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研究文章

脉冲振荡测量法和计算机断层扫描对先天性脊柱侧凸患儿呼吸系统的评估（初步结果）

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论证。椎体侧表面分割异常和肋骨融合是脊柱和胸部先天性病理中最严重的变异之一，导致胸廓功能不全综合征的发展，表现为胸部无法提供正常的呼吸力学。

本研究的目的介绍先天性胸椎侧凸伴椎体侧表面分割异常和单侧肋骨融合患者的肺功能和X线（CT形态测量）研究的初步结果。

材料与方法。研究设计是一个小的临床系列。该前瞻性研究包括脉冲振荡仪和CT形态测量数据，并对10名3至7岁的胸椎先天性脊柱侧弯并伴有单侧椎体侧表面分割异常和单侧肋骨融合的患者进行多螺旋计算机断层扫描数据的三维重建。

结果。在脉搏振荡测量呼吸功能的研究中，7例临床病例未发现呼吸功能障碍。在3例通气障碍患儿中，根据脉搏振荡测定，最显著的变化是总呼吸阻抗参数，以及谐振频率和电阻分量的频率依赖性。在所有患者中，三维肺模型识别的形态测量肺评估指标与脉冲振荡测量肺功能的研究结果相一致。

结论。对先天性脊柱侧凸患儿呼吸功能评估问题的进一步研究在诊断和确定手术治疗的有效性方面似乎都有希望。

关键词：分割障碍；先天性脊柱侧弯；胸不足综合征；脉冲高频指示。

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Journal Article

Assessment of the respiratory system in children with congenital scoliosis by impulse oscillometry and computed tomography (preliminary results)

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BACKGROUND: Segmentation disorder of the vertebral body lateral surfaces and rib synostosis are severe variants of congenital pathology of the spine and thorax. They lead to the development of thoracic insufficiency syndrome and are manifested by the inability of the thorax to provide normal respiratory mechanics.

AIM: This study presents the preliminary results of functional and radiological (CT-morphometric) methods of lung examinations in patients with congenital thoracic spine scoliosis with impaired segmentation of the lateral surfaces of the vertebral bodies and unilateral rib synostosis.

MATERIALS AND METHODS: This design is represented by a small clinical series. This study is a prospective study of 10 patients aged 3 to 7 years with congenital spinal deformity, with impaired segmentation of the lateral surfaces of vertebral bodies and unilateral rib synostosis. This paper presents the preliminary results of the pulmonary function assessment by pulse oscillometry and CT morphometry in a 3D reconstruction of multispiral computer tomography (MSCT) of the thorax.

RESULTS: The study of respiratory function using pulse oscillometry revealed no respiratory impairment in seven observations, also reflected in the CT morphometry results. According to the Institute of Medicine (IOM), three children with detected ventilatory abnormalities showed the following parameters with the most significant changes: total respiratory impedance, resonance frequency, and frequency dependence of the resistive component. In all patients, the morphometric indexes of the lung scoring revealed during 3D modeling of the lung were completely consistent with the results of the lung function study by the IOM method.

CONCLUSIONS: Further study of the problem of respiratory function assessment in children with congenital scoliosis seems promising in diagnostic terms and for evaluating effective surgical treatment.

Keywords: segmentation disorder; congenital scoliosis; thoracic insufficiency syndrome; pulse oscillometry.

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Научная статья

Оценка состояния респираторной системы у детей с врожденным сколиозом методом импульсной осциллометрии и компьютерной томографии (предварительные результаты)

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Обоснование. Нарушение сегментации боковых поверхностей тел позвонков и реберный синостоз — один из самых тяжелых вариантов врожденной патологии позвоночника и грудной клетки, которые приводят к развитию синдрома торакальной недостаточности, проявляющегося в неспособности грудной клетки обеспечивать нормальную дыхательную механику.

Цель — представить предварительные результаты функциональных и лучевых (КТ-морфометрических) исследований легких у пациентов с врожденным сколиозом грудного отдела позвоночника при нарушении сегментации боковых отделов тел позвонков и одностороннем синостозе ребер.

