

SHORT THESIS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY (Ph.D.)

**SEGMENTAL DEROTATION OF THE THORACIC CURVE IN
SCOLIOSIS - BIOMECHANICAL BASIS OF THE APPLICATION OF
THE CAB IMPLANT**

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The Examination takes place at the Library of the Orthopaedic Clinic, Medical and Health Science Center, University of Debrecen, at 11.00 a.m., 29th of June, 2012.

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The Ph.D. Defense takes place at the Lecture Hall of the 1st Department of Medicine, Institute for Internal Medicine, Medical and Health Science Center, University of Debrecen at 13.00 a.m., 29th of June, 2012.

1. Introduction

Scoliosis is a three-dimensional (3D) deformity of the spine which is accompanied by the intra- and intervertebral rotation of the vertebrae and can be characterized with a coronal plane curvature greater than 10° . The prevalence of the idiopathic form occurs from 0.5 to 1.6% in the pediatric population.

The majority of the curves are mild or moderate, which require only conservative treatment. The proportion of curves greater than 40° which require surgical treatment is 0.04%. In Hungary there are 100-150 scoliosis interventions annually.

Despite a broad screening protocol and the development of treatment, the fundamental problems of the etiology and natural course of the disease remain unanswered. Without clarification of these considerations, current methods (whether conservative or surgical) lack causative management.

Our research group has dealt with the peculiarities of scoliotic deformities since the outset of the nineties, paying particular attention to the biomechanics of the thoracic spine. The current importance of the topic, in addition to those mentioned previously, arises from the dynamic development and diversity of the implant systems used in surgical cases. Surgeries with different exposures (thoracotomy, thoracoscopy or posterior approach) may be based on different biomechanical principles and implants can also be fixed to different parts of the vertebrae. Our main interest is to improve the efficacy of derotation, the question of which remains unanswered even today.

At present, the golden standard is the Cotrel-Dubousset (CD) method which was introduced in the 1980s as a revolutionary innovation of the derotational concept, the implant being named after the innovators. This principle was the basis of future implant systems, further developing this surgical technique and the manufacture of implants.

As a result of their work, at first it appeared that they had solved the problem of 3D correction. However, evaluation of the surgical results sometimes revealed significant rotational abnormalities, which were the consequence of the fact that the reduction of the frontal and sagittal curve causes an increase in relative rotation.

For a better understanding and evaluation of the problem, a more profound knowledge of the anatomy and biomechanics of the spine are essential as even today certain details are still not entirely clear. One of these is the location of the axial rotational axis of the thoracic spine. Reviewing the literature, the presence of contradictory statements is notable, but even more surprisingly, these coexist without problem. We consider the exact location of the axis to be essential, as all components of 3D deformity, including rotation, must be corrected appropriately during surgery.

To simplify the surgical technique, Csernátóny developed an implant complementary to the CD systems, the CAB hook (Crochet à Appui Bilatéral), which simultaneously hooks onto the two transverse processes of the same vertebra.

In my work, following a critical review of the diverse and contradictory literature, I present some biomechanical relationships of the thoracic spine which are still unclear and the evaluation of the clinical application and the correctional action of the CAB implant.

2. Objectives

Considering the contradictions and diversity of the literature, we wanted to determine the axial rotational axis of the thoracic spine based on our own experiments. After promising preliminary results the biomechanical basis of segmental derotation and the correctional results achieved by the CAB implant were examined.

According to the above mentioned results our objectives were as follows:

2.1. Determination of the axial rotational axis of the thoracic spine with

2.1.1. Speculative methods

2.1.2. Measurement based experiments

2.2. Examination of the biomechanical basis of the segmental derotation achieved by the CAB implant

2.2.1. Examination of the static loadability of the transverse processes

2.2.2. Examination of the 3D correctional effect of the CAB implant

3. Material and methods

To determine the axial rotational axis of the thoracic spine, partly speculative methods and partly simple measurements were applied.

