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Comparative Analysis of Pedicle Screw Placement in Children with Congenital Scoliosis: Freehand Technique (*in vivo*) and Guide Templates (*in vitro*)

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Abstract

Objective — to evaluate accuracy between pedicle screw placement in vertebral bodies achieved in vivo with freehand techniques versus their placement in vertebrae plastic models achieved in vitro with the use of guide templates, in toddlers and preschool children with congenital kyphoscoliosis of the thoracolumbar transition and lumbar spine amid the vertebral malformation. ***Materials and Methods.*** The research is based on a retrospective analysis of the results of treatment of 10 patients with congenital kyphoscoliosis of the thoracolumbar transition and lumbar spine amid the vertebral malformation. Age – from 2 years 2 months to 6 years 8 months old (mean 3 years 8 months old), gender – 6 boys, 4 girls. Based on the postoperative multi-slice spiral computed tomography (MSCT) of the spine, the pedicle screws placement accuracy of the correcting multi-support metalwork was evaluated. These patients constituted the 1st research group (in vivo group). The 2nd research group (in vitro group) was formed from 27 vertebrae plastic models with pedicle screws inserted in them with the use of guide templates. The placement accuracy of the installed pedicle support elements was assessed based on the S.D. Gertzbein et al. scale (1990). ***Results.*** In the 1st group, there were 52 pedicle screws placed. The screw placement accuracy according to the rate of misplacement, as follows: 53.8% in Grade 0, 25% in Grade I, 11.6% in Grade II, 9.6% in Grade III. The number of screws with the rate of misplacement in Grade 0 + Grade I was 41 (78.8%). In the 2nd group, there were 54 screws placed and slightly larger than the 1st group. The screw placement accuracy according to the rate of misplacement was 94.4% in Grade 0, 1.9% in Grade I, 3.7% in Grade II, respectively. The number of screws with the rate of misplacement in Grade 0 + Grade I was 52 (96.3%). ***Conclusion.*** Comparative analysis showed that the number of pedicle screws successfully placed in vertebrae plastic models in children with congenital deformities of the thoracolumbar transition and lumbar spine achieved with the use of guide templates was significantly higher than the number of screws successfully placed with freehand techniques (96.3% versus 80.8%, p = 0.011). The results obtained with method of navigation templates in vitro showed high precision and accuracy of pedicle screw placement which gives the prospect for using this type of navigation in clinical practice in toddlers with congenital scoliosis.

Keywords: congenital scoliosis, hemivertebra, transpedicular fixation, guide templates, 3D-printing of prototypes, children.

Competing interests: the authors declare that they have no competing interests.

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Publishing ethics: legal representatives of children given the informed consent to clinical cases publication.

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Introduction

Hemivertebrae extirpation with subsequent radical correction of deformity and spine fixation by a local metal system at the early age [1–5] has become widely spread as the method of surgical correction of congenital deformities amid vertebral malformation in children. Surgical procedures in congenital scoliosis in children of older children do not allows to obtain radical deformity correction [6]. Transpedicular fixation versus laminar fixation from biomechanical point of view is advantageous, however, bears a risk of screws malposition due to structural vertebrae alterations amid scoliotic process and vertebral column malformation [7]. For that reasons it's important to ensure correct placement of transpedicular support fixators during treatment of patients with congenital scoliosis.

The prevalent method of transpedicular screws (TS) insertion in the spine surgery in general and in children with congenital deformities in particular is the free-hand method with subsequent fluoroscopic control of placement accuracy of support elements in vertebral bodies [8]. There are sporadic publications in foreign literature which present the analysis of TF placement accuracy in children with congenital spine deformities using intraoperative computer tomography (O-arm) and system of active optical navigation [9].

Recently, guiding templates (GT) have been used more often for TS insertion in cases of various diseases and deformities of spinal column (spine injury, degenerative and dystrophic diseases, inflammatory diseases, craniovertebral pathologies, idiopathic scoliosis, etc.). Such publications report rather high precision and accuracy of TS positioning in bony structures of vertebrae in various anatomical areas [10–13].

However, when analyzing national and world literature the authors of the present research did not find any publications dedicated to use of guiding templates for TS insertion in children of preschool age with congenital scoliosis.

Aim of the study — to conduct a comparative evaluation of accuracy of TS position inserted into vertebral bodies in toddlers and children of preschool age with congenital kyphoscoliosis of the thoracolumbar transition and lumbar spine amid the vertebral malformation by a free-hand technique *in vivo* and into vertebrae plastic models with the use of guiding templates (GT) *in vitro*.

Materials and Methods

The research in based on the retrospective analysis of examination and treatment outcomes in the randomized cohort comprised of 10 patients (6 males and 4 females) aging from 2 years and 2 months old to 6 years 8 months old (mean of 3 years 8 months) with congenital kyphoscoliosis with underlying vertebral malformation (posterolateral hemivertebrae in the thoracolumbar transition and lumber spine). All children underwent examination and surgical treatment during 2016 and 2017.

Standard preoperative and postoperative examination included multi-slice spiral computed tomography (MSCT) of thoracic and lumbosacral spine. Extirpation of affected hemivertebra with adjacent intervertebral disks was performed in all children as well as the correction of congenital spine deformity by a multi-supporting transpedicular implant system, anterior interbody fusion and posterior spine fusion by auto bone graft to create a bone block between removed hemivertebra and adjacent intact vertebrae.

