

· 临床研究 ·

仰卧位和俯卧位测量青少年特发性脊柱侧凸患者胸主动脉与椎体毗邻关系的差异

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【摘要】目的 通过术前仰卧位MRI和术中俯卧位O形臂X线机获得青少年特发性脊柱侧凸(AIS)患者横断面影像学资料, 探讨2种体位下主胸弯顶椎与胸主动脉的毗邻关系。**方法** 回顾性分析2013年4月—2018年7月美国梅奥医学中心骨科采用后路手术治疗的18例AIS患者资料。患者术前均行仰卧位全脊柱MRI平扫和术中俯卧位脊柱O形臂X线机平扫, 将影像资料上传至临床图像显示系统(Qreads 5.10)。选取主胸弯顶椎为测量平面, 测量顶椎椎体旋转角度(AVR), 主动脉到椎体距离(a线), 主动脉到左侧椎弓根置钉点距离(b线), 主动脉到椎管垂直距离(c线), 主动脉到椎弓根置钉点连线的垂直距离(d线), 主动脉椎体角(AVA), 左侧椎弓根置钉点和主动脉内侧切线与椎体中轴线平行线间的夹角($\angle\alpha$), 左侧椎弓根置钉点和主动脉中心点连线与椎体中轴线平行线间的夹角($\angle\beta$)。采用配对样本 t 检验比较2种体位下各参数变化, 采用Pearson相关分析对数据进行相关性分析。**结果** 俯卧位AVR、c线均大于仰卧位, 差异均有统计学意义($P<0.05$), 平均差值分别为 2.71° 、2.24 mm。俯卧位与仰卧位AVA平均差值为 4.45° , 差异有统计学意义($P<0.05$); 俯卧位AVR、a线、b线、c线、d线、AVA、 $\angle\alpha$ 、 $\angle\beta$ 与仰卧位相应指标呈正相关; 俯卧位 $\angle\beta$ 与主胸弯Cobb角呈正相关, 与俯卧位及仰卧位AVR均呈负相关; 俯卧位d线与主胸弯Cobb角呈负相关, 与俯卧位及仰卧位AVR呈正相关。**结论** 相较于仰卧位, 脊柱侧凸患者俯卧位时顶椎旋转度增大, 主动脉到椎管的垂直距离增大, 主动脉向椎体右前方移动。

【关键词】 胸椎; 脊柱侧凸; 放射测量术

【中图分类号】 R 682.3 **【文献标志码】** A **【文章编号】** 1672-2957(2019)06-0404-05

【DOI】 10.3969/j.issn.1672-2957.2019.06.008

Difference between supine and prone positions in adjacent relationship of thoracic aorta with vertebral body in adolescent idiopathic scoliosis patients

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【Abstract】Objective To obtain the cross-sectional imaging data of adolescent idiopathic scoliosis (AIS) patients by preoperative supine position MRI and intraoperative prone position O-arm system, exploring the adjacent relationship between the main thoracic curvature and the thoracic aorta in the 2 positions. **Methods** A retrospective study was conducted on 18 patients with AIS who underwent posterior surgeries from April 2013 to July 2018 in Mayo medical center. All the patients underwent the whole spine MRI plain scan in supine position at pre-operation and the O-arm system plain scan in prone position during the operation, and the clinical images uploaded to the Qreads 5.10 display system. The main thoracic curvature apex vertebra was selected as the measurement plane. The index included apical-vertebral rotation (AVR), the distance from the aorta to the vertebral body (line a), the distance from the aorta to the left pedicle point (line b), the vertical distance from the aorta to the spinal canal (line c), the vertical distance from the aorta to the connection line of the pedicle points (line d), the aorta-vertebral angle (AVA), the angle between the medial tangential line across the left pedicle screw placement point and the aortic and the parallel line of the central axis of the vertebral body ($\angle\alpha$), the angle between through the left pedicle screw placement point to the center point of the aorta and the parallel line of the axis of the vertebral body ($\angle\beta$). The paired-sample t -test was

