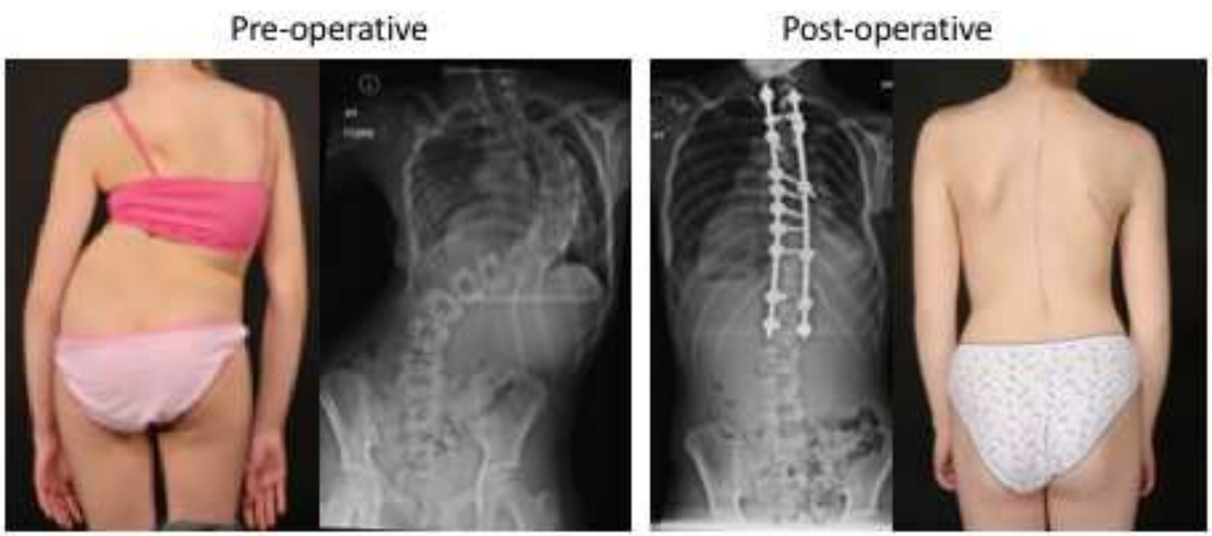

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