Original Article
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# Extirpation of the Thoracic and Lumbar Hemivertebrae from the Dorsal Access Using the Ultrasonic Bone Scalpel in Children: The Result of a Prospective Multicenter Study

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**Abstract**

***Background.*** The surgical treatment of congenital spinal deformity caused by hemivertebra is associated with high rate of complications. A research of a new surgery technique for operation time and blood loss decrease could potentially improve outcomes. ***The purpose*** — to evaluate the efficacy of ultrasonic bone scalpel in surgical treatment of pediatric congenital spinal deformities caused by monosegmental hemivertebra. ***Patients and Methods.*** Level of Evidence III. The study based on the data of 55 consecutively operated pediatric patients who underwent 59 posterior hemivertebra resection provided by ultrasonic bone scalpel from January 2015 to December 2019. The average age was 4 years and 4 months. 36 hemivertebra were located in thoracic spine and 23 were located in lumbar spine. Total duration of surgery, estimated blood loss (ml and % of circulated blood volume, CBV), complications rate and deformity correction were noted. The influence of posterior instrumentation length and patients age at time of surgery on evaluation parameters was analyzed. 5-year (2015–2019) systematic literature review was performed for compare with obtain results. ***Results.*** Total operation time was 131 min ± 33 min for thoracic spine and 165 min ± 50 min for lumbar spine ($p$ = 0,005). Estimated blood loss was 105 ml ± 74 ml (Me 80 ml) for thoracic resection and 123 ml ± 59 ml (Me 120 ml) — for lumbar ($p$ = 0,178). The length of posterior instrumentation were not influence on operation time and total blood loss ($p$ = 0,957; $p$ = 0,967), patients age at time of surgery were not influence on operation time ($p$ = 0,458), but correlate with total blood loss ($p$ = 0,023). Intraoperative complications was not observed. Four cases of transpedicular screw malposition without neurological deficit were noted (type C acc. Gertzbein-Robbins). ***Conclusions.*** Posterior hemivertebra resection with ultrasonic bone scalpel is safe and effective procedure provides decrease of operation time and estimated blood loss.

**Keywords:** congenital scoliosis, hemivertebra, ultrasonic bone scalpel, children, spine deformity.

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## Introduction

The congenital spinal deformities (CSD) in children develop against the background of various variants of vertebral anomalies, among which the hemivertebrae are the most frequent [1, 2, 3]. The most effective method of such deformities treatment is the hemivertebra extirpation from a combined or dorsal approach followed by posterior instrumental fixation (PIF) [4, 5, 6, 7].

The transpedicular hemivertebra extirpation from an single dorsal approach provides the effective correction of the deformity. However, this operation is associated with significant intraoperative blood loss (IBL), up to 35 to 40% of the circulating blood volume (CBV), a prolonged operative time (OT), 3 to 6 h, and the injury to the dura mater in 5 to 7% of the cases [8, 9, 10, 11]. These parameters affect the hospital stay length, the quality of patients life, and the complications rate in the late postoperative period [12, 13, 14].

The introduction of ultrasonic bone scalpel (UBS) into the spinal surgery provided a decrease of the soft tissues, vascular and neural structures damage in the operative field [14, 15]. There are no publications devoted to the use of this method in the surgery of CSD in children, with the exception of the only retrospective analysis that included a limited number of operations performed by a single surgeon. This study revealed a tendency towards a decrease of the OT and IBL during the pedicular extirpation of the hemivertebra in comparison with high-speed drilling [16].

*The purpose of this study* was to assess the effectiveness of the UBS in the surgery of CSD in the children with monosegmental hemivertebrae.

During this analysis, two questions were posed:

1. Does the use of the UBS for dorsal extirpation of a monosegmental hemivertebra provide a reduction in the OT and IBL?

2. Is the achievement of these parameters affected by the level of spinal anomaly/surgery, the patients age or PIF length?