Multi-slice spiral computed tomography (MSCT) examination was used in 10 patients with congenital spine deformities was used for 3D modeling as well as surgery planning software PME Planner (Polygon Medical Engineering) which allows to identify dimensions and optimal positioning of TS inserted into the vertebrae. 3D models of guiding templates (GT) were created given the virtually planned screws in specified positioning and feature of dorsal bone structures of involved vertebrae (Fig.1).

3D printer Formlabs Form 2 (SLA technology) was used for printing of guiding templates for insertion of TS into the vertebrae (Fig. 2).

3D printer PICASO DESINGER PRO250 (FDM technology) was used for prototyping of vertebrae in the fixation zone. Then guiding templates were placed on dorsal surface of the printed plastic model of the vertebra, 2,5mm drill bit was used for forming the holes at specified direction through pedicle into the vertebral body. Standard transpedicular support implants of 3.5 mm in diameter were inserted into the holes and then accuracy of TS positioning was visually checked (Fig. 3).

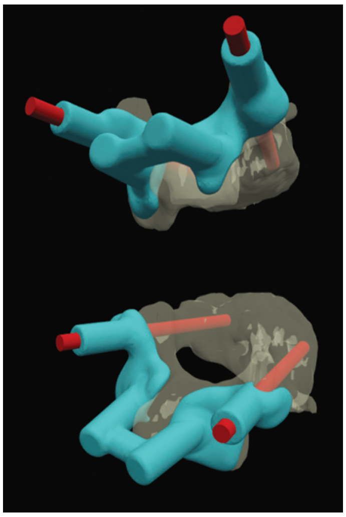

Fig. 1. Virtual screws and navigation templates planning within the PME Planner software environment

Fig. 2. Navigation templates for pedicle screws placement in vertebrae plastic models

Fig. 3. Vertebra plastic model with pedicle screws placed with the use of navigation templates

MSCT examination in postoperative period was used to assess the positioning accuracy of inserted TS in patients of group 1 (*in vivo*).

MSCT was also used to assess accuracy of positioning of support elements in group 2 (*in vitro*) which consisted of 27 plastic vertebra models with TS inserted using navigation templates.

Accuracy of insertion of transpedicular support implants was assessed by the scale suggested by S.D. Gertzbein et al, wherein:

– Grade 0 (full correct) — screw is placed fully intrapedicularly without any contacts with adjacent soft tissues;

– Grade I — < 2 mm implant displacement in relation to pedicle cortex;

– Grade II — 2-4 mm implant displacement;

– Grade III — > 4 mm implant displacement [14].

SLIM+V pattern was used for comparative analysis of accuracy of TS insertion into the vertebrae by free-hand technique *in vivo* and into plastic models of vertebrae using guiding templates *in vitro*. SLIM+V reads as follows: SLIM — identifies screw placement in relation to the pedicle walls: S (superior) - cranial pedicle wall, L (lateral) — outer pedicle wall, I (inferior) — caudal pedicle wall, M (medial) — inner pedicle wall. Second part of the abbreviation, V (vertebral body), represents the evaluation of TS placement in relation to anterolateral surface of the vertebral body [15].

Statistical analysis

Statistical analysis was made in the STATISTICA 10 software. Normalcy of distribution of obtained values was verified by descriptive statistics (histogrammic analysis), the data was described as Me (mi-max). Significance level of differences was evaluated by non-parametrical Mann Whitney U-test (results were considered statistically significant with $p<0.05$).

Results

Results of MSCT research of anatomical and anthropometrical features of vertebrae in thoracolumbar transition and in lumbar spine in children with congenital kyphoscoliosis along with vertebral malformation are demonstrated in table 1.

Obtained anatomical and anthropometrical data on vertebrae in thoracolumbar transition and lumbar spine in children with congenital kyphoscoliosis and vertebral malformation were taken into account during planning of guiding templates for insertion of TS into plastic models of vertebrae. It should be noted that parameters of lumbar vertebrae in children with isolated lumbar hemivertebrae in general were similar to parameters of lumbar vertebrae in toddlers and children of younger age without any spine pathologies [16].

Evaluation data of accuracy of TS positioning by free-hand technique in group 1 are presented in table 2.

Table 1

Anatomical and anthropometric parameters of vertebrae in thoracolumar transition and in lumbar spine

