Coll. Antropol. **33** (2009) Suppl. 2: 145–152
Original scientific paper

Changes in Pulmonary Functional Parameters after Surgical Treatment of Idiopathic Scoliosis

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A B S T R A C T

There is a controversy in results about influence of surgery on pulmonary function in idiopathic scoliosis. The aim of the study was to study pulmonary function in severe thoracic idiopathic scoliosis and to detect changes in pulmonary function after the three-dimensional anterior surgical correction in severe thoracic scoliosis. 91 patients at the age of 16±5.1yrs underwent surgery in order to make a correction of scoliotic deformity. All the curves were greater than 70° (86±5.1). Group I consisted of 60 patients with scoliotic curves between 70° and 100°, while group II consisted of 31 patients with curves greater than 100°. All the patients were operated by anterior instrumentation and the average correction was 74%±15 for group I, and 71%±18 for group II. Vital capacity (VC) and forced expiratory volume in the first second (FEV1) in group I remained unchanged. In group II, VC improved for 11%, while forced expiratory volume (FEV) improved for 13.6%. Our conclusion is that there is a significant correlation between the percentage of achieved correction and pulmonary function.

Key words: *idiopathic scoliosis, pulmonary function, anterior approach*

Introduction

Human spine, generally speaking, is straight in frontal plane, while in sagittal plane has the shape of double bended letter »S«. Under the term »scoliosis«, we mean a three-dimensional spine deformity, in combination with torsion deformity of the thorax which progresses in time. Beside existance of bony deformation, scoliosis is pressing on lungs and other intrathoracic organs, causing deterioration of pulmonary and/or cardiac function, which can cause development of lung and cardiac diseases, reduce quality of life, and even life expectancy[1–5]. Until now, it was considered that all scolioses above 60° are typically followed by a bigger or smaller decrease of pulmonary function[6]. However, some cases were described with very severe thoracic scolioses (whose lateral curvature was greater than 100°), with no significant pulmonary function deterioration[1,7–10].

Which patients will develop manifest respiratory and cardiac insufficiency, is there any connection between severity of the deformity and/or location of the deformity with the lung function, what changes of cardiopulmonary function are struck at earliest, still remain unanswered[11–13]. Literature published so far hasn't agreed on how much individual components of the scoliotic deformity influence on change of pulmonary function, as well as if correction of the spinal deformity improves function of the lungs[14–16]. Due to the discrepancy between the results in the literature, opinions differ whether the age when scoliosis develops or a certain component of spinal deformity (thoracic lordosis, rotation,...), which leads to the narrowing of the anterioposterior diameter of thorax, is responsible for deterioration of pulmonary function. The question is whether the cause of pulmonary insufficiency lies in the deformity itself, developmental/histological abnormality of the lungs, weakness of the respiratory muscles, or the problem lies in the physiological insufficiency of the respiratory function?

In this survey we comprised a huge number of scolioses operated by the method of anterior instrumentation, hoping that it would clear connection between spinal deformity (scoliosis) and functionality of lungs. Anterior approach is a method of the operative approach, which according to recent literature gives better postoperative corrective results[17], but at the same time it is less repre-

Received for publication July 8, 2009

sented, probably because of its invasivity and transitory negative effect on pulmonary function after the surgery.

Our intention was to study possible correlation between spinal deformity and deterioration of pulmonary parameters. For each patient before the surgery we determined severity of scoliosis by measuring Cobb's angle from conventional radiograms, and estimated pulmonary function by performing spirometry analysis. Improvement of pulmonary function after the anterior approach surgery, which accomplishes three-dimensional correction of the spinal deformity, was also a subject of our concern. We analyzed postoperative spirometry results 10 days, 1 month, 3 months, 6 months and one year after the surgery (or until normalization of spirometry results), with a goal to identify whether in the meantime improvement of pulmonary function occurred.

We wanted to make a connection between following three issues: spinal deformity, pulmonary function disorder, and surgical procedure. In that case, the surgical procedure could be the method that not only corrects a complex thoracic deformity with correction of major esthetic disadvantage, but also enables the patients to regain normal pulmonary function.