## Materials and Methods

### *The study design*

This was a three-center prospective trial carried out in the Department of Pediatric Surgery and Orthopedics of the St. Petersburg Research Institute of Phthisiopulmonology, (St. Petersburg, Russia), the Department of Spinal Pathology and Rare Diseases of the Ilizarov National Medical Research Center of Traumatology and Orthopedics (Kurgan, Russia) (50 patients), and the Department of Neuroorthopedics of the National Medical Research Center for Children's Health (Moscow, Russia) (5 patients).

*Inclusion criteria*:

– the CSD caused by vertebrae formation abnormalities with a leading defect in the form of a monosegmental hemivertebra (Winter/Kawakami type 1);

– the extent of the surgery in the range of the hemivertebra one-stage extirpation from a single dorsal approach followed by PIF;

– the removal of a hemivertebra with the UBS (Misonix USA);

– the patients are less than 18 years old at the time of the surgery;

– the thoracic and lumbar localization of the hemivertebrae, from Th2 to L4.

*Exclusion criteria*:

– the multiple unilateral hemivertebrae at the apex of the deformity;

– the combination of hemivertebrae with other vertebral anomalies required surgical expansion (first of all, with contralateral segmentation disorders, rib concretion, etc.).

– the patients included in the retrospective analysis, the results of which was previously published by some of this article authors [16].

### *The study ethics*

In all cases, the legal representatives (parents) of the patients gave their voluntary consent to include the children in the study. The study protocol and design were in line with the 2013 Helsinki Declaration.

The patients were recruited from January 1, 2015 to December 31, 2019, including a 2-year two-center cohort (50 patients) from 2018 to 2019.

The study group consisted of 55 patients (29 girls and 26 boys) aged from 10 months up to 13 years old, who consistently underwent 59 monosegmental extirpations of the hemivertebrae. In 4 cases, the hemivertebrae were localized at two levels. In these cases the surgeries were performed at least 4 months between the operations). The average children age at the time of the surgery was 4 years and 4 months (Me 3 years and 8 months; min 10 months, max 13 years). The age distribution was as follows: ≤3 years and 11 months (35 patients); 4 years to 6 years and 11 months (15 patients); and 7 years and older (9 patients).

All the patients underwent before the surgery and at the follow-up time:

1) the spine X-ray in 2 planes to determine the magnitude of the deformity and the long-term correction dynamics;

2) the spine CT before the surgery to determine the axial dimensions of the hemivertebra and the diameter of the arches roots and bodies of the intact vertebrae located above and below, the spine CT after the surgery to assess the bone block building.

The research subject was the following parameters:

1) the OT in minutes;

2) the absolute blood loss (ABL) in ml, estimated by the gravimetric method;

3) the relative blood loss (RBL) in % as the ratio of the ABL to the CBV, calculated by the reference age-weight indicator;

4) the number and the nature of the surgical complications.

As additional parameters not directly related to the use of UBS, we assessed the value of deformity correction (according to Cobb) and its dynamics in the early (up to 30 days), delayed (from 30 to 90 days) and late (more than 90 days) postoperative periods.

We also studied the influence of such factors as the surgery level (thoracic or lumbar), the patients age, the length of PIF of 1 (excluding the hemivertebra), 2 or 3 and more spinal motion segments on the OT and IBL.

### *The surgical technique*

The hemivertebra arch and transverse processes, as well as the arch of one or two cranial and caudal vertebrae, were skeletonized from the posterior median approach.

After marking, the extirpation of the hemivertebra was performed in the following sequence (Fig. 1).

The transverse process of the hemivertebra was cut off at the base using the UBS osteotomy attachment and removed. During surgery in the thoracic region, the vertebral end of the rib in the neck region was isolated and crossed. The subsequent removal of this fragment provided the access to the lateral surface of the abnormal hemivertebra. The posterior wedge-shaped vertebrotomy was performed by removing the hemivertebral arch together with the dissected inferior articular process of the superior adjacent vertebra.