During the evaluation of the biomechanical basis of the segmental derotation achieved by CAB hooks, the resistance of the transverse processes against vertical loading and axial torque were examined. Examining the 3D correctional effect of the CAB hooks, the surgeries performed using this implant at the Orthopedic Clinic of the Medical and Health Science Center of the University of Debrecen were analyzed.

3.1. Determination of the axial rotational axis of the thoracic spine

3.1.1. Speculative methods

Using a geometrical approach, the determination of the axis of the vertebrae from geometrical regularities was attempted. For the examination, the frontal, horizontal and sagittal x-rays of 126 human thoracic vertebrae from cadavers of different age and gender were used.

3.1.1.1. Determination of the rotational axis from the horizontal view – geometrical deduction

During the examinations, vectors were drawn on the horizontal x-ray of each vertebrae; three ellipses, one trapezoid determined by the articulations of the vertebrae, and two pairs of straight lines matching the longitudinal axis of the articular processes. After drawing the aforementioned setup, the geometrical centers of the 3 ellipses, the trapezoid and the intersections of the pairs of lines were determined.

3.1.1.2. Three-dimensional geometrical determination of the rotational axis

During this approach, the geometrical center of the thoracic vertebrae defining the positions of the longitudinal axis of the ellipses-based cylinders involving the vertebrae from 3 direc-

tions was determined. The center points of the ellipses were assigned, and then the x-rays were superposed based on the length of the same side. The longest distance between the centers of the vertebrae of the different projections determines the diameter of that sphere which involves the three centers of the ellipses.

3.1.2. Experiments based on measurements

3.1.2.1. The examination of the change in volume of the spinal canal

For the volumetric measurements of the thoracic spinal canal the determination of the volume was attempted depending on the localization of the rotational axis. During the measurements, 4 different rotational axes provided in the literature were imitated and 3 other possible axes determined by our presumption were supplemented. On the basis of these, seven identical plastic thoracic spines, each with 12 thoracic vertebrae were prepared and were rotated 85° according to the different rotational axes' sites. Once the desired rotation was achieved, a mold of the vertebral canal was made by injecting it with polyurethane foam. The volume of the molds was measured by immersion into water.

3.1.2.2. Ex vivo – in vitro measurements

During these experiments thoracic spine segments of 5-8 vertebrae were prepared from cadavers. Primarily thoracic spine segments with 5 cm rib stumps and later entire thoracic segments with the whole rib cage were utilized.

3.1.2.2.1. Measurements performed on thoracic spine segments with rib stumps

Twenty-four specimens were used in the study (14 males, average age 72 years; 10 females, average age 76 years). The specimens were inserted into a special cylindrical frame, allowing the possibility for rotation.

Pins were placed into the middle 3 adjacent vertebrae. After the insertion of these pins the upper and lower vertebrae were fixed centrally and axial x-rays were taken from a distance of

1 meter with the spine in a neutral, clockwise and counter clockwise position.

According to the co-rotation of the pins with the vertebrae, the rotational axis of the pins allowed us to draw the center of rotation using the above mentioned projections and parts of the immobile frame as fixed points. The localization of the center of rotation according to vertebrae was grouped as follows: rotational centers located in front of the vertebral body, in the vertebral body, lateral to the vertebra, in the vertebral foramen or behind the vertebral foramen. The measurements were repeated first with the resection of the spondylophytes, then removing one and later three rib stumps connected to the examined vertebrae.

3.1.2.2.2. Measurements performed on specimens retrieved with a slice of the entire rib cage

During these measurements, almost the same method described earlier was followed. The most important difference was that the effect of the entire rib cage was taken into account. An oblique slice of the trunk was made to include thoracic spine segments, corresponding ribs and a portion of the sternum. This time, the inserted pins were registered on digital pictures.

Altogether, 12 specimens were found suitable for the study (7 males, average age 65 years; 5 females, average age 68 years).