Influence of Scoliosis on Pulmonary Function

Scoliosis causes wide variety of problems: esthetic problems, impairment of pulmonary and cardiac function, and most important, shortening of patient's life expectancy. Scoliosis is a three-dimensional rotational and torsional deformity of the spine, of still unknown cause[18–21]. Because of spinal bending in all three planes, a change in its static occurs, which is clinically obvious as a posture change, formation of lateral deformity and all clinical symptoms with trunk, breasts, shoulder and pelvic girdle asymmetry, and asymmetric posture. Spine drags all other structures (ribs, muscles and intrathoracic organs). As ribs follow the spine, on the convex side they pull backwards, forming posterior rib hump on the back of the convex thoracic half. On the concave side, ribs are pushed forwards, forming anterior rib hump, and on the back posterior rib valley (Figure 1). So far, genetics has been considered as one of the most important components of the disease occurrence[22]. However, the multifactor model still gives the most complete picture of scoliosis origins, which beside genetics, finds lots of other factors responsible, like endocrinological disorders, growth factors, central nervous system, etc.

Several factors have been recognized as a cause of pulmonary function deterioration in scoliosis. Beside spinal and thoracic deformities, most possible reasons for this are following: weakness of muscle function[5,23,24], thoracic lordosis[25–29] and decreased compliance of the thoracic wall. Spirometry has proven that patients with scoliosis experience pulmonary dysfunction of restrictive type[11,30,31], because of compression on lung parenchyma and progressive decrease of lung volumes (Figure 2 and 3). Because of those changes in patients with scoliosis, characteristic decrease in certain lung volumes occurs: total lung capacity (TLC), vital capacity (VC), inspiratory capacity (IC), while residual volume (RV) in most patients remains normal or slightly lowered.

Mild respiratory restriction is represented only with decrease in lung volumes and is clinically well tolerated. VC is usually struck the most, and correlates with severity of degree of curvature, measured in Cobb's angle, especially beyond 60° of curvature. TLC often can be extremely low, with characteristic reduction of its components. TLC and VC in idiopathic scoliosis tend to de-

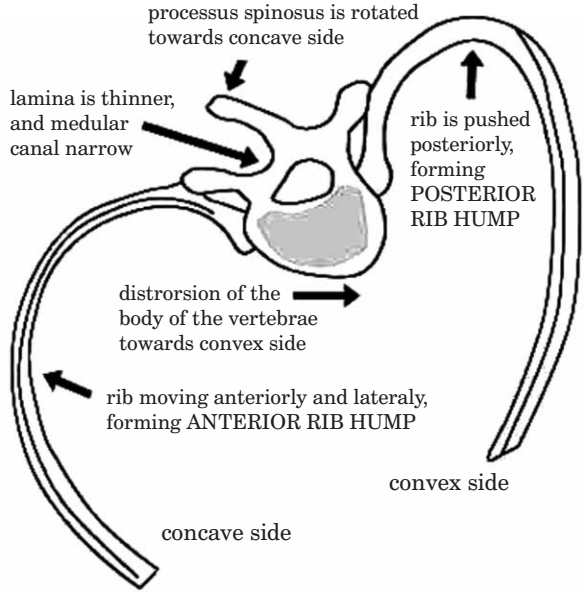

Fig. 1. Thoracic and spinal deformation. seen from horizontal plane.

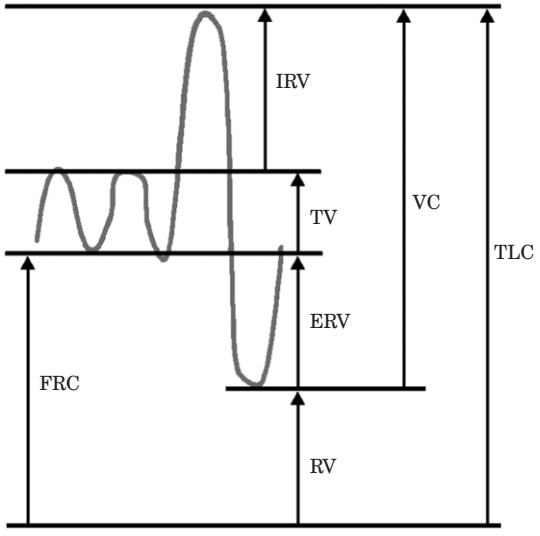

Fig. 2. Normal lung volumes. FRC – functional residual capacity. IRV inspiratory residual volume. TV – tidal volume. ERV – expiratory residual volume. RV – residual volume. VC – vital capacity. TLC – total lung capacity.