The spinal canal and the hemivertebra arch pedicle were exposed after the posterior sections removal. The subsequent stages of the removal were carried out with the UBS shaver attachment with the access to the hemivertebra body through its root (Fig. 2).

After the removal of all hemivertebra bone structures, the adjacent intervertebral discs were resected within the adjacent vertebrae endplates by the narrow raspator, lateral bone trays and Kerrison nippers. The medial endplate of the hemivertebra body, adjacent to the spinal canal, was finally removed with the UBS shaver. This minimized the risk of bleeding from the epidural space veins. Bleeding from radicular vessels was stopped by coagulation, from epidural veins – by local hemostatic materials.

The supporting elements (screws, hooks) placement, deformity instrumental correction, corporodesis and posterior fusion were performed according to the standard tech-

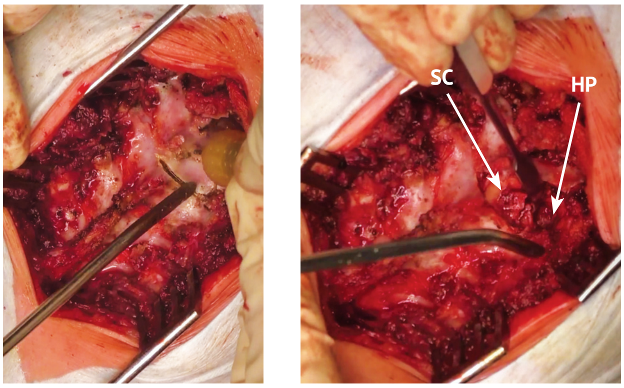


**Figure 1.** The stages of posterior column osteotomy:
SC — spinal cord;
HP — hemivertebra pedicle

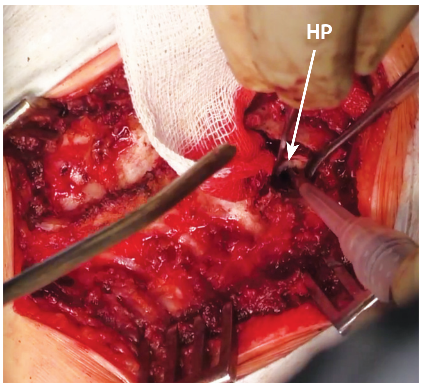


**Figure 2.** The stage of the hemivertebra body extirpation by the principle of "egg shell":
HP – hemivertebra pedicle

nique. The length of the posterior instrumentation was calculated taking into account the stability zone. The latter was assessed by the central sacral vertical line, which was the axis restored through the middle of the S1 vertebra. The preference was given to the screw support elements, placing them with the "free hands" method. The hooks were used in the case of the critical size of the supporting vertebrae arches roots determined by CT (when this parameter was less than the diameter of the minimum pedicle screw from the size bar). As a plastic material, the bone elements of the removed hemivertebra were used. The wound was hermetically sutured without additional drainage.

The clinical examples are presented in Figures 3 and 4.