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used to compare the positional changes of parameters in the 2 positions, and the Pearson correlation analysis was performed to analyze the correlation between the above parameters. **Results** The AVR and line c in prone position were larger than those in supine position, with significant differences ($P < 0.05$). The mean difference was 2.71° and 2.24 mm, respectively. The average difference of the AVA between prone position and supine position was 4.45° , and the difference was statistically significant ($P < 0.05$). The prone position AVR, line a, line b, line c, line d, AVA, $\angle\alpha$, and $\angle\beta$ were positively correlated with the corresponding index in supine position; prone position $\angle\beta$ was positively correlated with Cobb's angle of main thoracic curve, and negatively correlated with AVR in supine position and prone position; prone position line d was negatively correlated with Cobb's angle of main thoracic curve, and positively correlated with AVR in supine position and prone position. **Conclusion** Compared with those in supine position, the apical-vertebral rotation increases, the vertical distance from the aorta to the vertebral canal increases, and the aorta moves to the right front of the vertebral body in prone position of the scoliosis patients.

【Key Words】Thoracic vertebrae aorta; Scoliosis; Radiometry

J Spinal Surg, 2019, 17(6): 404-408

青少年特发性脊柱侧凸(AIS)是最常见的脊柱畸形,是一种严重的脊柱三维空间畸形^[1-2]。脊柱融合矫正手术是治疗脊柱侧凸的重要手段,其中后路手术应用最为广泛^[3-5]。胸椎前方存在大量重要结构(如主动脉、食管等),因椎弓根置钉不佳造成的主动脉损伤虽不多见,但一旦发生后果严重,甚至危及患者生命^[6]。相关研究发现,脊柱侧凸手术中胸椎螺钉位置不佳的概率为10%~15%^[7-8],置钉穿孔率为1.2%~65.0%^[9],其中螺钉误置导致主动脉损伤的发生率为0.29%~1.50%^[10-11],主动脉损伤导致的死亡率为15%~65%^[12],因而了解椎体与主动脉的毗邻关系非常重要。通过术前MRI或CT平扫,可以获得椎体横断面影像,进而了解椎体和主动脉的毗邻关系,但这种影像是于仰卧位获得的,而后路手术中体位却是俯卧位。因此,探究不同体位下椎体和主动脉的毗邻关系具有一定意义。O形臂X线机的应用可辅助术中椎弓根螺钉的安全置入^[13],同时可获取术中俯卧位下椎体横断面影像,为研究2种体位下主动脉位置的变化提供依据。本研究通过术前仰卧位MRI和术中俯卧位O形臂X线影像研究2种体位下主胸弯顶椎和主动脉的毗邻关系。

1 资料与方法

1.1 一般资料

纳入标准:①综合分析病史、物理检查结果、术前全脊柱正侧位X线和MRI资料,确诊为AIS;②均行单纯后路(标准俯卧位)切开三维矫形植骨融合内固定术;③术中使用O形臂X线机辅助手术,影像资料齐全;④术中O形臂X线机获得的椎体横断面影像资料中主动脉成像清晰;⑤主胸弯为右弯。排除标准:①先天性、神经源性、椎体结构极端异常、遗传性疾病、神经系统结构异常、内分泌