Материалы и методы. Дизайн исследования — малая клиническая серия. В проспективное исследование включены данные импульсной осциллометрии и КТ-морфометрии при 3D-реконструкции данных мультиспиральной компьютерной томографии органов грудной клетки 10 пациентов в возрасте от 3 до 7 лет с врожденным сколиозом грудного отдела позвоночника при одностороннем нарушении сегментации боковых поверхностей тел позвонков и одностороннем синостозе ребер.

Результаты. При исследовании дыхательной функции с применением импульсной осциллометрии в 7 клинических случаях не выявлено дыхательных нарушений. У 3 детей с вентиляционными нарушениями по данным импульсной осциллометрии наиболее значимые изменения касались параметров общего дыхательного импеданса, а также резонансной частоты и частотной зависимости резистивного компонента. У всех пациентов морфометрические показатели оценки легких, выявленные по 3D-модели легкого, соответствовали результатам исследования легочной функции методом импульсной осциллометрии.

Заключение. Дальнейшее изучение проблемы оценки функции дыхания у детей с врожденным сколиозом представляется перспективным как в диагностическом плане, так и для определения эффективности хирургического лечения.

Ключевые слова: нарушение сегментации; врожденный сколиоз; синдром торакальной недостаточности; импульсная осциллометрия.

Как цитировать:
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ЭКО•ВЕКТОР

论证

脊柱先天性畸形合并胸廓异常的最严重的变体之一是椎体外侧表面的单侧节段化（无节段脊柱杆），同时合并单侧肋骨融合，导致畸形的形成和迅速发展[1，2]。

脊柱先天性弯曲的快速发展形成了胸廓发育不良综合征的发展基础。这一概念由Campbell提出，其特点是胸廓不能提供生理性的呼吸生物力学和肺部生长[3，4]。

该畸形变异体患儿在生长发育过程中，早期就形成了严重、僵硬的脊柱侧凸畸形，患者的质量和预期寿命明显降低，主要原因是呼吸衰竭[5]。

根据Yabing Tong等人的研究，目前美国约有4000名儿童患有胸廓发育不良综合征[6]，而俄罗斯联邦的发生情况目前尚无准确的数据[7]。

由于需要纠正严重的、迅速发展的脊柱弯曲，以及需要考虑脊柱、胸腔和心肺系统形成的潜在增长，因此对这种变异的先天性畸形患者的治疗是一个复杂的、尚未解决的问题[8]。脊柱畸形的快速发展，在自然过程中每年达到8-10° 以上，导致在儿童期的第二个阶段就出现极其严重的弯曲。这证实了保守治疗的无效性和手术技术在病人早期矫正先天性弯曲的适当性[9，10]。

仍未解决的一个重要方面是在外科治疗开始时和儿童成长过程中的各个阶段对呼吸系统的评估[11-13]。在大量的临床观察中，外呼吸功能的分析结果可以作为先天性脊柱侧弯患儿单侧无节段脊柱杆和肋骨融合治疗策略选择的决定因素[14，15]。需要注意的是，对于早期、低龄患者外呼吸功能的研究，需要资源密集型的技术支持[16-18]，因此通常不进行测量，难以解释治疗效果的结果[19-21]。

本研究的目的介绍胸椎先天性脊柱侧凸伴椎体侧表面分割异常和肋骨融合患者肺功能和放射测量（CT-形态测量）方法的初步结果。

材料与方法

研究设计是一个小的临床系列。该前瞻性研究包括10名胸椎先天性脊柱侧弯并伴有单侧椎体侧表面分割异常和肋骨融合的患者的术前检查结果。他们在 H. Turner National Medical Research Center for Children's Orthopedics and Trauma Surgery 的脊柱病理和神经外科部门接受了检查和治疗。