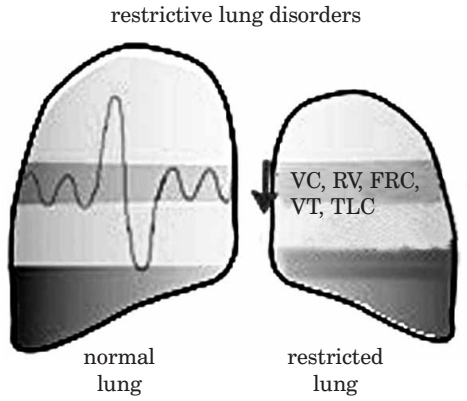

Fig. 3. Restricted lung volumes. VC – votal capacity. RV – residual volume. FRC – functional residual capacity. VT – tidal volume. TLC – total lung capacity.

crease paralelly, especially in more severe cases, beyond 90°. Together with the worsening of deformation, pulmonary function often gets worse as well, evidenced by occurrence of arterial hypoxemia, hypercapnia, pulmonary hypertension, and acute respiratory failure classified as a preterminal event[32,33]. Decrease in forced expiratory volume in the first second (FEV1), which is often present in patients with scoliosis, is not explained as pulmonary pathology of obstructive type, but as a consequence of respiratory tract infection to which patients with scolioses are very often exposed. Today, 60° curvature according to Cobb can most often be found as threshold for changes in respiratory function[6], with more serious deficits of pulmonary function expected at 90–100° curvature, when TLC drops at 50% or less of normal findings, and VC on 60% or less[34]. Some authors even determine 70° as a boundary for irreversible changes[35,36]. However, there are papers published on scolioses with very mild deformation in which limitation of pulmonary function starts already above 25°[37], as well as scolioses with very severe deformation with no significant deficit of pulmonary function[38].

Influence of Scoliosis on Cardiac Function

Right ventricle hypertrophy, with or without congestive cardiac insufficiency, is defined as a »scoliotic heart disease« (cor pulmonale, pulmonary heart disease), which besides cardiac insufficiency is often accompanied with developing pulmonary hypertension, elevated cardiac output, and polycythemia and hypervolemia[33]. It is still unknown how many patients with cardiopulmonary insufficiency end up fatally, although there are papers which studied causes of death in scoliotic patients, and connection of cor pulmonale and cardiac diseases in scolioses[39–41]. Postoperative mortality of scoliotic heart diseases is lately known to be around 35%[42].

Congenital heart valve anomalies are, along pulmonary hypertension, cor pulmonale and cardiac insufficiency, according to literature, also connected to scolioses, with mitral valve prolapse being most often. Prolapse is proven to be most often in patients with thorax abnormalities, such as scoliosis[43–46]. According to the literature, 75% of patients with mitral valve prolapse have accompanying thorax deformity, while[44,46] in a group of patients with idiopathic scoliosis there is approximately 25% of patients with accompanying mitral valve prolapse.

Effects of Operative Correction of Scoliosis on Spine and Cardiopulmonary Function

After the finalization of growth swing, the formation of physiological shape is aimed by applying force on the spine. That is achieved by spondylodesis after gaining the corrected position of the spine (Figure 4). Spondylodesis means the fusion of individual spinal segments, which are involved in the scoliotic deformation. Correction of the curvature, achieved by instrumentation, is permanently kept in the corrected position after ending of bony fusion 3–12 months after the surgery. Improvement manifests by improvement of thoracic mobility, and regaining the symmetry of hemithoraces movements[4].