Vert.	Right				Left			
	W	H	L	A	W	H	L	A
Th10	6,0 (5,7; 6,3)	10,3 (10,1; 10,5)	31,6 (29,9; 33,2)	11,5 (10,3; 12,7)	5,9 (5,7; 6,0)	9,8 (9,2; 10,4)	30,5 (30,0; 31,0)	12,9 (10,5; 15,3)
Th11	5,6 (4,5; 6,6)	10,0 (8,6; 10,9)	31,4 (29,7; 34,9)	11,6 (5,7; 17,6)	5,6 (4,0; 6,5)	9,8 (9,0; 11,4)	32,8 (31,2; 35,2)	13,2 (10,2; 16,5)
Th12	5,3 (4,9; 7,9)	9,8 (9,4; 11,0)	31,9 (30,5; 35,4)	12,1 (7,7; 18,1)	5,6 (3,7; 8,3)	10,0 (8,7; 11,4)	32,9 (30,2; 35,1)	12,3 (8,8; 15,7)
Th13	6,0 (5,7; 6,9)	10,4 (9,1; 11,4)	33,1 (30,5; 33,3)	10,7 (10,5; 11,6)	6,2 (5,8; 6,5)	9,7 (9,6; 10,1)	34,1 (32,1; 34,7)	12,7 (11,4; 15,0)
L1	5,7 (4,6; 8,9)	9,9 (7,2; 10,8)	32,7 (31,3; 36,8)	12,0 (8,2; 13,6)	5,3 (3,9; 6,1)	9,5 (7,8; 10,6)	32,6 (26,2; 36,2)	12,1 (4,6; 16,3)
L2	5,8 (4,1; 7,7)	8,7 (7,1; 11,0)	34,0 (30,0; 36,2)	11,5 (9,7; 23,0)	5,8 (4,5; 7,4)	9,2 (7,4; 10,6)	34,0 (31,8; 39,8)	16,2 (13,2; 20,2)
L3	6,5 (4,3; 7,9)	9,4 (6,8; 10,8)	33,0 (28,6; 39,5)	14,7 (11,8; 25,4)	5,7 (3,7; 7,6)	9,4 (0,1; 11,6)	33,6 (31,9; 40,4)	15,2 (11,5; 24,2)
L4	6,8 (5,4; 12,4)	9,0 (6,0; 9,7)	34,5 (28,4; 37,9)	17,0 (7,8; 26,0)	7,0 (4,1; 9,8)	9,3 (6,8; 10,3)	35,0 (32,2; 39,3)	15,8 (14,4; 23,1)
L5	9,1 (7,2; 11,9)	7,7 (6,0; 9,1)	32,8 (29,3; 35,3)	23,7 (13,5; 41,2)	7,8 (5,5; 10,4)	8,4 (7,0; 10,5)	33,7 (32,5; 37,8)	18,5 (12,2; 28,7)
L6	11,1 (9,5; 13,7)	6,9 (5,3; 10,0)	34,2 (30,3; 35,5)	31,2 (19,6; 41,5)	8,4 (7,0; 11,9)	7,4 (4,2; 7,8)	34,0 (27,2; 35,7)	29,8 (19,4; 40,7)
L7	10,3	6,9	31,1	36,0	13,3	7,1	33,4	32,1

V — vertebra; W — width of pedicle base; H — height of pedicle base; L — length of screw hole; A — pedicle angle in axial plane. Data is presented as median, Me (min-max).

Table 2

TS positioning accuracy in group I (*in vivo*)

UO	Vert.	Th10	Th11	Th12	Th13	L1	L2	L3	L4	L5	L6	L7
1	Dex	–	–	V2	N	V3	HV	V3	–	–	–	–
	Sin	–	–	0	N	0		0	–	–	–	–
2	Dex	–	–	–	–	–	0	HV	V1	–	–	–
	Sin	–	–	–	–	–	L2, V3		0	–	–	–
3	Dex	–	–	–	–	–	0	HV	0	–	–	–
	Sin	–	–	–	–	–	0		V1	–	–	–
4	Dex	–	–	0	V2	HV	0	–	–	–	–	–
	Sin	–	–	V1	V1		0	–	–	–	–	–
5	Dex	–	–	0	N	0	HV	0	–	–	–	–
	Sin	–	–	V2	N	NS		NS	–	–	–	–
6	Dex	–	–	–	–	–	–	–	–	V3	HV	V3
	Sin	–	–	–	–	–	–	–	–	I2		0
7	Dex	–	–	–	0	0	HV	M1	–	–	–	–
	Sin	–	–	–	V2	V1		0	–	–	–	–
8	Dex	0	0	HV	0	–	–	–	–	–	–	–
	Sin	V1	L1, V1		V1	–	–	–	–	–	–	–
9	Dex	–	–	0	0	HV	0	–	–	–	–	–
	Sin	–	–	0	0		0	–	–	–	–	–
10	Dex	–	L1	L1	N	HV	0	–	–	–	–	–
	Sin	–	L1	L1, V2	N		0	–	–	–	–	–
TScrew		2	4	10	8	5	10	5	4	2	0	2
Mal		1	3	5	5	2	1	2	2	2	0	1

UO — case; Vert. — vertebra; Dex — screws inserted on the right side; Sin — screws inserted on the left side; T screw — total number of screws inserted into vertebra; Mal — malpositioned screws; HV — hemivertebra; N — vertebra at reported order number is absent; "-" — vertebrae no included into interbody fusion; NS — no screws in the zone of interbody fusion. SLIM+V: S — superior, L — lateral, I — inferior, M — medial walls of pedicle; V — vertebral body (0, 1, 2, 3 — screw malposition by grade of displacement).

The total number of transpedicular support implants inserted in the group 1 was 52 screws. Correct placement of screws in relation to bony structure of fixed vertebrae generally was observed in 53.8% of cases (28 screws), screws malpositioning was observed in 46.2% of cases (24 transpedicular support implants) during analysis of postoperative spine MSCT. Grade I screws displacement was reported in 25% of cases (13 screws), Grade II — in 11.6% of cases (6 screws), Grade III — in 9.6% of cases (5 screws). V type displacement prevailed — 69.2% (18 cases), L type displacement — 23.1% (6 cases), I and M type displacements — 3.85% (one case of each). Screws displacement of Grade 0 + Grade I was 78.8% (41 screws) (Fig. 4).