本研究纳入患者的标准除解剖变异缺陷外，还包括研究时无神经功能障碍和3至7岁的年龄。

排除标准是由其发育异常的其他变异引起的脊柱畸形；内脏器官严重伴随躯体病理，包括支气管肺系统畸形；拒绝参与研究。

对患者的术前检查，除了临床和实验室方法外，还包括使用放射学诊断方法：标准X射线和脊柱及胸腔器官的多层螺旋CT（MSCT）（图 1），以及根据 St. Petersburg Children's municipal multi-specialty clinical center of high medicaltechnology named after K.A. Rauhfus，通过脉冲振荡测量法（IOS）对外呼吸功能进行评估。

多层螺旋CT是在Brilliance 64（PHILIPS）上进行的。检查方案包括进行拓扑图，对脊柱和胸腔器官进行原始检查，以评估骨和肺实质的状况。在所有患者中，使用了特殊的儿科方案，使用了定位工具、过滤器和降低扫描场和电子管电压（70 kV或更低）的程序。技术参数、儿童方案和剂量减少技术的选择取决于儿童的体重。多层螺旋CT以患者仰卧位，从锁骨上缘水平，通过两侧肋隔角，向颅尾方向行。扫描的螺旋模式参数如下：Quality Reference 110 mAs，KV / Effectivem As / Rotationtime 120 / 110 / 0.5 s；Detector Collimation 1.5 mm，Slice Thickness 1.0 mm，Pitchfactor 0.3 to 1，Increment 2 mm。

利用后处理程序评估脊柱和肋骨畸形的变异性，计算出半胸容积指标和肺实质的密度特征：三维、多平面重建、最大强度投影和表面阴影图像（图 1，*a-d*）。研究中使用的断层扫描软件包括一个组织分割技术，从肋骨、纵隔软组织和血管中划出肺实质，然后对获得的区域和肺组织体积值进行绘图（图 1，*e*）。评估了气化减少区域的定位和范围，选择了密度密度测量特征小于-500单位HU的变化作为标准。在视觉上密度均匀的区域，用Hounsfield尺度确定平均肺面积值；在密度不规则的区域，在几个点进行测量，然后计算平均值。使用CT软件计算肺容积（CT容积）。使用厚片，并以5 mm的切片厚度重建