Progression of pulmonary function deterioration is stopped by surgery. Surgical stabilization of the spine and correction of thoracic deformity lead to decompression of lung parenchyma and the heart, which directly influences the functionality of thoracic organs. Certain authors believe that surgical correction of the spine improves pulmonary function instantly after the surgery[47]. In an early postoperative period it is relatively difficult to estimate pulmonary function due to postoperative recovery, hypoventilation due to analgetic therapy, different types of breathing due to experiencing postoperative pain and postanesthetic changes[33]. Due to the reasons

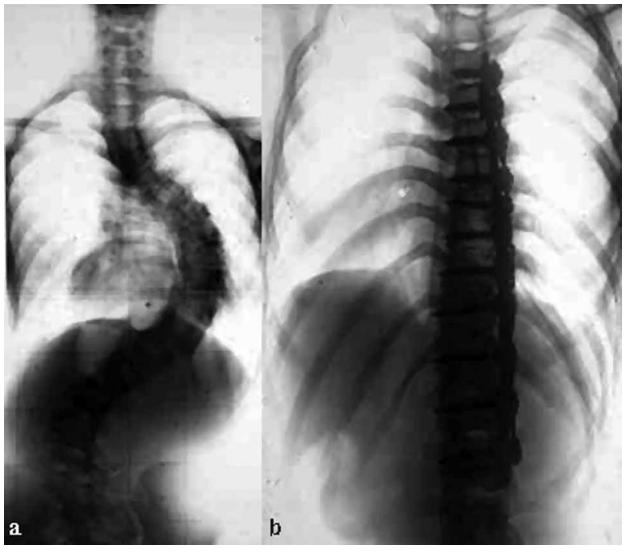

Fig. 4. a) X-rays of severe scoliotic deformity (preoperative 100° curvature according to Cobb). b) successful correction of the right thoracal scoliosis by modified anterior instrumentation and spondylodesis (postoperative 6° curvature according to Cobb).

stated, measured lung volumes and maximal expiratory flow of the patient could be 10–30% lower. The only parameter that usually improves in all patients directly after the surgery is arterial oxygenation (PaO_2)[48], which is the result of improved regional ventilation. Because of decrease in pulmonary function, one should be careful with patients who already preoperatively had moderate or severe reduction of respiratory function. In those patients, detailed preoperative tests, including assessment of cardiopulmonary function are recommended[33,49,50].

It is expected that pulmonary function will improve after recovery from the surgery. Until now, however, it hasn't been proven that correction of scoliosis leads to improvement of pulmonary parameters. Although literature states that in most cases this improvement happens within 2 years from the surgical correction of scoliotic deformity[51–53], there are numerous studies, which described insignificant improvement of pulmonary function after the surgical correction[33,52–56]. It is necessary to cease the further progression of scoliosis, because its influence on pulmonary deterioration is unquestionable[33].

Patients

In this research we included patients who were diagnosed with idiopathic thoracic scoliosis of moderate or severe degree of curvature. We treated 91 patients, 74 (81%) female and 17 (19%) male. Mean age was 16+5.1 years (Graph 1). All patients were treated surgically by anterior approach method, while average number segments fused during the surgery was 9. Average follow-up was 4 years and 9 months.

In this research, 91 patients were involved, who were divided into 2 groups, according to the severity of the scoliotic deformity. Considering that all patients had scoliosis over 70° curvature according to Cobb (average deformity was 86°+5.1), in the first group we involved all patients of moderate degree of scoliosis (70°–100° curvature according to Cobb), and in the other all the other patients with severe degree of deformity (>100° curvature according to Cobb, Table 1).

Methods

In the first phase we determined degree of spinal curvature for all the patients, calculated from the X-rays, according to Cobb's method. In the second phase we started their preoperative assessment, which[32,49,57] among other things, included assessment of cardiorespiratory function, with accent on spirometry, which is the golden standard for pulmonary function assessment. In the third phase we considered surgical procedure itself – correction via anterior approach – its performance and the results. We measured achieved correction of the curvature and spirometric parameters after the surgical procedure. Spirometry was performed as a measure of respiratory functionality. All examinees were operated by same surgeon, by anterior approach.