The determination of the center of rotation was done in the same manner as the aforementioned experiment (3.1.2.2.1.). Aside from the presence of the rib cage, the direction of the rotational torque and the mobility of the ribcage were considered. The rate of rotation with the sternum both fixed and unfixed was also examined.

3.2. Evaluation of the biomechanical basis of the segmental derotation achieved by CAB hooks

3.2.1. Examination of the static resistance of the transverse process

During our experiments 10 spinal segments from the thoracic spines of fresh cadavers were examined. The average age was 67.5 years [8 female (average age 64.75 years) and 2 male (average age 79.5 years)]. The removed spine was prepared into vertebral pairs with the rib stump of the lower vertebra left attached, and the lower pair of rib stumps was extracted.

All together 107 vertebrae were removed, so 214 transverse processes were available. Instron 8874 (Instron Ltd., High Wycombe, UK) servo-hydraulic material testing apparatus was used for the measurements.

The prepared vertebral pairs with the rib stumps were fixed with threaded rods drilled through the vertebral bodies onto a hard wooden block that was fixed rigidly to the testing apparatus with bolts. Another rod was placed in the spinal canal to prevent rotation of the vertebral pairs during the axial rotation torque testing. After fixation, the transverse process of the lower vertebra (to be referred to later as vertebra with rib stumps) was examined with CAB hook placed on it so that the end of the hook lay between the transverse process of the lower vertebra and its rib stump. The vertical measurements were taken with a simple hook placed on a transverse process with a vertical load of 0.5 mm/s. An axial rotational torque with an angular velocity of 8.5°/sec was achieved. The axial rotational torque was achieved using bilateral hooks (symmetric) fixed to a metal block. The symmetric hooks were placed bilaterally on the transverse processes of the same vertebra. The distance between the rotational axis and the load transfer was 32 mm for all specimens.

By way of the hooks, constantly increasing vertical load or axial rotation torque was applied onto the transverse process until failure occurred. The load was increased until the transverse process was fractured or compressed having lost its mechanical resistance. The ultimate load

or ultimate torque necessary for mechanical failure was recorded graphically according to data registered by the material testing apparatus. The lower vertebra was then removed with its rib stump and the mechanical examination was performed on the remaining upper vertebra alone (to be referred to later as vertebra without rib stumps).

Altogether 142 results were recorded of which 99 were for vertical load and 43 for sagittal torque. The difference between specimens tested with and without rib stumps was examined. Statistical analysis of the data was performed using chi-square test with a 95% level of significance.

3.2.2. Examining the 3D correctional effect of the CAB hooks

In our examination the surgeries were performed by SCS implants and CAB hooks.

Antero-posterior and lateral x-rays were taken of patients in a standing position both prior to and 6 days following surgery. The mobility of the curve with the preoperative bending projection was examined. The so-called bending x-ray was taken in a supine position before the intervention; and the physiological flexibility bending towards the convex side of the curve was analyzed. The size of the curve was measured by the Cobb method. Kyphosis was always measured between the end plates of thoracic vertebrae 5-12 on the lateral x-rays.

The effectiveness of the 3D correction achieved by the intervention as compared to the preoperative flexibility was analyzed with the CCI (Cincinnati Correctional Index) and the KC (Kyphosis Correction) percentage according to Vora.

4. Results

4.1. Determination of the axial rotational axis of the thoracic spine

4.1.1. Speculative methods

4.1.1.1. Determination of the rotational axis from the horizontal view – geometrical deduction

In all cases the centers of the ellipses and the trapezoid were located in the vertebral canal near to the sagittal axis of symmetry. The intersection of the lines drawn to the projection of the articular process fell to the anterior edge of the vertebral body.

4.1.1.2. Three-dimensional geometrical determination of the rotational axis

The centers of the ellipses are located with 97.62% accuracy inside a sphere the diameter of which is 10% of the vertebra. It can also be stated that in the majority of the vertebrae (60%) this sphere is only 3-6% of the vertebral volume. The average volume was 5.37%, with a standard deviation of 2.16%.