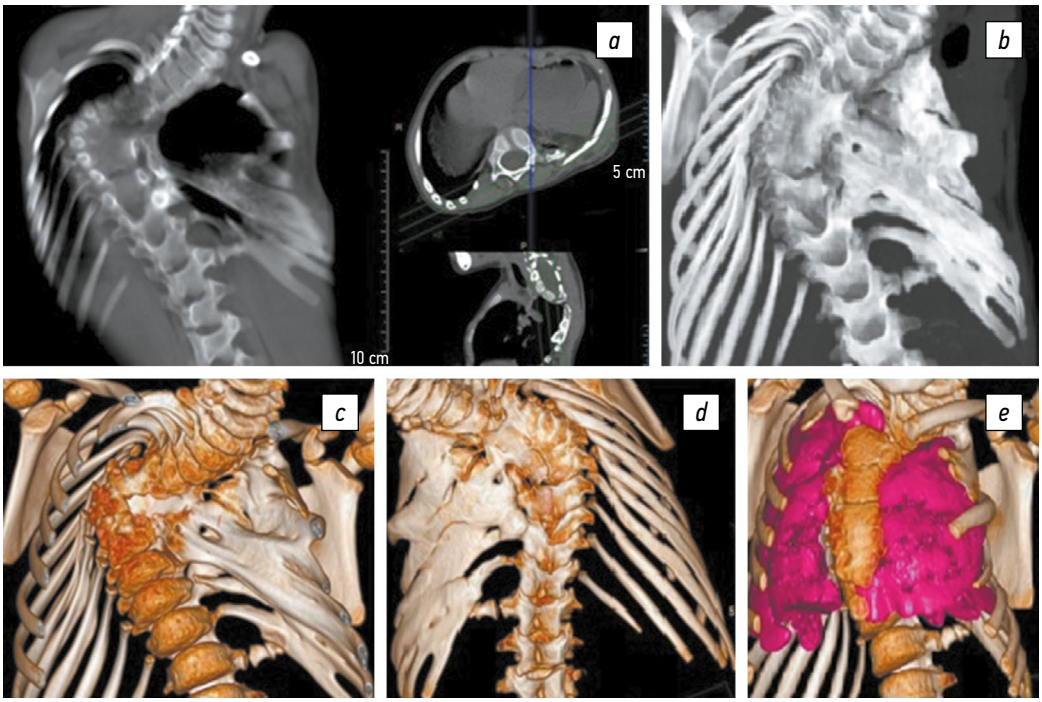

图 1 S.患者，5岁。脊柱和胸腔器官在目标结构模式下的多螺旋计算机断层扫描。在多面斜冠状重建（*a*）和三维图像——最大强度投影（*b*）。表层阴影图像——前视图（*c*），后视图（*d*）椎体外侧表面的异常分割，左侧肋骨融合不全（后外侧切面）；利用组织分割技术对骨骼和肺实质进行隔离可视化的胸腔重建（*e*）

图像，增量为5 mm。计算原理是基于改进的辛普森公式。

使用DICOM数字数据处理获得了支气管肺系统的虚拟模型（图 2）。根据病变的一侧、患病率（段、叶）和相对于脊柱侧弯顶部的程度，在颅底方向和周边（前胸）对已确定的肺组织变化与通气不足的区域进行定位。

为了评估肺的功能状态，所有患者都接受了IOS。IOS是强制振荡技术的一个变种，可以对肺部力学进行被动测量。IOS研究是在Master Screen IOS（Viasys Health care，德国）上进行的。IOS的原理是基于正常呼吸噪音的声波叠加，导致气道流量和压力的变化[22-24]。IOS是用5赫兹的呼吸阻抗（总）（Zrs5）；5和20赫兹的呼吸阻抗的电阻（摩擦）部分（Rrs5和RRrs20）来评估的。IOS参数的异常是由基线Rrs5和Xrs5指数的变化决定的[22,24]。

结果

纳入研究的患者的脊柱弯曲度从30° 到90° 不等。大多数病人在矢状面有低下的脊柱，在一些病例中发现病理性的胸椎前凸，最高可达15° 。

通过脉冲振荡仪对肺功能的研究发现，在7次观察中没有发现通气障碍。尽管冲动阻力值正常，但儿童在气流速度参数方面表现出气道阻塞。这就是所谓的下分流，由于肺部组织过度充气，导致部分冲动振荡（阻力）的损失。

在三个有呼吸障碍的儿童中，总呼吸阻抗的参数，即其反应性和电阻性成分（分别为Xrs5和Rrs5），电阻性成分（FD Rrs5-20）的频率依赖

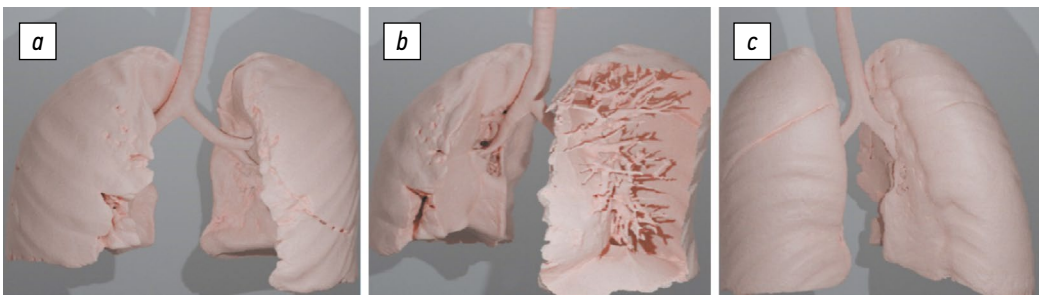

图 2 通过构建基于吸入式多螺旋计算机断层扫描数据的支气管肺系统虚拟三维模型，计算出A.患者（5岁）的肺组织体积。虚拟肺部模型：*a*——前视图；*b*——侧视图；*c*——后视图