Evaluation data on positioning accuracy of TS inserted by guiding templates is presented in table 3.

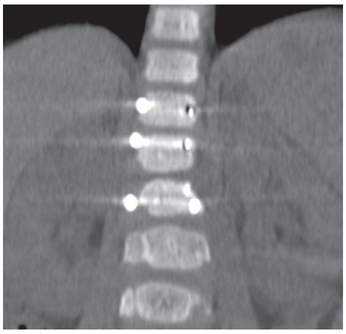

Fig. 4. MSCT of the spine of a patient with congenital kyphoscoliosis following the posterolateral L2 hemivertebra resection, pedicle screw malposition: Th12 vertebra — V2 (vertebral body, Grade II), L1 and L3 vertebrae — V3 (vertebral body, Grade III)

Table 3

TS positioning accuracy in group 2 (*in vitro*)

UO	Vert.	Th10	Th11	Th12	Th13	L1	L2	L3	L4	L5	L6	L7
1	Dex	–	–	0	N	0	HV	0	–	–	–	–
	Sin	–	–	V2	N	0		0	–	–	–	–
2	Dex	–	–	–	–	–	0	HV	0	–	–	–
	Sin	–	–	–	–	–	0		0	–	–	–
3	Dex	–	–	–	–	–	0	HV	0	–	–	–
	Sin	–	–	–	–	–	0		0	–	–	–
4	Dex	–	–	0	0	HV	0	–	–	–	–	–
	Sin	–	–	0	0		0	–	–	–	–	–
5	Dex	–	–	0	N	0	HV	0	–	–	–	–
	Sin	–	–	0	N	0**		0**	–	–	–	–
6	Dex	–	–	–	–	–	–	–	–	0	HV	0
	Sin	–	–	–	–	–	–	–	–	0		0
7	Dex	–	–	–	0	0	HV	0	–	–	–	–
	Sin	–	–	–	V2	0		0	–	–	–	–
8	Dex	0	0	HV	0	–	–	–	–	–	–	–
	Sin	0	L1		0	–	–	–	–	–	–	–
9	Dex	–	–	0	0	HV	0	–	–	–	–	–
	Sin	–	–	0	0		0	–	–	–	–	–
10	Dex	–	0	0	N	HV	0	–	–	–	–	–
	Sin	–	0	0	N		0	–	–	–	–	–
TScrew		2	4	10	8	6**	10	6**	4	2	0	2
Mal		0	1	1	1	0	0	0	0	0	0	0

UO — case; Vert. — vertebra; Dex — screws inserted on the right side; Sin — screws inserted on the left side; Tscrew — total number of screws inserted into vertebra; Mal — malpositioned screws; HV — hemivertebra; N — vertebra at reported order number is absent; "-" — vertebrae no included into interbody fusion; ** — additional screws inserted in the group 2. SLIM+V: S — superior, L — lateral, I — inferior, M — medial walls of pedicle; V — vertebral body (0, 1, 2, 3 — screw malposition by grade of displacement).

Total number of TS placed in the group 2 was 54 screws. Accurate screw positioning in relation to the structure of plastic vertebral models generally was reported in 94.4% of cases (51 screws), malpositioning was observed in 5.6% of cases (3 screws) during the analysis of MSCT examination. Grade II displacement was reported in 2 out of 3 malpositioned screws (3.7%), and Grade I — in one screw (1.9%). L type displacement was reported in 1 case, type V — in other two cases. Number of screws with displacement of Grade 0 + Grade 1 amounted to 52 (96.3%) (Fig. 5).

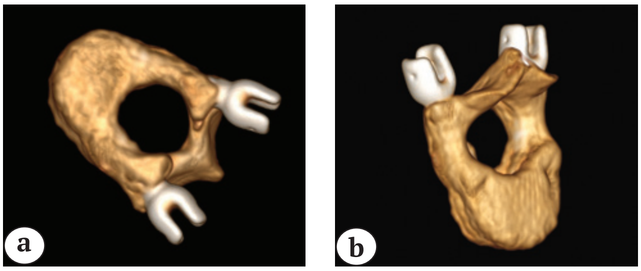

Fig. 5. 3D MSCT scan of the vertebra plastic model of a patient with congenital kyphoscoliosis with pedicle screws placed with the use of navigation templates, the position of the screws is completely successful:
a — top view;
b — bottom view

Thus, comparative analysis demonstrated that in group 2 the number of malpositioned TS inserted by guiding templates was significantly less (5.6%) vs the number of malpositioned TS inserted by free-hand technique in group 2 (46.2%, *p* = 0,011).

Discussion

While analyzing the current literature on guiding templates use for holes formation and insertion of TS *in vitro* it was observed that there are studies where authors evaluate the efficiency of guiding templates for TS insertion into cervical spine [17–20], thoracic spine [21, 22] and lumbar spine [23-26]. There are also publications with analysis of positioning accuracy for TS inserted by guiding templates in thoracic as well as in lumbar spine [18, 27, 28].

