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3D 打印技术在脊柱侧凸矫形术中的应用研究 *

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摘要 目的：通过 3D 打印技术建立患者脊柱的立体实物模型，并探讨其在脊柱侧凸矫形手术中的临床应用价值。**方法：**2013 年 9 月～2017 年 8 月的 15 例脊柱侧凸畸形患者，采集患者的薄层 CT 扫描数据，利用 3D 打印技术建立实物模型，术前模拟置钉、模拟截骨，完善术前规划，并按照术前计划进行手术。**结果：**所有患者均按照根据术前 3D 打印模型制定的手术方案完成手术，术中置钉顺利，置钉准确率为 93.6%。所有患者术中、术后无神经、血管、内脏损伤等并发症。**结论：**3D 打印技术为术者提供了更加直观、立体、即时的影像资料，能够完善术前规划，提高置钉准确率，降低手术风险，在脊柱矫形手术中应用前景广泛。

关键词：3D 打印；脊柱侧凸；脊柱矫形；临床应用

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Application of 3D Printing Technology in Scoliosis and Orthopaedic Surgery*

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ABSTRACT Objective: To establish a three-dimensional physical model of patients' spine by 3D printing technology and to explore its clinical value in scoliosis and orthopaedic surgery. **Methods:** From September 2013 to August 2017, 15 cases of scoliosis deformity were collected by CT scan data, and the physical model was established by 3D printing technique. The preoperative simulation of nail, simulated osteotomy, improvement of preoperative planning, and operation according to the pre operation plan. **Results:** All patients completed the operation according to the preoperative 3D printing model, and the nail placement rate was 93.6%. All patients had no complications such as nerve, blood vessel and visceral injury during and after operation. **Conclusion:** 3D printing provides more visual, three-dimensional and immediate image data for the operator. It's helpful for diagnosing and operation planning. It can improve the preoperative planning, improve the accuracy of nail placement, reduce the risk of operation, and have a wide range of applications in the scoliosis and orthopedic surgery.

Key words: 3D printing; Spinal scoliosis; Spinal orthopedics; Clinical application

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前言

脊柱侧凸畸形是脊柱外科常见的疾病之一，脊柱后路椎弓根固定技术因其具有三维固定等独特的优势，目前是用于治疗先天性和特发性脊柱侧凸的主要技术[1-3]。脊柱侧凸畸形不仅仅是脊柱侧凸、后凸、椎体旋转，甚至伴有半椎体、椎体形成不全、分节不全、椎弓根发育异常等畸形[4-6]，大大增加了手术风险。因此，术前根据侧凸患者每个椎弓根的解剖特征制定个体化的置钉方案，可有效提高置钉的成功率。3D 打印技术通过制作脊柱实体模型，可以将虚拟计算机辅助设计模型准确、快速地转化为三维实物模型，术者术前可详细了解病变椎弓根的部位、形态、大小及局部解剖情况，并可实现术前在模型上模拟置钉、模拟截骨，完善术前规划，并且在医患沟通方面有独特的价值[7-9]。本研究采用 3D 打印技术辅助治疗脊柱侧凸畸形患者 15 例，经过随访疗效满意，现报道如下。

1 材料与方法

1.1 病例资料

选取 2013 年 9 月～2017 年 8 月我院收治的脊柱侧凸畸形患者共计 15 例，其中男 6 例，女 9 例，年龄 11～52 岁，平均 (17± 11.4) 岁，分类：特发性脊柱侧凸 4 例，先天性脊柱侧凸 11 例，均为半椎体畸形，其中 2 例为多发畸形，胸椎半椎体畸形 5 例，腰椎半椎体畸形 6 例。所有患者术前均完善站立位脊柱全长正侧位、左右侧屈位、前屈后伸位片、核磁共振及 CT 扫描。

1.2 术前 3D 打印模型制备

设备使用 64 排螺旋 CT，进行连续薄层 CT 扫描，扫描范

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围选取为患者畸形椎体上、下各 3 个椎体。CT 扫描结果以 DICOM 格式文件存储，并将数据导入 Mimics 软件，构造形状曲面，建立出三维模型。再将数据保存为能够被 3D 打印机识别的 STL 格式，将 STL 格式的数据被移交给医院外的 3D 打印公司。采用选择性激光烧结技术，在 1:1 的比例尺上打印模型。印刷材料为尼龙粉末材料，模型的印刷时间通常为 24～36 h。

1.3 制定置钉方案及模拟置钉

根据 3D 打印模型术者可以从各个角度和平面研究患者脊柱侧凸的类型、畸形椎体的病变部位和严重程度，从而决定是否需要截骨、截骨的方法、范围以及固定和融合的节段，并具体研究每个椎弓根的三维数据，明确该椎弓根的形态、大小、是否适合置钉、选取最佳的进钉点及螺钉合适的直径和长度，为患者制定个体化的置钉方案，必要时可术前在模型上模拟置钉、模拟截骨和矫形。