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性根据IOS变化最大（表 1）。这些冲动阻力参数不仅反映了气道的通畅性，也反映了参与呼吸循环的呼吸结构的弹性特性。阻力成分参数的增加表明气管支气管树不同层次的通畅性受损，阻抗Xrs5的反应性成分的弹性部分的减少，反映了呼吸结构弹性特性的变化。

应该指出的是，通过三维肺模型和CT-容积测量法检测到的形态指数下降的三名患者，通过IOS检测到的功能指数变化最为明显（见表 1，2）。

文献报道，儿童正常肺发育存在生理不对称性，达到5%[25-27]。椎体侧表面分割异常及肋骨融合患儿肺容积差异为12至56.2%。这类患者在分割障碍一侧有减小肺的趋势（见表 2）。

根据文献来源，将所得数据与常模指标进行比较，研究患者可能的最大肺容积指数有明显降低的趋势。同时平均肺容积值超过常模的相对值，这可能表明代偿机制的早期激活。所得数据如表 3所示。

讨论

呼吸衰竭是先天性脊柱畸形最严重的后果，其椎体侧表面分割异常，并合并单侧肋骨融合[28，29]。

胸腔衰竭综合征从儿童早期开始就可能与肺功能受损有关，随着儿童的成长，这种情况会恶化[5，30，31]。未经治疗的儿童因心肺功能衰竭

表 1 脉冲振荡测量结果

患者	年龄	电阻成分Zrs（Rrs5）正常*在0.78和1.36之间	反应性成分Zrs（Xrs5）正常*在-0.61和-0.32之间	电阻成分的频率依赖性（FD Rs5-20）正常*在0.25和0.57之间
1	3岁	1.32	−0.42	0.26
2	7岁	1.05	−0.35	0.28
3	3岁	0.72	−0.34	0.27
4**	**5岁**	**1.48**	**−0.28**	**0.21**
5**	**4岁**	**1.51**	**−0.25**	**0.19**
6	3岁	0.9	−0.34	0.26
7	4岁	0.81	−0.36	0.31
8	3岁	0.89	−0.31	0.28
9**	**5岁**	**1.45**	**−0.27**	**0.18**
10	7岁	0.9	−0.39	0.27

*根据Elida Duenas-Meza等人的研究，正常参数值的范围[44]。**参数变化最大的患者。

表 2 数字X光片和多螺旋CT扫描的结果

患者	年龄	无节段脊柱杆的定位	柯布脊柱侧弯畸形，度数	脊柱主曲线的侧面，D/S	右肺容积，cm^3	左肺容积，cm^3	肺部总体积，cm^3
1	3岁	Th_5–Th_8	48	D	392.0	317.8	709.8
2	7岁	Th_4–Th_7	61	S	324.3	365.6	689.9
3	3岁	Th_7–Th_{10}	38	D	295.7	247.8	543.5
4*	**5岁**	**Th_1–Th_5**	**34**	**D**	**485.3**	**351.7**	**837.0**
5*	**4岁**	**Th_6–Th_{12}**	**52**	**D**	**717.5**	**561.3**	**1278.8**
6	3岁	Th_3–Th_9	69	D	230.7	183.7	414.4
7	4岁	Th_2–Th_9	44	S	334.4	392	726.4
8	3岁	Th_4–Th_9	42	S	240.1	286.7	526.8
9*	**5岁**	**Th_4–Th_9**	**90**	**D**	**434.5**	**190.7**	**595.2**
10	7岁	Th_9–Th_{11}	30	D	583.4	486.4	1069.8

*研究中发现的变化最明显的患者。

表 3 所研究的患者通过多螺旋计算机断层扫描测得的肺部容积值与生理常态下的肺部容积值的比较[27]