4.1.2. Experiments based on measurements

4.1.2.1. The examination of the change in volume of the spinal canal

Based on the examination, it was determined that the smallest change in the volume of the vertebral canal occurred in the axis located on the antero-lateral portion of the vertebra and on the posterior longitudinal ligament.

4.1.2.2. Ex vivo – in vitro measurements

4.1.2.2.1. Measurements performed on thoracic spine segments with rib stumps

Based on the results, the following were established:

- The majority of the results of the measurements placed the center point on, or a little in front of the vertebral body; the minority of the results placed it in the vertebral canal.
- The localization of the center of rotation shows the same location pattern both in the intact spine segments as well as following spondylophyte removal.
- Following rib removal, the point of axial rotation moved forward.

In our opinion, based on the measurements performed on thoracic spine segments with rib stumps the location of the rotational axis is in the ventral portion of the vertebral body.

4.1.2.2.2. Measurements performed on specimens retrieved with a slice of the entire rib cage

These points were grouped according to the protocol described under the heading 3.1.2.2.1.

According to our results, the following can be stated:

- Most of the center points fell on the vertebral body, on or behind the spinal canal on the midsagittal axis of the vertebra.
- If two ribs were removed, the axis moved forward onto the vertebral body or onto the vertebral canal.
- Fixation of the sternum resulted in the axis moving backwards.

Based on our data, the location of the points determined with the 2 methods of measurement were compared (sections 4.1.2.2.1. and 4.1.2.2.2.), and found to be significantly different ($P < 0001$; Pearson chi square = 143.476). It can be concluded from these results that the rib cage has a significant effect on the determination of the axis.

4.2. Evaluation of the biomechanical basis of the segmental derotation achieved by CAB hooks

4.2.1. Examination of the static resistance of the transverse process

The maximal load or torque, or the so-called load limit which was demonstrated during the measurements was clearly shown on graphs recorded by the servo-hydraulic material testing apparatus.

4.2.1.1. Vertical load

During the vertical measurements, all examined transverse processes became mechanically insufficient. The average load limit necessary for mechanical failure was 338N (92.85-620.41) with a standard deviation of 128N. This result was 353N (92.85-618.34) in cases of vertebrae without rib stumps, with a standard deviation of 138N. In cases of vertebrae with rib stumps this result was 316N (111.54-620.41) with a standard deviation of 110N.

4.2.1.2. Axial rotational moment

During the measurements of the axial rotation of the vertebra the maximal axial torque was determined. Of the 43 rotations performed, in 40 cases only the examined transverse process (sagittally rotated backward) became insufficient, in one case contralateral, and in two cases bilateral transverse process failure was observed.

The average torque necessary for failure was 14.4 Nm (5.4-24.69) with a standard deviation of 4.5 Nm. This result was 12.5Nm (5.4-19.91) in cases of vertebrae without rib stumps, with a standard deviation of 4.4Nm. In cases of vertebrae with rib stumps this result was 15.9Nm (9.01-24.69) with a standard deviation of 4.1Nm.

4.2.2. Examining the 3D correctional effect of the CAB hooks

There were 23 scoliosis operations performed using only CAB hooks between September 2007 and October 2011 in the Orthopaedic Clinic of the Medical and Health Science Center, University of Debrecen. The gender ratio was 4.75:1 (19 female: 4 male) with an average age

of 15.85 years (11.5-25.75 years). The mean follow up was 12.74 months.

Based on the future growth potential of the spine, so-called spinal regulation was performed in 10 cases, which is to say that spinal instrumentation was achieved without arthrodesis, with regard to future spinal growth. Among those 13 patients where spinal growth was considered to be nearly complete, the correctional intervention was accompanied by arthrodesis.