1.4 手术方法

患者全麻后取俯卧位，脊柱后正中切口显露，按照术前置钉方案充分显露出骨性标志点，经开口、钻孔、测深等步骤，并经 C 臂机透视后验证，置入椎弓根螺钉；在显露病变椎体时需参考 3D 模型所提示的解剖变异并结合术中所见，小心操作避免损伤神经和血管；按照术前制定的截骨方案截骨，包括蛋壳技术切除半椎体畸形、椎体双侧的不对称性截骨、小关节突截骨等；再用椎弓根钉棒系统于凸侧加压、凹侧撑开矫正侧凸及后凸畸形，术中常规行神经电生理监测以确保无脊髓损伤的发生。

1.5 术后处理

术后患者常规进行预防感染治疗。术后 2 天拔除负压引流管，术后早期行使下肢主动、被动功能，佩戴支具 3～6 个月。术后复查脊柱全长正侧位片了解脊柱侧后凸矫正情况，术后复查 CT 评价置钉准确率。

2 结果

所有患者均按照根据术前 3D 打印模型制定的手术方案完成手术，术中置钉顺利，无神经、血管、内脏损伤等并发症。术中共置钉 171 枚，置钉准确率为 93.6%(160/171)。术后复查 X 线片提示矫形效果满意。典型病例检查结果见图 1。

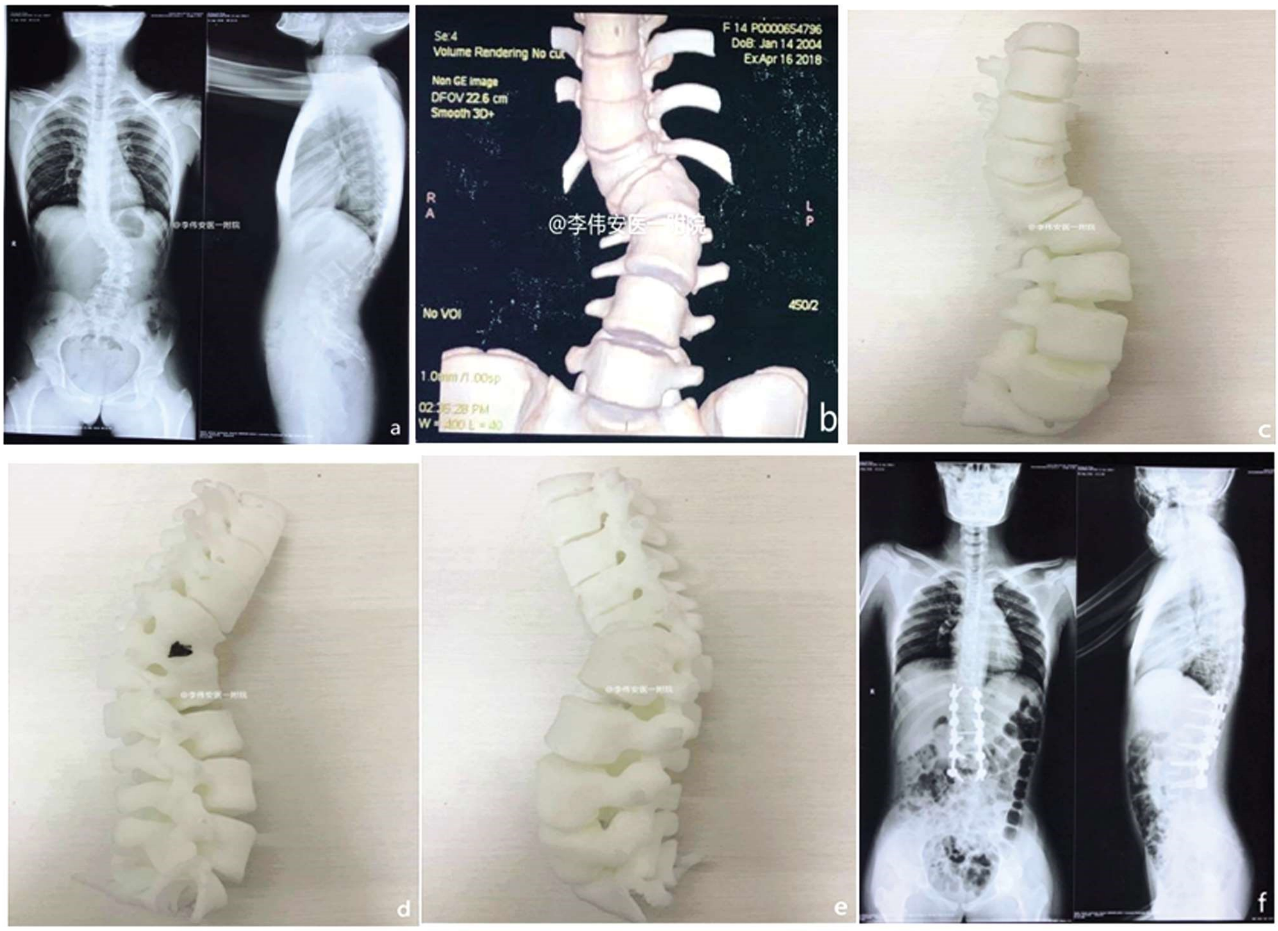

图 1 典型病例图

Fig.1 Diagram of typical cases

注：患者为 14 岁女性，图 a 为患者术前脊柱全长正侧位片；图 b 为患者术前的三维 CT；图 c-e 为 3D 打印的模型，提示患者胸腰段存在两个半椎体畸形，术前制定截骨方案和范围，术中按照既定计划实施手术；图 f 为患者术后脊柱全长正侧位片，患者的侧后凸畸形得到满意矫形。