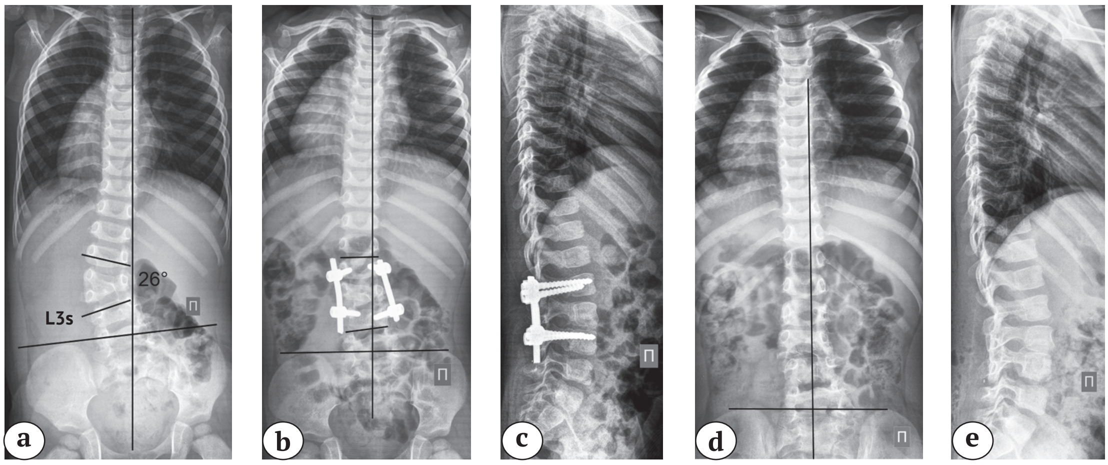


**Figure 3.** The female infant of 1 year 10 months age: congenital scoliotic deformity with L3s hemivertebra. X-ray before the surgery (a). Dorsal hemivertebra extirpation and posterior transpedicular fixation L2–4 were performed, the operative time 120 min, the surgical blood loss of 100 ml (7.8% of the circulating blood volume). X-ray in 1 year after the surgery (b, c) and after the removal of the posterior instrumentation fixation (d, e)

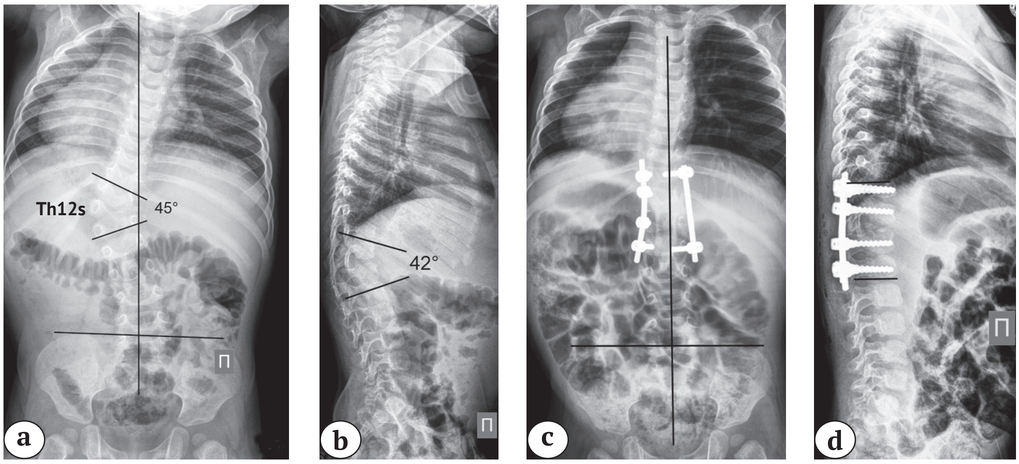


**Figure 4.** The male infant of 10 months. Congenital kyphoscoliotic deformity with Th12s hemivertebra. X-ray before the surgery (a, b). The dorsal extirpation of the hemivertebra and posterior transpedicular fixation Th10-L1 were performed, the operative time 130 min, the surgical blood loss of 30 ml (5% of the circulating blood volume). X-ray in 1 year 1 month after the surgery (c, d)

### *Statistical analysis*

The data statistical processing was performed using the Statistical Package for the Social Sciences (SPSS), version 22.0 (SPSS Inc., Chicago, IL, USA). All studied parameters were evaluated for normal distribution by the Kolmogorov–Smirnov test. For all parameters, the level of bilateral significance was $p<0.01$. This indicated the abnormality of their distribution. Therefore the results were presented as M±m and Me (min, max). The Mann-Whitney U-test was used to assess the statistical significance of differences in the OT and IBL depending on the localization of the hemivertebra. The statistical significance of the differences in the studied parameters with various PIF length and age intervals was carried out by the Kruskal–Wallis H-test. The values differences were considered statistically significant at a two-sided $p<0.05$.