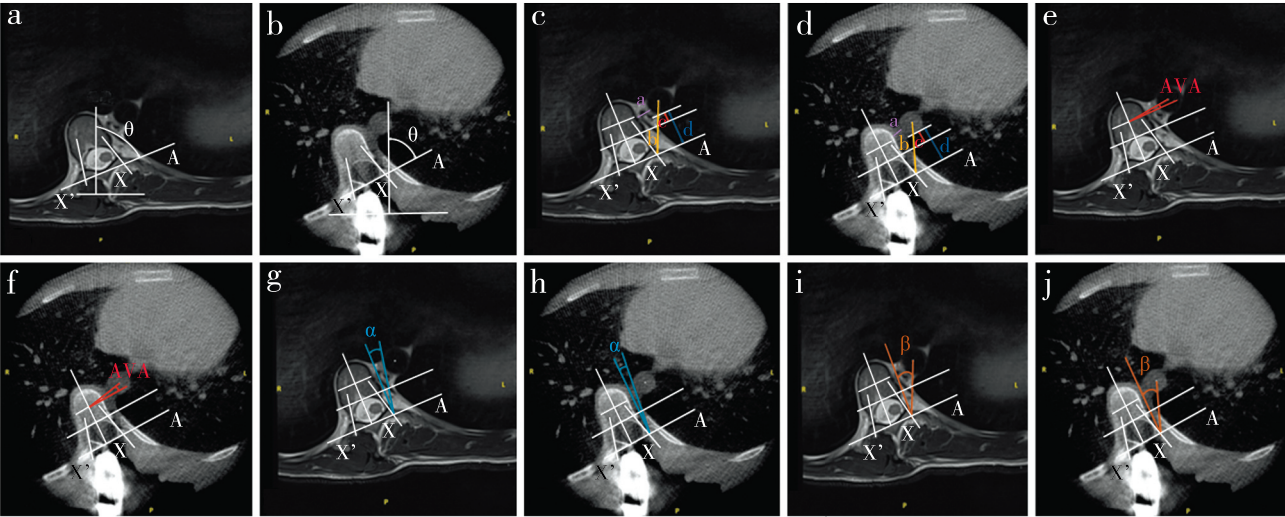
泌系统异常或结缔组织病导致的脊柱侧凸;②年龄>18岁或<10岁;③无结构性胸弯的AIS(Lenke 5型);④主胸弯Cobb角 $\leq 40^\circ$ 或 $\geq 100^\circ$ 。根据以上标准,共纳入2013年4月—2018年7月美国梅奥医学中心收治的AIS患者18例,其中男3例、女15例,年龄10~18(13.50 ± 2.12)岁;Lenke 1型7例,2型7例,3型2例,6型2例;主胸弯顶椎位于T₆ 1例,T₇ 4例,T₈ 8例,T₉ 3例,T₁₀ 2例;主胸弯Cobb角为 $46.5^\circ \sim 80.7^\circ$ ($60.09^\circ \pm 11.62^\circ$);T₅₋₁₂后凸角为 $7.3^\circ \sim 52.1^\circ$ ($21.68^\circ \pm 11.36^\circ$)。

1.2 测量方法及指标

将患者术前全脊柱仰卧位MRI和术中俯卧位O形臂X线机(美敦力,美国)采集的影像资料处理后上传至临床图像显示系统(Qreads 5.10),测量以下指标。选择MRI和O形臂X线机平扫中主胸弯顶椎椎弓根最粗的平面,改良Göçen等^[14]的方法测量顶椎椎体旋转角(AVR),原方法通过标记椎体横断面两侧椎弓根最后点(X、X'),本研究将其方法进一步改进,X、X'点为通过椎弓根中心的椎弓根轴线与后方骨性结构的交点(可看作椎弓根螺钉左右置钉点),过X、X'点做一条直线(A线),此线与矢状面的夹角为 $\angle\theta$,AVR为 $90^\circ - \angle\theta$,椎体向右旋转AVR记为负值,向左旋转记为正值(图1a,b);主动脉到椎体距离,即主动脉外壁到椎体的最小距离(a线;图1c,d);主动脉到左侧椎弓根置钉点距离,即左侧椎弓根置钉点X和主动脉中心点的连线与主动脉外壁相交,此交点与X的距离(b线;图1c,d);主动脉到椎管垂直距离,即经过主动脉后壁和椎管前壁分别作A线的平行线,两线间的垂直距离(c线;图1c,d);主动脉后壁到椎弓根置钉点连线(A线)的垂直距离(d线;图1c,d);主动脉椎体角(AVA),即主动脉中心点和椎体中心点连线与A线

平行线间的夹角, 在测量时如主动脉中心点和椎体中心点连线在 A 线平行线前方时为正值, 反之为负值(图 1e, f); 左侧椎弓根置钉点和主动脉内侧切

线与椎体中轴线平行线间的夹角($\angle\alpha$; 图 1g, h); 左侧椎弓根置钉点和主动脉中心点连线与椎体中轴线平行线间的夹角($\angle\beta$; 图 1i, j)。