The 10 spinal regulations were performed exclusively on female patients, mean age 13.1 years (11.5-14.5 years). Of the 13 cases which included arthrodesis nine were female and four were male with a mean age of 17.96 years (14.74-25.75 years).

The average curvature prior to surgery was 60.5° (38° - 92°). The average bending curve angle was 33.7° (8° - 64°), which signifies a 46% preoperative flexibility. The postoperative correction of the curves was 22.7° (8° - 42°), which constitutes a 63% postoperative correction. The corrected mean CCI value determined by the aforementioned results was 1.66, thus demonstrating that 66% more effective correction was achieved than with physiological flexibility.

In case of kyphosis the target value was between 10° - 40° . The preoperative mean kyphosis was 18.69° (2° - 56°), while the postoperative value was 14.34° (-14° - 30°). During the intervention the objective was to maintain angles between 10° - 40° in cases which were already between these values, to increase it in cases of hypokyphosis and to reduce it in cases of hyperkyphosis. In 12 cases the preoperative values were between the physiological intervals, and this was maintained in all but two cases. In nine cases the preoperative values were hypokyphotic and in six of these normokyphosis was achieved. In two cases normokyphosis was achieved from hyperkyphosis. In total, 18 out of 23 cases (78.26%) were maintained or corrected into the optimal range.

5. Discussion

Currently quite a lot is known about the biomechanics of healthy and pathologic spines. Nonetheless, the literature gives contradictory results for a seemingly simple question like the position of the axial rotation of the thoracic spine. The importance of the issue is undisputed. We wanted to clarify this question, so we examined the thoracic spine from many different aspects.

Our initial hypothesis was that the rotational axis must be in the vertebral canal. If not, during rotation of two adjacent vertebrae, a so-called „cigar-cutting” effect could significantly reduce the diameter of the vertebral canal and in already narrow anatomical circumstances it could have a shearing effect on the spinal cord. In other words, a rotational axis far from the spinal canal would endanger the spinal cord due to the reduction of the diameter.

During our work the thoracic spine was examined in many different ways:

With the speculative approach (section 3.1.1.), we tried to determine the axis of the vertebrae from geometrical regularities. When determining the rotational axis from the horizontal view (section 3.1.1.1.) the location of the geometrical centers (ellipses and trapezoid) and the intersections of the pairs of lines were examined.

During the three-dimensional geometrical determination of the rotational axis (section 3.1.1.2.) it was assumed that the 3 directional rotational axes of the vertebra intersect each other at the same point, which is the geometrical center of the vertebra. We tried to determine the center by the positions of the longitudinal axis of the ellipses-based cylinders involving the vertebrae from 3 directions.

For the volumetric measurements of the thoracic spinal canal we tried to determine the volume depending on the localization of the rotational axis (section 3.1.2.1.). The thoracic spine was fixed along different axes and rotated. A mold of the vertebral canal was made in the ro-

tated position by injecting it with polyurethane foam, and the volume of the mold was measured by immersion into water.

During the ex vivo and in vitro measurements thoracic spine segments from cadavers (section 3.1.2.2.) were prepared. First thoracic spine segments with rib stumps were used (section 3.1.2.2.1.), and later entire thoracic segments with the whole rib cage were utilized (section 3.1.2.2.2.). The retrieved specimens were fixed and pins were placed into the middle 3 adjacent vertebrae. Axial x-rays were taken in a neutral position, and then the spine was rotated in clockwise and counter clockwise directions according to the initial position. The measurements were repeated with resection of the spondylophytes, then removing one and later three rib stumps connected to the examined vertebrae. The rotations were documented with x-rays, but later in the cases of specimens retrieved with a slice of the entire rib cage, digital pictures were used for documentation. The axial rotational axis was constructed utilizing geometrical methods with the help of the pins according to the different circumstances of the experiments. Summarizing the results and placing the supposed location of the axial rotational axis determined by the different methods onto one vertebra, it can be concluded that the most likely place of the axial rotational axis

- is in the midsagittal axis
- falls on the vertebral body, in front of the vertebral body or in the spinal canal.