TABLE 1
PREOPERATIVE VALUES, EACH GROUP RESPECTIVELY

	I. Group	II. Group
Number of patients	60	31
Mean age/years	16.8	15.2
Preoperative values of Cobb curvature/°	74.7°±13	108°±11
Preoperative values of VC/%	81.6%±15	65.8%±20
Preoperative values of FEV1/%	80.3%±17	65.3%±22

VC – vital capacity. FEV1 – forced expiratory volume in he first second

Spirometric parameters used in this research

In accessible literature[10,12,13,24,30,31,33,50,58–61] it has been proven that severe scoliosis causes restrictive type of impairment of pulmonary function, with reduction of most of the lung volumes, due to reduced transfer of gases on alveolar surface. In patients whose spirometric findings were pathological, it was recommended to calculate Tiffenau index. This index is FEV1/VC ratio, which discovers whether ventilation problems are of obstructive (>70%) or restrictive (<70%) type. In case that patient has restrictive ventilatory deficit, as in scoliosis, both FEV1 and VC are reduced proportionally, so that their ratio remains inside of physiological boundaries, higher than 75%[62].

Operative correction of scoliosis by anterior approach

Anterior approach was developed in late 1960s in Australia (Dwyer, 1969), and Klaus Zielke from Germany perfected it in the 1970s, as an alternative for traditional posterior approach – posterior fusion. Main advantage of the anterior approach is that in certain cases it enables the surgeon a better postoperative correction of the curvature, performed with less segments fused. Today's possibilities of anterior mobilization and scoliosis correction comprise resection of discus, osteotomy of the ribs and, if needed, joined posterior osteotomy of the spine.

Statistcs

Results that we got, we analyzed statistically in a Excel programme from Windows XP package. We described the data by methods of descriptive statistics. We categorized them, calculated average values of each analyzed parameter (age, preoperative curvature according to Cobb, VC, FEV1, and the same parameters measured postoperatively). Finally we compared preoperative values with the ones achieved after the surgery.

Results

Curvature according to Cobb and degree of postoperative correction.

TABLE 2
PREOPERATIVE AND POSTOPERATIVE VALUES OF CURVATURE ACCORDING TO COBB. FOR EACH GROUP RESPECTIVELY

	I. Group	II. Group
Preoperative values of curvature according to Cobb	74.7°±9	108°±11
Postoperative values of curvature according to Cobb	19°	36.6°
Degree of correction	74%±16	71.5%±18

Average curvature according to Cobb in our research was 86°±5.1. Average correction of the curvature in a group with mild scoliosis (group I) was 74%±16 (starting from 74.7°±9 before the surgery to average 19° after the correction). In the group with more severe scolioses (group II) achieved correction was 71.5%±18 (from 108°±11 before the surgery to 36.6°, Table 2).

Lung volumes before and after the surgical correction

Changes in lung volumes occurred, after which the average value of VC for the first group was –1.0%, and for the second 12.5% (Table 3). Total accrual of FEV1 in the first group was positive, although very low and was 0.9%, and on another 13.6% (Table 4).

Discussion

The term »scoliosis« is known from time of Hippocrates[63] and during the centuries it occupied doctors' attention. However, the connection between spinal deformities and the decrease of respiratory function is mentioned in researches, which date only from the mid-twentieth century. In 1975 Kafer published that Cobb's angle greater that 100° correlates with decrease in lung volumes from 29 to 37%[64].

Most of the published researches confirmed that cardiopulmonary changes emerge as a result of spinal deformity, which results in decrease of lung volumes and reduction of pulmonary function, appearance of arterial hypoxemia, pulmonary hypertension and possible development of cor pulmonale[10,12,33]. Opposed to that, some studies still state that cardiopulmonary changes and the development of bony deformity occur at the same time in scoliosis[45,65], and that scoliosis is more frequent in patients with congenital heart diseases. If alleged processes really develop paralelly, there is a question whether those changes in skeleton, lungs and heart could have the same origin, possible collagen defect?