男, 17 岁, Lenke 1 AIS, 主胸弯顶椎为 T₉, 术前仰卧位 MRI 和术中俯卧位 X 线片测量平面均为 T₉。a: 仰卧位测量 AVR b: 俯卧位测量 AVR c: 仰卧位测量 a, b, c, d 线 d: 俯卧位测量 a, b, c, d 线 e: 仰卧位测量 AVA f: 俯卧位测量 AVA g: 仰卧位测量 $\angle\alpha$ h: 俯卧位测量 $\angle\alpha$ i: 仰卧位测量 $\angle\beta$ j: 俯卧位测量 $\angle\beta$

Male, 17 years old, Lenke 1 AIS, main thoracic curvature is T₉, measurement planes of preoperative MRI in supine position and intraoperative roentgenograph in prone position are T₉。a: Measurement of AVR in supine position b: Measurement of AVR in prone position c: Measurement of line a, b, c and d in supine position d: Measurement of line a, b, c and d in prone position e: Measurement of AVA in supine position f: Measurement of AVA in prone position g: Measurement of $\angle\alpha$ in supine position h: Measurement of $\angle\alpha$ in prone position i: Measurement of $\angle\beta$ in supine position j: Measurement of $\angle\beta$ in prone position

图 1 2 种体位下测量脊柱侧凸病例主胸弯顶椎与主动脉毗邻关系的影像学资料

Fig. 1 Imaging data of adjacent relationship of apical vertebra of main thoracic curvature with aorta in 2 positions of scoliosis patients

1.3 统计学处理

采用 SPSS 25.0 软件对数据进行统计学分析, 计量资料采用 $\bar{x} \pm s$ 表示, 2 种体位数据差异比较采用配对样本 *t* 检验, 采用 Pearson 相关分析对数据进行相关性检验; 以 $P < 0.05$ 为差异有统计学意义。

2 结 果

患者术前仰卧位 MRI 和术中俯卧位 O 形臂 X 线

机测量主胸弯顶椎主动脉与椎体毗邻关系见表 1。俯卧位 AVR 大于仰卧位, 平均差值为 2.71°, 差异有统计学意义 ($P < 0.05$); 俯卧位 *c* 线大于仰卧位, 平均差值为 2.24 mm, 差异有统计学意义 ($P < 0.05$); 俯卧位 AVA 与仰卧位平均差值为 4.45°, 差异有统计学意义 ($P < 0.05$), 数值由负转正, 说明主动脉向椎体右前方移动; 俯卧位和仰卧位 *a* 线、*b* 线、*d* 线、 $\angle\alpha$ 、 $\angle\beta$ 差异无统计学意义 ($P > 0.05$)。

表 1 两种体位下测量主胸弯顶椎与主动脉毗邻关系

Tab. 1 Measurement of adjacent relationship of apical vertebra of main thoracic curvature with aorta in 2 positions

N=18, $\bar{x} \pm s$

体位 Position	AVR/(°)	a 线/mm Line a/mm	b 线/mm Line b/mm	c 线/mm Line c/mm	d 线/mm Line d/mm	AVA/(°)	$\angle\alpha$ /(°)	$\angle\beta$ /(°)
仰卧 Supine	-16.76 ± 4.71	6.70 ± 2.59	25.77 ± 4.89	2.37 ± 5.45	21.34 ± 5.96	-3.74 ± 9.84	14.94 ± 6.68	29.13 ± 8.38
俯卧 Prone	-19.47 ± 5.89*	6.67 ± 2.97	25.10 ± 5.50	4.61 ± 5.73*	20.51 ± 6.46	0.71 ± 10.24*	13.89 ± 9.25	27.64 ± 10.87

注: *与仰卧位相比, $P < 0.05$

Note: * $P < 0.05$, compared with supine position

俯卧位 AVR、a 线、b 线、c 线、d 线、AVA、 $\angle\alpha$ 、 $\angle\beta$ 与仰卧位相应指标均呈正相关 ($r=0.531$ 、 0.624 、 0.761 、 0.742 、 0.700 、 0.675 、 0.609 、 0.699)。俯卧位 $\angle\beta$ 与主胸弯 Cobb 角呈正相关 ($r=0.682$)，与俯卧位及仰卧位 AVR 均呈负相关 ($r=-0.526$ 、 -0.575)；俯卧位 d 线与主胸弯 Cobb 角呈负相关 ($r=-0.583$)，与俯卧位及仰卧位 AVR 呈正相关 ($r=0.624$ 、 0.480)。