Some authors conducted cadaveric research including MSCT examination of vertebrae specimen with computer processing of obtained data and further 3D printing of guiding templates and their testing on cadavers [17–19, 22–24, 27]. There are research wherein transpedicular screws were inserted by guiding templates into plastic vertebra models obtained during MSCT examination of patients with intact spine [25]. Authors of some publication first created a plastic vertebra model based on MSCT data of cadaveric specimen, tested the method and guiding templates design and then inserted TS into vertebrae of study material [20, 21].

According to the data of conducted research, in general, from 4 to 240 screws (646 screws in total) were inserted by guiding templates *in vitro* [17–28].

TS positioning accuracy per grade of displacement, according to literature, was: Grade 0 — from 58.3% up to 97.6%, Grade I — from 2.4% to 39.5%, Grade II — 8.7%, Grade 0 + Grade I — from 91.3% to 100%. Screws malpositioning of Grade III displacement was not observed [17, 21, 27, 28]. Authors of research without TS malpositioning analysis by displacement grade report placement accuracy from 71.7% to 100% (mean of 96%) [18–20, 22–26].

Authors of some research conducted a comparative analysis of positioning accuracy for TS inserted by free-hand technique and using guiding templates. Placement accuracy after use of guiding templates was from 97.9 up to 100%, by free-hand technique — from 81.3 to 89.2% ($p<0,05$) [21, 26, 28].

Material of the most research was vertebra specimen of cadavers over 18 years [17–25, 27, 28]. The authors of the present paper identified only one cadaveric study with analysis of guiding templates use in lumbar spine in children from 6 to 13 years old. In that study 10 guiding templates were produced and used for insertion of 20 screws into lumbar spine; no malpositioning of transpedicular screws was reported [26].

When analyzing publications on guiding templates use for TS insertion *in vivo* the authors of the present paper noted that the majority of papers cover issues of screw fixation in cervical spine [10, 29–36]. Such focus on cervical spine is conditioned by its anatomical features (small dimensions of pedicle, vicinity of spinal arteries) that require high precision and accuracy in screws insertion. Some authors analyzed the use of guiding templates in cervical spine in general including both atlantoaxial segment and subaxial cervical spine [10, 29, 30]. Other authors elaborated on such technique for insertion of screws with different fixation methods only in atlantoaxial segment [31–35]. There are some papers covering the use of guiding templates in subaxial cervical spine [36].

There is some research in literature specifically dedicated to the aspect of guiding templates use for TS insertion in thoracic [11, 37—40] and lumbar spine [12, 41, 42]. Some authors reported studies where positioning accuracy is analyzed by TS inserted by guiding templates both in thoracic and in lumbar spine [13, 43] (table 5).

Majority of publications reflect that research design consisted of preliminary testing of constructive features of guiding template form and insertion of TS into plastic vertebra models obtained by prototyping based on MSCT spine data of the patients, and further evaluation of screws positioning accuracy in prototyped spine segments. The second stage included surgical procedure where screws were inserted by guiding templates *in vivo* and positioning accuracy in relation to vertebral bony structure was evaluated [10, 11, 13, 29, 30, 32, 33, 35–38, 42]. In some research prototypes of plaster cast were used instead of plastic models [39]. Some authors tested the insertion technique and constructive features of guiding templates during cadaveric studies prior to surgical interventions [12, 31]. Some authors inserted TS by guiding templates directly *in vivo* during surgery without a prior stage of prototyping of operated spine segment [34, 40, 41, 43].

According to literature, guiding templates were used for insertion overall from 6 to 582 screws in conducted *in vivo* research (2323 screws in total) [10–13, 29–43].

Analysis of distribution of TS positioning accuracy according to displacement grade provided the following results: TS positioning of Grade 0 constituted from 80.7% to 98.4% (mean 92.2%), Grade I — from 1.4% to 15.9% (mean — 6.8%), Grade II — from 0.2% to 4.0% (mean — 2.7%), Grade 0 + Grade I — from 96.1% to 100% (mean — 98.8%). Grade III screws malpositioning was not reported [10, 13, 29, 34, 36, 37, 39–41, 43]. The papers where authors analyzed TS malpositioning only by its presence without evaluation of displacement grade, accurate screws positioning constituted from 96.1% up to 100% (mean — 99,4%) [11, 12, 30–33, 35, 38, 42].

Some research reported comparative analysis of positioning accuracy for TS inserted by free-hand technique and by guiding templates. The correct TS positioning (Grade 0) inserted by guiding templates was observed in 92.6% to 96% of cases, by free-hand technique — from 75% to 88.8% of cases. Cumulative percentage of TS with displacement of Grade 0 + Grade I in group of guiding templates was from 96,7% to 100% and was significantly higher (p<0.05) than the cumulative percentage of TS inserted by free-hand technique with displacement of Grade 0 + Grade I in the range of 86.9% to 98.1% [34, 40, 41, 43].

The greater part of studies on the guiding templates use in the clinical practice concerns the patients of older age (mean of 51.5 years) suffering such spine pathologies as degenerative and dystrophic diseases, rheumatoid arthritis, atlantoaxial instability along craniovertebral malformation, injuries and metastases in the spine [10–12, 29, 31–36, 38, 41, 42].

Significantly less publications are dedicated to the use of guiding templates in children. Majority of those provide data on the guiding templates use for surgical treatment of spine deformities in cases of idiopathic scoliosis, systemic and congenital scoliosis in children of older age [13, 30, 37, 39, 40, 43].