The results of the examinations performed with spinal segments with the rib stumps and rib cages demonstrated that the effect of the ribs on the axis must be taken into account.

At this point, it became clear to us that the contradiction in the literature is caused by the fact that the spine segments were examined without ribs or with an improper method. In both of the examination series, it can be observed that the rotational axis is located more anteriorly if

the ribs are not present. Therefore, only the cadaver spine segment examinations performed on specimens retrieved with a slice of the entire rib cage can be considered accurate.

Following the same argument our results must be revised to consider only those which take into account this aspect.

In summary, the most likely place for the physiological axial rotational axis is on the median-sagittal plane, in the anterior portion of the spinal canal.

After the results of the initially theoretical and later laboratory *ex vivo* and *in vitro* experiments, the biomechanical basis of the segmental derotation achieved by the CAB hook was examined.

The advantage of the CAB hook is that it is fixed onto both of the transverse processes simultaneously and should therefore generally require half the load for a given torque. Also, it rests in an anatomically “safe” place and furthermore the centre of the arch along which it is displaced falls approximately within the vertebral canal.

After the examination of the biomechanical basis of the use of CAB hooks, it can be stated that the vertical and the sagittal (axial rotation) loading capability of the transverse process is fairly large (section 4.2.1.).

The average vertical compression load required for the mechanical failure of one transverse process was 338 N, and since in normal circumstances a vertebra has two transverse processes, and the CAB hooks are placed simultaneously on both, the load limit for the transverse processes of the vertebra should be $2 \times 338 \text{ N} = 676 \text{ N}$. This far exceeds the intraoperative force reported by Nachemson et al. (412 N). Since the cadaver segments were retrieved from elderly patients (average age 67.5 years), we propose that this force would be even larger in the intraoperative setting.

The average axial rotational torque was 14.4 Nm in case of CAB implants placed on both transverse processes of the thoracic vertebrae, the results of which are 1.5 times more than the rotational resistance of the transverse processes of the lumbar vertebra obtained by Arregui-Dalmases et al.

Calculations performed for the load limit of the transverse processes against different forces, found no significant difference ($p=0.1548$) between vertebrae without or with rib stumps. At the same time the axial rotation torque for the load limit of specimens with rib stumps was significantly greater ($p=0.0113$) than for specimens without rib stumps.

Based on these results it can be stated that after the placement of the CAB hooks significantly large corrective forces can be utilized. Additionally, it can be concluded from these results that the stabilization function of the rib for the transverse process prevails only during sagittal load (axial vertebral rotation).

Taking into account the fact that during an intervention the hooks are placed on different transverse processes, the value can be multiplied by each transverse process. If the postoperative physiological load is examined and compared to that found prior to surgery, it can be stated that after the placement of the CAB hooks the montage can be safely manipulated, and a stable environment is provided in the postoperative period as well.

During the examination of the corrective effect of the CAB hooks 23 scoliosis operations (where only CAB hooks were implanted) were examined between September 2007 and October 2011 in the Department of Orthopaedics of the Medical and Health Science Center, University of Debrecen. For the evaluation of the results the indexes of CCI and KC were used. The postoperative correction was 66% better than preoperative flexibility, so 66% better correction was achieved than the physiological flexibility. During the evaluation of the kyphosis, 18 out of 23 cases (78.26%) were maintained or corrected into the optimal range. These results correlate with the relevant literature.

The examination of the derotation achieved by CAB hooks is a very important aspect during the evaluation of the postoperative results which unfortunately presents many difficulties.

There is no valid comparative method in the evaluation of the preoperative and postoperative rotation on the x-rays. The classification applied by Nash and Moe – which is based on the asymmetry of the projection of both pedicles – cannot be used on the postoperative x-rays, because often the superposition of the implant and the vertebra prevents a good view.