Note: The patient was a 14-year-old female,Fig a was a full-length anterolateral spine film before operation. Fig.b was the three-dimensional CT before operation. Fig.c-e was a 3-D printed model, showed that there were two hemivertebral deformities in the thoracolumbar segment of the patient, the osteotomy plan and scope were made before the operation and the operation was carried out according to the established plan during the operation. Fig.f was a full-length posterolateral radiograph of the spine after surgery, and the kyphosis deformity of the patient has been corrected satisfactorily.

3 讨论

脊柱畸形常合并脊柱侧凸、后凸、椎体旋转,甚至半椎体、椎体形成不全、分节不全、关节突半脱位等畸形[10-12],尤其是脊柱侧凸，由于长期的旋转其在解剖形态上发生一系列变异:凹侧椎弓根变短变窄、椎体变形不对称、脊髓向凹侧偏移,紧贴椎弓根内壁[13-15]。由于脊柱侧凸患者脊柱形态学的复杂性和多样性,在后入路手术中很难识别和定位解剖标记物。手术的关键是准确定位进钉点、矢状和横断面的倾角、合适的深度、安全的椎弓根螺钉钉道等。这对外科医生的术前判断、经验和技能提出了很高的要求。虽然 CT 三维重建的影像可以立体、直观地显示患者脊柱畸形的具体情况,并在 CT 工作站中可以从任意角度、全方位显示,但其导出的图像是平面图,不能转动观察,并且图像呈现的是完整的脊柱序列,无法提取出病变椎体单独的形态;其次,由于患者脊柱合并侧凸、后凸及旋转,术中为了验证椎弓根螺钉钉道的准确性，需要将 C 形臂变换各种角度、方向,反复地进行透视,并且每次透视只能获得单一平面的图像,反复的透视会显著增加患者和术者的辐射剂量并延长手术时间。并且脊柱侧凸患者凹侧椎弓根往往会发生各种复杂的变异,导致置钉困难,螺钉常穿破内侧骨,突入到椎管内,可能造成极大损害[16-19]。即使调整后二次置钉,但椎弓根受到结构破坏会导致力学稳定性下降增加螺钉松动的机会。因此在脊柱矫形手术中,螺钉的准确置入是保障手术安全性的关键所在。Belmont PJ Jr 等[20]回顾分析 40 例脊柱矫形手术后发现有 43%的胸椎椎弓根螺钉穿破骨皮质,Modi H 等[21]回顾分析的脊柱侧凸病例中共计置入 854 枚螺钉中，经调整后置钉失败率仍达 10.1%。为提高术中置钉的准确率,也有学者研究采用导航技术来辅助置钉,但导航技术操作较复杂、学习曲线较长且费用高昂,目前难以在基层医院中推广。

3D 打印技术可以将虚拟计算机辅助设计 (CAD) 模型准确、快速地转化为立体实物原型[22-25]。利用 3D 打印机打印出手术段的脊柱模型,获得各病变椎弓根的三维数据,确定椎弓根的形状和大小,是否适合钉类型,直观地显示椎弓根的位置、范围和局部解剖,并可在模型上进行模拟置钉、模拟截骨,制定手术计划,提高医师的自信心,缩短手术时间,提高了置钉的准确性[26,27],Wu ZX 等[28]的研究表明 3D 模型组置钉准确率胸椎高达 94.4%、腰椎 91.6%,明显高于对照组。本组病例中的置钉准确率也达到 93.5%。近年来也有学者采用 3D 打印的导向模板辅助置钉[29],本组病例中也曾尝试使用导向模板,但发现其尚有不足之处。3D 打印导向模板所采用的数据是仰卧位的 CT 扫描数据,而患者手术中的体位为俯卧位,并且患者麻醉后全身松弛的状态都会给局部解剖特征带来变化,这些差异直接影响导向模板辅助置钉的准确性。人们积极探索新型导向模板来提高导向模板的贴合度和置钉的准确性。Takemoto M 等[30]制作了新型钛质导向模板,辅助置钉的准确率高达 98.6% ,但目前导向模板的技术尚不完全成熟,仍在探索中,且会进一步增加患者的诊疗费用,加重患者的经济负担。

综上所述,3D 打印模型为术者提供了更加直观、立体、即时的影像资料,能够提高置钉准确率,减少置钉时间和手术并发症,并且随着技术的发展和成熟、新型材料的选用,成本会更加低廉,其在脊柱侧凸矫形手术中的应用更加普及,为广大患者带来福音。

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