The authors of the present paper note that during analysis of literature no papers were found which would be dedicated to the use of guiding templates for TS insertion in toddlers with congenital scoliosis.

Thus, when collating literature data with own research the authors of the present paper observed a rather high accuracy of TS positioning using guiding templates both *in vitro* (Grade 0+I — 91.3–100%) and *in vivo* (Grade 0+I — 96.1–100%) which conforms with obtained value of TS positioning accuracy in group 2 (*in vitro*) of the present study — Grade 0+I — 96.3%. Accuracy of TS positioning by free-hand technique in group 1 (Grade 0+I — 78,8%) was similar to the literature data on comparative analysis of positioning accuracy of TS inserted by guiding templates and by free-hand technique (Grade 0+I: 96.7% — 100% against 86.9% — 98.1%).

The authors did not find any papers of the same research design which is presented in the current paper. The advantage of this design is the possibility to conduct a comparative analysis of positioning accuracy of already inserted TS in patients by free-hand technique with the potential of guiding templates use and their impact on TS positioning accuracy in plastic models of vertebrae of the same patients. Thus, apart from significantly higher accuracy of TS positioning in group 2 (*in vitro*) of the current study in comparison with group 1 (*in vitro*) the authors also managed to insert a bigger number of TS by guiding templates.

Obtained results look promising and allow to consider the option on further research dedicated to the use of guiding templates for TS insertion in surgical treatment of congenital spine deformities in patients of younger age.

Conclusion

The number of correctly placed TS into the plastic vertebral models of children with congenital deformities of thoracolumbar and lumbar spine using guiding templates was significantly higher than the number of correctly placed screws by free-hand technique (96.3% vs 78.8%, p = 0,011).

The results of guiding templates use in vitro demonstrated a high accuracy for TS placement which opens perspectives for use of such navigation in clinical practice in children of young age with congenital scoliosis.

References

1. Vissarionov S.V., Kokushin D.N., Kartavenko K.A., Efremov A.M. [Surgical treatment of children with congenital deformity of the lumbar and lumbosacral spine]. *Hirurgia pozvonochnika* [Journal of Spine Surgery]. 2012;(3):33-37. DOI: 10.14531/ss2012.3.33-37. (In Russ.)
2. Vissarionov S.V., Kokushin D.N., Belyanchikov S.M., Murashko V.V., Kartavenko K.A. [Surgical treatment of congenital deformation of thoracolumbar spine in children]. *Ortopediya, travmatologiya i vosstanovitelnaya hirurgiya detskogo vozrasta* [Pediatric Traumatology, Orthopaedics and Reconstructive Surgery]. 2013;1(1): 10-15. DOI: 10.17816/PTORS1110-15. (In Russ.).
3. Mihailovskii M.V., Fomichev N.G. Khirurgiya deformatsii pozvonochnika [Surgery of spinal deformities]. Novosibirsk, 2011. 592 p. (In Russ.)
4. Riabykh S.O., Gubin A.V., Savin D.M., Filatov E.Yu. [The results of thoracic and lumbar hemivertebrae resection by a dorsal pedicular approach in children]. *Genij Ortopedii* [Orthopaedic Genius]. 2015;(4):42-47. DOI: 10.18019/1028-4427-2015-4-42-47. (In Russ.).
5. Ryabykh S.O., Filatov E.Yu., Savin D.M. [Results of hemivertebra excision through combined, posterior and transpedicular approaches: systematic review]. *Hirurgia pozvonochnika* [Journal of Spine Surgery]. 2017;(1): 14-23. DOI: 10.14531/ss2017.1.14-23. (In Russ.).
6. Mikhailovsky M.V., Novikov V.V., Vasyura A.S., Udalova I.G. [Surgical treatment of congenital scoliosis in patients over 10 years old]. *Hirurgia pozvonochnika* [Journal of Spine Surgery]. 2015;12(4):42-48. DOI: 10.14531/ss2015.4.42-48. (In Russ.)
7. Kuleshov A.A., Lisyansky I.N., Vetrile M.S., Gavryushenko N.S., Fomin L.V. [Comparative experimental study of hook and pedicle fixation systems used at surgical treatment of spine deformities]. *Vestnik travmatologii i ortopedii imeni N.N. Priorova*. 2012;(3):20-24. (In Russ.).
8. Gubin A.V., Riabykh S.O., Burcev A.V. [Retrospective analysis of screw malposition following instrumented correction of thoracic and lumbar spine deformities]. *Hirurgia pozvonochnika* [Journal of Spine Surgery]. 2015;12(1):8-13. DOI: 10.14531/ss2015.1.8-13. (In Russ.).
9. Larson A.N., Polly D.W. Jr., Guidera K.J., Mielke C.H., Santos E.R., Ledonio C.G., Sembrano J.N. The accuracy of navigation and 3D image-guided placement for the placement of pedicle screws in congenital