## Results

Thirty six of 59 extirpations were performed in the thoracic region (Th2–12), 23 – in the lumbar (L1–4). In the case of pushing the pedicle during the compression maneuver (5 observations), the screws were changed to hooks without prolonging the length of the preselected fixation zone. No other intraoperative complications were reported apart from pushing the pedicles.

The follow-up was carried out within 1 year and 2 months. (Me 1 year and 1 month; min 6 months; max 5 years and 5 months). 4 cases of pedicle screw malposition were detected by CT in the mid-term period (6 months). This amounted to 1.5% of the total number of the placed screws. In all cases, the lateral displacement Gertzbei-Robbins type C (less than 4 mm) was observed. This situation was not accompanied by the loss of surgical correction and did not require any revision.

The dynamics of the deformity value estimated by its initial nature and the extent of spinal anomaly, is presented in Table 1. These data are comparable with the deformity correction value presented in other studies. This confirmed that the extirpation technique did not affect the correction value [17, 18, 19, 20, 21]. No loss of deformity correction that required a revision was noted by the end of the follow-up.

The operative time and IBL by the level of spinal anomaly are presented in Table 2.

The study did not reveal any significant relationship between the OT and the IBL on the one hand and the length of PIF on the other. In turn, the age of the patients had a direct correlation with the ABL. However, the recalculated for the value of the RBL (% of the CBV), this relationship was not confirmed (Table 3).

*Table 1*

**The spinal deformity dynamics**

| The assessment indicator | | Before the surgery | | After the surgery | | p |
|---|---|---|---|---|---|---|
| | | Thoracic spine | Lumbar spine | Thoracic spine | Lumbar spine | |
| *Isolated scoliosis,* n=36 | | | | | | |
| M±m | | 37±11º | 29±8º | 8±7º | 4±3º | $p^{Th}<0.001$ |
| Me (min; max) | | 35º (18º; 58º) | 28º (14º; 42º) | 4º (1º; 27º) | 1º (1º; 15º) | $p^{L}=0.,001$ |
| *Kyphoscoliosis,* n=23 | | | | | | |
| Kyphotic component | M±m | 33±11º | 28±17º | 7±67º | 6±4º | $p^{Th}<0.001$ |
| | Me (min; max) | 30º (16º; 58º) | 28º (10º; 60º) | 7º (1º; 30º) | 1º (1º; 25º) | $p^{L}=0.016$ |
| Scoliotic component | M±m | 36±9º | 32±8º | 3±2º | 4±3º | $p^{Th}=0.001$ |
| | Me (min; max) | 37º (23º; 52º) | 34º (18º; 44º) | 3º (1º; 8º) | 1º (1º; 21º) | $p^{L}=0.035$ |

The differences significance was determined by the Wilcoxon test
pTh – for the thoracic spine deformity; pL– for the lumbar spine deformity.

*Table 2*

**The operative time and blood loss by the level of spinal anomaly, M±m**

| Indicator | Total | Thoracic spine | Lumbar spine | p |
|---|---|---|---|---|
| Operative time, min | 145±44 | 131±33 | 165±50 | 0.005 |
| Absolute blood loss, ml | 112±69 | 105±74 | 123±59 | 0.178 |
| Relative blood loss, % of the CBV | 8.8±4.8 | 6.8±3.1 | 11.5±5.5 | 0.002 |

The differences significance was determined by the Mann-Whitney U-test.
CBV – circulating blood volume.