TABLE 3
PREOPERATIVE AND POSTOPERATIVE VALUES OF VC. FOR EACH GROUP RESPECTIVELY

	I. Group	II. Group
Preoperative values of VC	81.6%±15	65.8%±20
VC 10 days after the surgery	79.3%±12	59.9%±24
VC 1 month after the surgery	79.8%±11	72%±16
VC 3 months after the surgery	80.6%±17	76.8%±19
VC 6 months after the surgery	–	78.3%±8
VC 1 year after the surgery	–	–
Accrual	–1.0%	+12.5%

VC – vital capacity

TABLE 4
PREOPERATIVE AND POSTOPERATIVE VALUES OF FEV1. FOR EACH GROUP RESPECTIVELY

	I. Group	II. Group
Preoperative values of FEV1	80.3%±17	65.3%±22
FEV1 10 days after the surgery	80.7%±14	60.1%±26
FEV1 1 month after the surgery	80.5%±3	68%±17
FEV1 3 months after the surgery	81.2%±11	75.4%±20
FEV1 6 months after the surgery	–	78.9%±14
FEV1 1 year after the surgery	–	–
Accrual	+0.9%	+13.6%

FEV1 – forced expiratory volume in the first second

Some studies investigated the influence of many individual factors on genesis and progression of scoliosis and the decrease of pulmonary function: degree of curvature, thoracic mobility, influence of exercising, influence of orthoses, weakness of muscle function[5,23,24], influence of thoracic lordosis[25–29], reduced compliance of thoracic wall[66], as well as other surgical approaches to the correction of scoliosis[43,65,67–72].

It is generally believed that lung volume mostly determines pulmonary function in scolioses, although it depends on the shape and the size of the thorax, and its biomechanic features which can be changed due to spinal deformity[12]. Numerous papers have shown that correction of the deformity leads to improvement of pulmonary status of the patients[73,74]. In the literature, successful surgical treatments of very severe scoliosis were described (90°–200°), even with limited pulmonary function[10,42]. Today's state of the art is that progression of scoliosis and its influence on respiratory function must be stopped in time. For example, as indication for surgical corrective treatment of scoliosis Zielke takes vital capacity below 1000 mL[75]. However, there are some individual researches (Goldberg, Gillic et al., 2003), which don't recommend surgical correction of scoliosis primarily in order to improve lung function. As reasons for that, authors give examples where only mild or no improvement of respiratory function occurred after the surgical procedure[54,76].

There are many references in the literature, which assess the influence of operative approach on patients' pulmonary function. For example, recent literature considers that posterior approach, which was used in scoliosis surgery more often in the past, is inferior to the anterior

approach because posterior approach enables correction of spine in one or two planes, while anterior approach enables correction of the scoliotic deformity in all three planes. It is proven that correction by posterior approach can be related to relatively modest improvement of pulmonary function, while anterior spinal fusion through the open thoracotomy is most often related to additional decrease of pulmonary function[51,52,76,77]. Most of the authors agree that this is just a transitory phase of lung function, and therefore Graham[51] and Lenke[53] specify period of two years within which pulmonary function in patients who underwent anterior spinal fusion returns to normal. Operative correction of scoliosis by posterior approach achieves correction of 55–60%, with derotation of 15%, while by anterior approach achieves correction of 76% with derotation of about 65%[78–83]. That is why it is thought that possible reason of the resistency in treating pulmonary insufficiency could lie in a type of operative procedure, or that better results in treating respiratory insufficiency could be obtained by correction via anterior approach.

Despite many studies conducted[80,84,85], so far there are still no answers to question of eventual improvement of pulmonary function after operative correction of scoliosis by anterior approach[76]. Reason maybe lies in numerous controverse conclusions, which resulted from those researches[11–13,86], but also in relatively small number of patients (especially those with more severe forms of idiopathic scoliosis) who were operated worldwide by anterior approach.