spine deformity. *J Pediatr Orthop.* 2012;32(6):23-29. DOI: 10.1097/BPO.0b013e318263a39e.
10. Lu S., Xu Y.Q., Lu W.W., Ni G.X., Li Y.B., Shi J.H., Li D.P., Chen G.P., Chen Y.B., Zhang Y.Z. A novel patient-specific navigational template for cervical pedicle screw placement. *Spine (Phila Pa 1976).* 2009;34(26):E959-966. DOI: 10.1097/BRS.0b013e3181c09985.
11. Hu Y., Yuan Z.S., Spiker W.R., Dong W.X., Sun X.Y., Yuan J.B., Zhang J., Zhu B. A comparative study on the accuracy of pedicle screw placement assisted by personalized rapid prototyping template between pre- and post-operation in patients with relatively normal mid-upper thoracic spine. *Eur Spine J.* 2016;25(6): 1706-1715. DOI:10.1007/s00586-016-4540-2.
12. Lu S., Xu Y.Q., Zhang Y.Z., Li Y.B., Xie L., Shi J.H., Guo H., Chen G.P., Chen Y.B. A novel computer-assisted drill guide template for lumbar pedicle screw placement: a cadaveric and clinical study. *Int J Med Robot.* 2009;5(2):184-191. DOI: 10.1002/rcs.249.
13. Putzier M., Strube P., Cecchinato R., Lamartina C., Hoff E.K. A new navigational tool for pedicle screw placement in patients with severe scoliosis: a pilot study to prove feasibility, accuracy, and identify operative challenges. *Clin Spine Surg.* 2017;30(4):E430-E439. DOI: 10.1097/BSD.0000000000000220.
14. Gertzbein S.D., Robbins S.E. Accuracy of pedicular screw placement in vivo. *Spine (Phila Pa 1976).* 1990;15(1):11-14.
15. Kokushin D.N., Belyanchikov S.M., Murashko V.V., Kartavenko K.A., Khusainov N.O. [Comparative analysis of the accuracy of pedicle screws insertion in surgical treatment of children with idiopathic scoliosis]. *Hirurgia pozvonochnika* [Journal of Spine Surgery]. 2017;14(4): 8-17. DOI: 10.14531/ss2017.4.8-17. (In Russ.).
16. Vissarionov S.V. [Anatomic-anthropometric basis of transpedicular fixation in children of 1.5–5 years old]. *Hirurgia pozvonochnika* [Journal of Spine Surgery]. 2006;(3):19-23. (In Russ.)
17. Lu S., Xu Y.Q., Chen G.P., Zhang Y.Z., Lu D., Chen Y.B., Shi J.H., Xu X.M. Efficacy and accuracy of a novel rapid prototyping drill template for cervical pedicle screw placement. *Comput Aided Surg.* 2011;16(5):240-248. DOI: 10.3109/10929088.2011.605173.
18. Berry E., Cuppone M., Porada S., Millner P.A., Rao A., Chiverton N., Seedhom B.B. 2005. Personalised image-based templates for intra-operative guidance. *Proc Inst Mech Eng H.* 2005;219(2):111-118. DOI: 10.1243/095441105X9273.
19. Ryken T.C., Owen B.D., Christensen G.E., Reinhardt J.M. Image-based drill templates for cervical pedicle screw placement. *J Neurosurg Spine.* 2009;10(1):21-26. DOI: 10.3171/2008.9.SPI08229.
20. Bundoc R.C., Delgado G.G., Grozman S.A. A novel patient-specific drill guide template for pedicle screw insertion into the subaxial cervical spine utilizing stereolithographic modelling: an in vitro study. *Asian Spine J.* 2017;11(1):4-14. DOI: 10.4184/asj.2017.11.1.4.
21. Ma T., Xu Y.Q., Cheng Y.B., Jiang M.Y., Xu X.M., Xie L., Lu S. A novel computer-assisted drill guide template for thoracic pedicle screw placement: a cadaveric study. *Arch Orthop Trauma Surg.* 2012;132(1):65-72. DOI: 10.1007/s00402-011-1383-5.
22. Chen H., Guo K., Yang H., Wu D., Yuan F. Thoracic pedicle screw placement guide plate produced by three-dimensional (3-D) laser printing. *Med Sci Monit.* 2016;22:1682-1686. DOI: 10.12659/MSM.896148.
23. Radermacher K., Portheine F., Anton M., Zimolong A., Kaspers G., Rau G., Staudte H.W. Computer assisted orthopaedic surgery with image based individual templates. *Clin Orthop Relat Res.* 1998;(354):28-38.
24. Birnbaum K., Schkommodau E., Decker N., Prescher A., Klapper U., Radermacher K. Computer-assisted orthopaedic surgery with individual templates and comparison to conventional operation method. *Spine (Phila Pa 1976).* 2001;26(4):365-370.
25. Shao Z.X., Wang J.S., Lin Z.K., Ni W.F., Wang X.Y., Wu A.M.. Improving the trajectory of transpedicular transdiscal lumbar screw fixation with a computer-assisted 3D-printed custom drill guide. *PeerJ.* 2017;5:e3564. DOI: 10.7717/peerj.3564.
26. Wang X., Shi J., Zhang S., Zhang Z., Li X., Li Z. Pediatric lumbar pedicle screw placement using navigation templates: a cadaveric study. *Indian J Orthop.* 2017;51(4):468-473. DOI: 10.4103/0019-5413.209955.
27. Lamartina C., Cecchinato R., Fekete Z., Lipari A., Fiechter M., Berjano P. Pedicle screw placement accuracy in thoracic and lumbar spinal surgery with a patient-matched targeting guide: a cadaveric study. *Eur Spine J.* 2015; 24(Suppl 7):937-941. DOI: 10.1007/s00586-015-4261-y.
28. Farshad M., Betz M., Farshad-Amacker N.A., Moser M. Accuracy of patient-specifc template-guided vs. freehand fuoroscopically controlled pedicle screw placement in the thoracic and lumbar spine: a randomized cadaveric study. *Eur Spine J.* 2017;26(3):738-749. DOI: 10.1007/s00586-016-4728-5.
29. Kawaguchi Y., Nakano M., Yasuda T., Seki S., Hori T., Kimura T. Development of a new technique for pedicle screw and Magerl screw insertion using a 3-dimensional image guide. *Spine (Phila Pa 1976).* 2012;37(23):1983-1988. DOI: 10.1097/BRS.0b013e31825ab547.
30. Burtsev A.V., Pavlova O.M., Ryabykh S.O., Gubin A.V. [Computer 3d-modeling of patient-specific navigational template for cervical screw insertion]. *Hirurgia pozvonochnika* [Journal of Spine Surgery]. 2018;15(2):33-38. DOI: 10.14531/ss2018.2.33-38. (In Russ.).
31. Goffin J., Van Brussel K., Martens K., Vander Sloten J., Van Audekercke R., Smet M.H. Three-dimensional computed tomography-based, personalized drill guide for posterior cervical stabilization at C1-C2. *Spine (Phila Pa 1976).* 2001;26(12):1343-1347. DOI: 10.1097/00007632-200106150-00017.
32. Lu S., Xu Y.Q., Zhang Y.Z., Xie L., Guo H., Li D.P. A novel computer-assisted drill guide template for placement of C2 laminar screws. *Eur Spine J.* 2009;18(9):1379-1385. DOI: 10.1007/s00586-009-1051-4.
33. Kaneyama S., Sugawara T., Sumi M., Higashiyama N., Takabatake M., Mizoi K. A novel screw guiding method with a screw guide template system for posterior C-2 fixation: clinical article. *J Neurosurg Spine.* 2014;21(2):231-238. DOI: 10.3171/2014.3.SPINE13730.
34. Jiang L., Dong L., Tan M., Qi Y., Yang F., Yi P., Tang X. A modified personalized image-based drill guide template for atlantoaxial pedicle screw placement: a clinical study. *Med Sci Monit.* 2017;16(23): 1325-1333.
35. Sugawara T., Higashiyama N., Kaneyama S., Sumi M. Accurate and simple screw insertion procedure with patient-specific screw guide templates for posterior C1-C2 fixation. *Spine (Phila Pa 1976).* 2017;42(6):E340-E346. DOI: 10.1097/BRS.0000000000001807.
36. Kaneyama S., Sugawara T., Sumi M. Safe and accurate midcervical pedicle screw insertion procedure with the patient-specific screw guide template system. *Spine (Phila Pa 1976).* 2015;40(6):341-348. DOI: 10.1097/BRS.0000000000000772.
37. Lu S., Zhang Y.Z., Wang Z., Shi J.H., Chen Y.B., Xu X.M., Xu Y.Q. Accuracy and efficacy of thoracic pedicle screws in scoliosis with patient-specific drill template. *Med Biol Eng Comput.* 2012;50(7):751-758.