*Table 3*

**The correlation of the operative time and blood loss with the length of posterior instrumentation fixation and the patients age**

| Indicators | PIF length, number of SMS | | | Age, years (+months) | | | p |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | ≤3 (+11) | 4 to 6 (+11) | ≥7 | |
| Operative time, min | 148±55 | 151±48 | 146±35 | 146±48 | 130±36 | 130±15 | $p^1=0.957$ $p^2=0.458$ |
| ABL, ml | 92±59 | 108±64 | 108±75 | 89±56 | 115±70 | 191±89 | $p^1=0.967$; $p^2=0.0023$ |
| RBL, % of CBV | 9.4±6.1 | 8.5±2.7 | 8.5±4.5 | 8.8±5.7 | 8.0±3.8 | 9.1±3.7 | $p^1=0.997$; $p^2=0.0894$ |

The differences significance was determined by the Kruskal-Wallis H-test.
ABL – absolute blood loss, RBL – relative blood loss, PIF – posterior instrumental fixation,
SMS – spinal motion segment, p1 – the differences significance for various age groups,
p2 – the differences significance for various spinal motion segment number.

## Discussion

The surgical treatment of CSD in children against with hemivertebrae continues to be considered as traumatic with a relatively high rate of complications [22, 23, 24], statistically related to the OT and IBL [25, 26, 27]. That is why the UBS, primarily used in the surgery of degenerative pathology of the cervical spine, can be considered as one of the ways to reduce the complications rate [28, 29]. The greatest experience of the UBS employment in children was presented by S. Wahlquist et al. [30]. The authors found a significant decrease in the OT and IBL using UBS in the patients with adolescent idiopathic scoliosis. In the patients with neuromuscular deformities, a significant (43%) decrease in the IBL was accompanied by a slight (7%) increase in the OT.

Evaluating the publication trends on the extirpation of the hemivertebrae in children, it is necessary to note the existing consensus regarding the possibility of performing such a surgery from an single dorsal approach both in the thoracic and lumbar spine. This can be considered to be sufficient for complete resection of the hemivertebra bone structures and adjacent intervertebral discs, and complete correction of deformity and anterior fusion (spondylodesis). The dorsal approach was just the decisive criterion for inclusion publications in our analysis. The publications were identified by information retrieval in the PubMed, Google Scholar, Clinical Key databases 5 years deep (2015 to2019) using the keywords “hemivertebra resection”, ”congenital scoliosis”, “kyphosis” and “ultrasonic bone scalpel”. The publications analysis is presented in Table 4.

We used 13 publications for the final analysis, summarizing 373 hemivertebrae dorsal pedicular extirpations in children with a high-speed drill. It should be noted that our study is the 2$^{nd}$ in the number of observations among the analyzed and is close in terms of the children average age at the time of the surgery to the work of L. Ma et al. The latter authors presented the largest number of observations with the lowest average age of the operated patients [13].

The average age of the children included in the analyzed works at the time of the operation was 7 years (min 3.0; max 17.0). The direct comparison of the ABL in our own cohort with this indicator in the analyzed works, in our opinion, would be not entirely correct due to the heterogeneity of the patients average age (4 years and 4 months vs 7 years). In this regard, we recalculated the RBL according to the following formula: RBL(%)=ABL(ml)/CBV(ml)×100%. Here, the CBV was concordant with average age and weight indicators.

According to the analyzed publications, the average OT was 3 hours and 58 minutes, the ABLs – 502 ml, and the RBL – 28.1% of CBV. This allows us to state that in our group, with a slightly lower average age of the patients (4 years and 4 months), it was possible to reduce the OT and the RBL by 39.1% and 68.7%, respectively.

A somewhat unexpected result of our study was the fact that the use of UBS for the hemivertebra extirpation in the thoracic region was associated with a shorter OT and IOBV than in the lumbar region. This could be explained by the larger size of the lumbar epidural ("Betsonian") veins. In addition, the use of UBS made it possible to exclude the risks of complications such as damage to the dura mater and transient neurodeficiency, noted in 5 out of 13 analyzed publications.

### *The study limitation*

The authors note a limited number of children, undergone the surgery, over the age of 4, especially over 7, in comparison with the younger age group.