3 讨 论

AIS 手术矫正治疗中使用椎弓根螺钉，由于胸椎和胸主动脉的位置比较接近，螺钉位置不佳会发生胸主动脉损伤，后果严重^[9, 15-16]。正常脊柱主动脉在 T₄ 水平向下形成降主动脉，位于椎体左前方，大约在 T₁₂ 水平穿过膈肌进入腹腔。脊柱侧凸导致的椎体变形、旋转、移位都伴随着主动脉位置变化。Sucato 等^[17]的研究发现，脊柱侧凸患者主动脉的位置较正常人更偏向外侧和后方，提示脊柱侧凸患者后路手术置钉时，较无脊柱侧凸患者发生主动脉损伤的可能性增加。此外，各患者畸形情况不同，侧凸或后凸角度不同，主动脉的位置变化也不一致^[18]。MRI 和 CT 检查时患者处于仰卧位，而患者手术时多为俯卧位，体位变化时椎体的畸形会发生部分变化，主动脉相对于椎体的毗邻关系也将发生变化，因此，用术前仰卧位的影像指导俯卧位手术可能存在一定偏差。获知术中实际体位下椎体畸形情况和主动脉位置信息，可为术中安全置钉提供保障。

O 形臂 X 线机的应用不仅提供了术中安全置钉的 3D 影像辅助，同时也提供了患者俯卧位状态下胸椎和胸主动脉的位置毗邻关系。本研究发现，俯卧位 AVR 较仰卧位大，平均增加 2.71° ，提示术中置钉时的外展角度亦适度增大，考虑出现这种现象的原因是仰卧位时“剃刀背”区的肋骨直接受到仪器检查台的力量，传导至椎体时产生向左旋转的力量，导致 AVR 在仰卧位时比俯卧位时小；俯卧位主动脉到椎管垂直距离 (c 线) 大于仰卧位，平均差值为 2.24 mm ，说明主动脉在顶椎水平向前方远离椎管区；俯卧位 AVA 时仰卧位的平均差值为 4.45° ，数值由负转正，进一步说明主动脉向椎体右前方移动。

本研究相关性分析结果显示，2 种体位下 AVR、a 线、b 线、c 线、d 线、AVA、 $\angle\alpha$ 、 $\angle\beta$ 均呈正相关。俯卧位 $\angle\beta$ 与主胸弯 Cobb 角呈正相关，俯卧位 d 线与主胸弯 Cobb 角呈负相关，说明冠状面畸形越大，顶椎左侧椎弓根进针点在椎体横断面上与主动脉的成角越大，左侧椎弓根进针点到主动脉外壁的垂直

距离越小。俯卧位 $\angle\beta$ 与 AVR 呈负相关，俯卧位 d 线与 AVR 呈正相关 (测量时规定椎体向右旋转数值为负值)，说明顶椎旋转越明显，顶椎左侧椎弓根进针点在椎体横断面上与主动脉的成角越大，左侧椎弓根进针点到主动脉外壁的垂直距离越小。

通过本研究的数据分析，同一患者俯卧位对比仰卧位，主动脉会远离顶椎区。不同患者主胸弯 Cobb 角越大，主动脉离左侧椎弓根进针点垂直距离越小；顶椎椎体旋转越大，顶椎左侧椎弓根进针点在横断面上与主动脉成角越大，说明患者顶椎旋转越大，置钉时只要掌握好置钉外展角度，风险反而降低，损伤主动脉的可能性随之降低。

综上所述，相较于仰卧位 MRI 数据，AIS 患者俯卧位时顶椎旋转度增大，主动脉到椎管垂直距离增大，主动脉向椎体右前方移动。本研究样本量偏小，因为术中使用了 O 形臂 X 线机获得椎体横断面影像资料时采用了骨算法进行数据重建，以便为置钉提供骨性结构图像，导致软组织分辨率明显下降，无法区分主动脉和周围软组织影，顶椎区主动脉显影清晰病例资料明显减少。下一步的研究可针对单一 Lenke 亚型患者进行分析。

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- (收稿日期: 2018-09-10)
(本文编辑: 刘映梅)