DOI: 10.1007/s11517-012-0900-1.
38. Sugawara T., Higashiyama N., Kaneyama S., Takabatake M., Watanabe N., Uchida F., Sumi M., Mizoi K. Multistep pedicle screw insertion procedure with patient-specific lamina fit and-lock templates for the thoracic spine: clinical article. *J Neurosurg Spine*. 2013;19(2):185-190. DOI: 10.3171/2013.4.SPINE121059.
39. Takemoto M., Fujibayashi S., Ota E., Otsuki B., Kimura H., Sakamoto T., Kawai T., Futami T., Sasaki K., Matsushita T., Nakamura T., Neo M., Matsuda S. Additive-manufactured patient specific titanium templates for thoracic pedicle screw placement: novel design with reduced contact area. *Eur Spine J*. 2016;25(6): 1698-1705. DOI: 10.1007/s00586-015-3908-z.
40. Pan Y., Lü G.H., Kuang L., Wang B. Accuracy of thoracic pedicle screw placement in adolescent patients with severe spinal deformities: a retrospective study comparing drill guide template with free hand technique. *Eur Spine J*. 2018;27(2):319-326. DOI: 10.1007/s00586-017-5410-2.
41. Merc M., Drstvensek I., Vogrin M., Brajlih T., Recnik G. A multi-level rapid prototyping drill guide template reduces the perforation risk of pedicle screw placement in the lumbar and sacral spine. *Arch Orthop Trauma Surg*. 2013;133(7):893-899. DOI: 10.1007/s00402-013-1755-0.
42. Azimifar F., Hassani K., Saveh A.H., Tabatabai Ghomshe F. A low invasiveness patient's specific template for spine surgery. *Proc Inst Mech Eng H*. 2017;231(2):143-148. DOI: 10.1177/0954411916682770.
43. Liu K., Zhang Q., Li X., Zhao C., Quan X., Zhao R., Chen Z., Li Y.. Preliminary application of a multi-level 3D printing drill guide template for pedicle screw placement in severe and rigid scoliosis. *Eur Spine J*. 2017;26(6):1684-1689. DOI: 10.1007/s00586-016-4926-1.

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