For this research we retrogradely analyzed the results of operative correction of idiopathic scolioses in 91 patients. Besides the influence of operative correction on the degree of spinal curvature, we also studied the influence on correction of pulmonary function in same patients. Achieved correction by operative procedure in the group with moderate scolioses was 74%, and in the group with severe scolioses achieved correction was 71.5%. Our results partially confirm results of few earlier surveys, but they also open additional questions related to relation between spinal deformity and pulmonary function. Accoding to the literature, the decrease in pulmonary function is most often found in an early postoperative recovery, which is in most cases estimated by measuring values of VC and FEV1. Results of the first spirometry 10 days after the surgery, showed the same trend of decrease, which is recorded in surveys described in literature[13,30,52,69,76,86,87]. Later, during the recovery period from the surgery, many authors tried to connect achieved correction of scoliosis with pulmonary parameters, which is equivalent of pulmonary function. Most of the authors[26,48,65] recorded significant improvement of respiratory function, first of all VC, although in very different time intervals from the surgery: from the instant recovery after the surgery up to 25 years after the procedure[88,89]. In majority of cases there is a vast improvement of pulmonary function recorded only within 2 years from operative correction of scoliotic deformity[51–53]. Some authors (Zorab et al., Shnersson and Edgar 1979, Ordiales 1998) didn't record any improvement of pulmonary parameters at all, which is mostly explained by the fact that in those papers patients with mild forms of scolioses were included, who preoperatively didn't have any significant abnormalities of pulmonary function[90,56], or in those patients there was no improvement because they had severe forms of spinal deformations with irreversible changes in ventilation and perfusion[77]. It is considered that increase of postoperative VC values occurs because scoliosis correction ceases deterioration of already struck pulmonary function, which is correlated with the intensity and localization of spinal curvature. One factor that influences pulmonary improvement is lung parenchyma decompression[26,48,73,74,91].

One must have in mind that correction of cardiorespiratory function doesn't follow equally correction of spinal curvature. It is considered that it is consequence of certain irreversible damages to the pulmonary parenchyma, which occurred during the years. There is still very little data about the pulmonary function estimation before and after the scoliosis surgery by anterior approach, because most of the researches analyze patients operated by posterior approach. However, although this approach is much more aggressive for recovery of the respiratory function (because of the section of m. latissimus dorsi and the diaphragm, section of at least one rib, and in some patients formation of postoperative adhesions and atelectases[92,93]), it gives much better postoperative results of scoliotic curve correction[79–81].

The use that patients will have from surgical correction of the scoliosis is lung preservation and improvement of systemic oxygenation[33]. Today, a lot is expected from the surgical treatment of scolioses, because besides correcting a cosmetic defect, we expect correction of pulmonary function in patients, which can significantly influence quality of life, as well as length of lifespan.

Conclusion

After conducted research, we conclude that surgical correction idiopathic scoliosis, by anterior approach has a significant influence on improvement of lung volumes. There is a positive correlation between spine deformity (Cobb's angle) and reduced values of pulmonary parameters (VC, FEV1) in persons with idiopathic scoliosis.

After the surgery via anterior approach, which pursued three-dimensional correction of the spinal deformity, in patients with more severe form of scoliotic deformity, lung function improved.

Although every scoliosis is an individual case and that its clinical presentation, occurrence of cardiorespiratory dysfunction, as well as outcome depend on numerous factors, not only on the degree of curvature, we can say that there is a proportional relation between spinal curvature degree (Cobb's angle) and severity of respiratory insufficiency and that its correction leads to significant correction both of the deformity and correction of pulmonary dysfunction.

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PROMJENE PLUĆNIH FUNKCIONALNIH PARAMETARA NAKON KIRURŠKOG LIJEČENJA IDIOPATSKE SKOLIOZE

S A Ž E T A K

U rezultatima o utjecaju kirurške korekcije na plućnu funkciju u bolesnika s idiopatskom skoliozom postoje kontroverze. Cilj ove studije bio je ispitati plućnu funkciju u bolesnika s teškom torakalnom idiopatskom skoliozom prije operacije te njene promjene nakon provedene trodimenzionalne prednje korekcije skolioze. Operiran je 91 bolesnik u dobi od prosječno 16±5,1 godina. Sve skoliotične krivine iznosile su više od 70° (86±5,1). Grupu I sačinjavali su bolesnici sa skoliozama između 70° i 100°, dok je grupu II sačinjavao 31 bolesnik sa skoliozom većom od 100°. Svi su ispitanici operirani metodom prednje instrumentacije, a prosječno dobivena korekcija iznosila je 74%±15 za grupu I i 71%±18 za grupu II. VC i FEV1 u grupi I su ostali nepromijenjeni. U grupi II se VC poboljšao za 11%, dok je FEV porastao za 13,6%. Zaključujemo da je postojala značajna korelacija između postignutog postotka korekcije i plućne funkcije.