The measurement of the rib hump is another frequently used indirect method, but it is misleading in the rigid cases.

The only objective method would be CT scan, but performing CT for this purpose is unethical due to the radiation risk to patients. Additionally, the CT scan is technically problematic due to the presence of the metal implant which can cause disturbing artefacts making evaluation impossible.

In spite of this, we would like to solve the examination of the derotation in the future. We want to perform an AP x-ray intraoperatively, after the placement of the CAB hooks but before the implantation of the rods. This x-ray should help to compare the situation of the hooks with the postoperative x-ray. In this manner the effect of the CAB hook on the curvature delineated both before and after the correction can be documented.

6. New results

- 6.1.** Our findings have clarified that the rib stumps and the slice of the entire rib cage significantly affect the determination of the axial rotational axis, so we can take into account those experiments which consider this effect.
- 6.2.** Based on our data, the location of the axial rotational axis of the thoracic vertebrae is on the anterior wall of the spinal canal.
- 6.3.** During the examination of the biomechanical basis of segmental derotation achieved by the CAB implant, it was established that the average resistance of the transverse process against vertical compression in the elderly population of the study (average age 67.5 years) was 338 N.
- 6.4.** The average ultimate axial rotation moment for the transverse process (derotation) in the elderly population (average age 67.5 years) was 14.4 Nm.
- 6.5.** When taking into account the results mentioned above, the fact that the CAB hooks are placed simultaneously on both transverse processes of the same vertebra, and that they are placed at different levels, as well as taking into consideration the maximal vertical compression force (412 N) and axial rotational moment (9.6 Nm) referred to in the literature, we can claim that the montage can be manipulated safely during the intervention.
- 6.6.** The comparison was performed using the index of Vora, which is the most commonly used in the literature.
- 6.7.** Examining the 3D correctional effect of the CAB hooks it was established that the curves which were rigid prior to surgery (where flexibility cannot be taken into account) were not suitable for the determination of the Vora index.

- 6.8.** The CCI and KC indexes of the Department of Orthopaedics, Debrecen correlate with those found in the literature.
- 6.9.** A new work method for the examination of the derotation of the vertebrae was determined which will be employed in future clinical practice.

7. Summary

The derotation of the thoracic vertebrae even nowadays is still one of the hardest tasks in scoliosis deformity correction. Lack of knowledge regarding physiological rotation is an impermissible luxury when trying to efficiently overcome abnormal rotation with dynamically developed implant systems.

Inconsistencies in the literature and the results of preliminary experiments have led us to find a theoretical model for the explanation of thoracic vertebrae rotation. In our work we have tried different ways to approach the question in a speculative way, and also with direct and indirect measurements. We summed up our results, and then by reevaluating our method we finalized our general statement: the most probable location of the axis of rotation of the thoracic vertebrae is at the portion of the anterior wall of the spinal canal that falls into the medio-sagittal plane. Our results contradict most of the findings published in the literature. Examining the biomechanical basis of the CAB implant we can conclude that through the hooks significant correctional forces can be safely achieved. Based on these results we can also conclude that the stabilizing function of the ribs on the transverse process only prevails in sagittal forces. In addition it should also be noted that the CAB hooks are placed on both transverse processes of one vertebra, and also that during surgery multiple hooks are placed. Therefore the otherwise also significant correctional forces that can be achieved through a transverse process can be added up. If we examine the postoperative physiological load and compare it to the previous one, we can state that after the placement of the CAB hooks the montage can be safely manipulated, and that it provides a stable environment in the postoperative period as well. This is supported by the correctional results of patients operated with CAB hooks at the University of Debrecen, Department of Orthopaedics.

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Candidate: Szabolcs Molnár

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List of publications related to the dissertation

1. Csemátóy, Z., **Molnár, S.**, Hunya, Z., Manó, S., Kiss, L.: Biomechanical examination of the thoracic spine: The axial rotation moment and vertical loading capacity of the transverse process.
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