*Table 4*

**The publications 2015–2019 with summary indicators**

| Author | Number of cases | Average age, years+months | Localization (number of cases) | OT, min | IBL, ml / % of CBV | Complications (number of cases) |
|---|---|---|---|---|---|---|
| Wang Y. et al., 2019 [9] | 23 | 7+8 | L (10); L–S (13) | 196 | 271/14.1 | TND (1), TPFM (1) |
| Huang Y. с соавт., 2019 [23] | 21 | 11+5 | Th (21) | 240 | 809/26.6 | TND (1), TPFM (2), DP (4) |
| Liu D. et al., 2019 [8] | 50 | 10+1 | Th (10); L (40) | 259 (RR); 206 (PR) | 690 (RR)/26.9 502 (PR)/19.6 | TND(2), DDM (2), TPFM (2), |
| Ma L. et al., 2019 [13] | 103 | 3+0 | Non indicated | 176 | 225/19.8 | SISS (4), TND (1) |
| Wang S. et al., 2017 [17] | 18 | 5+4 | Th10-L2 (9) ; L–S (3) | 175 | 334/22.8 | TND (1) |
| Erturer R. et al., 2017 [10] | 9 | 9+2 | Th3–11 (4); Th12–L1 (5) | 292 | 236/10.3 | None |
| Basu S. et al., 2017 [25] | 20 | 9+2 | Th (10); L (10) | 300 | 611/26.8 | TPFM (1) |
| Zhang Y. et al., 2017 [22] | 15 | 11+9 | Non indicated | 282 | 836/26.7 | DISS (1) |
| Guo J. et al., 2016 [18] | 39 | 3+6 | Th1–5 (8); Th6–9 (5); Th10–L2 (20); L3–S1 (10) | 189 | 306/25.8 | TPFM (2), Rod fracture (1), DP (1) |
| Zhuang Q. et al., 2016 [21] | 14 | 10 | L5 (8); L5–S1 (5); L6 (1) | 207 | 235/9.2 | TPFM (1) |
| Feng Y. et al., 2016 [20] | 19 | 5+10 | Th1–9 (7); Th10–L2 (8); L3–4 (4) | 153 | 214/13.9 | TPFM (2) |
| Chang D.G. et al., 2015 [19] | 18 | 6+6 | Non indicated | 158 | 472/28.2 | SISS (1), DP (2) |
| Qureshi M.A. et al., 2015 [24] | 24 | 17+0 | Non indicated | 263 | 787/18.2 | TND(1), SISS (2), PJK (1), TPFM (1) |
| TOTAL of indicators for analyzed articles | 373 | 7+0 | Th (65); Th–L (42); L (65); L–S (31) | 238 | 502/28.1 | TPFM (9), TN (7), DP (6), DDM (2), PJK (1) |

CBV – circulating blood volume, DDM – damage to the dura mater,
DISS – deep infection of the surgical site, DP – deformity progression, IBL – intraoperative blood loss,
OT – operative time, PJK – proximal junctional kyphosis, PR – partial resection, RR – radical resection,
SISS – superficial infection of the surgical site, TND – transient neurodeficiency,
TPFM – transpedicular fixation malposition.

## Conclusion

The study results allow us to state the following:

– the use of UBS for dorsal pedicular extirpation of the hemivertebrae in children can reduce the OT and the IBL in comparison with the use of a standard high-speed drill;

– the use of UBS ensures the safety of the operation in relation to potentially possible neurological complications, namely trauma to the dura mater and transient neuropathies;

– the lumbar hemivertebrae extirpation in comparison with the thoracic using UBS is accompanied by a greater OT and IBL;

– the length of the PIF during hemivertebrae extirpation has no significant effect on the OT and IBL;

– the patients age influences the ABL, but exerts no effect on the RBL.

### Ethics approval

In all cases, the legal representatives (parents) of the patients gave their voluntary consent to include the patients in the study. The study protocol and design were in line with the 2013 Helsinki Declaration.

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