肺部总体积，cm^3 (M; min–max)		右肺容积，cm^3 (M; min–max)		左肺容积，cm^3 (M; min–max)	
正常	研究的患者	正常	研究的患者	正常	研究的患者
689.0; 313.0–2180.0	739.8; 414.4–1278.0	379.0; 192.0–1218.0	403.8; 230.7–717.5	310.0; 106.0–962.0	338.4; 183.7–561.3

而早期死亡的风险增加[32-34]。目前还没有明确的定量或定性标准来诊断胸廓发育不全综合征[5，35]。

直到最近，还没有一种无创、可靠的方法来评估幼年先天性畸形患儿的呼吸功能[36-38]。长期以来，儿童依从性低一直是广泛开展功能测试的一个障碍[24]。绕过这些限制的一个可能的方法是使用医疗镇静剂，但由于对呼吸中枢可能产生的影响以及呼吸道平滑肌组织张力的变化，结果被扭曲，因此这种方法没有被广泛使用[6，22]。我们所考虑的IOS不存在上述的缺点。

由于观察的数量不多，我们不能可靠地说明检测到的呼吸异常是否与儿童的年龄和主弓畸形的大小有关。在临床上，患者一般不主动诉说呼吸功能受损。这是由于儿童身体的代偿能力，但在儿童早期已经可以发现外部呼吸功能有逐渐恶化的趋势。

文献表明，早期严重脊柱和胸廓畸形的病人在生活中的运动活动接近正常[39-41]，然而在以体重增加为特征的青春期，不可避免地出现呼吸抑制[42，43]。

在七次临床观察中，在椎体外侧表面分割受损和单侧肋骨突起的背景下，先天性脊柱畸形患者没有呼吸障碍。三名儿童表现出总的呼吸阻抗、共振频率和电阻成分的频率依赖性方面的异常。

三维肺部模型中发现的三名患者的肺部形态指标的下降与IOS的肺功能测试结果一致。在我们研究的病人中，肺容积的差异为12%至56.2%。同时，可以观察到平均肺容积有增加的趋势，超过正常值，这可能表明代偿机制的早期激活。

迄今为止，治疗的选择是根据临床和放射学数据确定的，但显然需要对呼吸系统状态进行功能评估。

本研究结果可靠性的局限性。这项研究是初步的。研究中纳入的少量临床观察不允许进行统计和因子分析。另外一个限制标准是所选年龄范围。

结论

脉冲振荡测量法（IOS）是一种快速、简单、无创的方法，用于评估年轻患者自发呼吸时的外呼吸功能。

使用三维CT模型对肺部进行IOS和形态测量，使我们能够获得新的、以前无法获得的先天性脊柱侧凸儿童呼吸系统状态的客观数据。

本研究从肺功能变化评估的角度，对学龄前儿童先天性脊柱侧凸的诊断和手术治疗效果分析具有重要意义。

附加信息

资金来源。没有资金来源。

利益冲突。作者声明，不存在与本文发布有关的明显和潜在利益冲突。

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已获得患者代表的书面同意以处理和发布个人数据。

作者的贡献。*S.V. Vissarionov*——负责制定目标和开发研究设计，对病人进行外科治疗。*M.S. Asadulaev*——负责文章各部分的写作，数据收集与分析，文献分析，逐级和最终的文章文本编辑。*E.A. Orlova*——负责患者肺部检查，逐步编辑文章文本。*V.G. Toriya*——负责辐射检测数据的收集和分析，逐步编辑文章文本；创建肺的3D模型，计算肺组织的体积。*K.A. Kartavenko*——负责文章文本的逐步编辑、数据收集*T.S. Rybinskikh*——负责文章文本的逐级编辑，将文章摘要和作者信息翻译成英文。*T.V. Murashko*——负责MSCT结果的描述，逐步编辑文章的文本。*M.A. Khardikov*——负责设计参考文献列表，分步编辑文章文本。*D.N. Kokushin* ——逐步编辑文章文本。

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