临床论著

3D 打印体外导板辅助经皮椎弓根螺钉固定术治疗胸腰椎骨折的临床疗效观察

连学辉[1]，肖红利[1]，卢 涛[1]，韩子冀[1]，邓 江[2]，蒋朝辉[3]

（1 贵州省贵阳市第一人民医院骨科 550000；2 贵州省遵义市第一人民医院骨科 563000；
3 贵州省贵阳市第一人民医院检验科 550000）

【摘要】目的：观察 3D 打印体外导板辅助经皮椎弓根螺钉固定术治疗胸腰椎骨折的临床疗效。**方法**：回顾性分析 2017 年 8 月~2020 年 8 月行经皮椎弓根螺钉固定手术的 47 例胸腰椎骨折患者的临床资料，男 13 例，女 34 例；年龄 21~69 岁。均为单节段损伤，T12 11 例，L1 26 例，L2 7 例，L3 2 例，L4 1 例。22 例术前制作 3D 打印个体化体外导板，模拟置钉，术中辅助置钉（导板组）；25 例采用 X 线透视辅助下徒手置钉（徒手组）。对比两组手术时间、置钉时间、术中 X 线透视次数、术中出血量、术后并发症；采用 Neo 分级标准评价两组手术置钉等级，计算置钉准确率；在术前、术后 X 线片上测量骨折椎体前缘高度和 Cobb 角，计算椎体矢状面指数，评价骨折复位及矫正情况；术前和术后 1d、7d 及 1 年时进行疼痛视觉模拟评分（visual analogue scale，VAS）评分、日本骨科协会（Japanese Orthopedics Association，JOA）评分和 Oswestry 功能障碍指数（Oswestry disability index，ODI）评定。**结果**：导板组手术时间、置钉时间、术中 X 线透视次数、术中出血量分别为 63.57±12.18min、23.69±3.63min、15.26±4.15 次、48.82±13.72ml；徒手组分别为 85.56±16.27min、41.36±8.12min、26.93±6.93 次和 74.35±18.64ml；导板组均少于徒手组，差异有统计学意义（$P<0.05$）。导板组 0 级置钉 119 枚，1 级置钉 3 枚，置钉准确率为 97.54%；徒手组 0 级置钉 128 枚，1 级置钉 10 枚，2 级置钉 1 枚，置钉准确率为 92.09%，导板组置钉准确率高于徒手组，差异有统计学意义（$P<0.05$）。术后两组的椎体前缘高度、椎体矢状面指数和 Cobb 角与术前相比均有显著性改善（$P<0.05$）；两组同时间点比较均无统计学差异（$P>0.05$）。两组术后 VAS 评分、JOA 评分和 ODI 与术前比较均有显著性改善，差异有统计学意义（$P<0.05$），两组间同时间点比较均无统计学差异（$P>0.05$）。两组患者术后伤椎均达到骨性愈合，均未出现术后并发症。**结论**：3D 打印体外导板辅助经皮椎弓根螺钉固定术治疗单节段胸腰椎骨折可取得良好效果，与徒手经皮椎弓根螺钉固定术相比能够显著性提高置钉准确率，并缩短手术时间、减少术中辐射暴露。

【关键词】 胸腰椎骨折；3D 打印体外导板；椎弓根螺钉；微创

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Clinical observation of 3D printed external guide plate assisted percutaneous pedicle screw fixation in the treatment of thoracolumbar fractures/LIAN Xuehui, XIAO Hongli, LU Tao, et al//Chinese Journal of Spine and Spinal Cord, 2022, 32(8): 704-712

【Abstract】Objectives: To observe the clinical effect of 3D printed external guide plate assisted percutaneous pedicle screw fixation in the treatment of thoracolumbar fractures. **Methods:** A retrospective analysis was performed on 47 patients with thoracolumbar fractures who underwent percutaneous pedicle screw fixation from August 2017 to August 2020, including 13 males and 34 females, aged 21-69 years. The patients were all single-segment fractures, involving T12 in 11 cases, L1 in 26 cases, L2 in 7 cases, L3 in 2 cases, and L4 in 1 case. 22 cases were treated with 3D printed customized in vitro guide plates made before surgery in simulating screw placement and assisting placement during operation (guide plate group), and the other 25 cases were treated with freehand screw placement under X-ray fluoroscopy (freehand group). The operative

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第一作者简介：男（1973-），医学博士，主任医师，研究方向：脊柱退变、损伤的再生修复研究

电话：（0851）88575694 E-mail：2630909737@qq.com

time, screw placement time, intraoperative X-ray fluoroscopy times, intraoperative blood loss, and postoperative complications were compared between the two groups. The Neo classification was used to evaluate the grades of screw placement in the two groups, and the accuracy of screw placement was calculated. The anterior height of the fractured vertebral body and the Cobb angle were measured on the preoperative and postoperative X-ray images, and the sagittal plane index of the vertebral body was calculated to evaluate the reduction and correction of the fracture. The visual analogue scale(VAS) score, Japanese Orthopedics Association(JOA) score and Oswestry disability index(ODI) were recorded before operation and at 1 day, 7 days and 1 year after operation. **Results:** The operative time, screw placement time, intraoperative X-ray fluoroscopy times, and intraoperative blood loss of the guide plate group were all less than those of the freehand group, which were 63.57±12.18min vs 85.56±16.27min, 23.69±3.63min vs 41.36±8.12min, 15.26±4.15 vs 26.93±6.93, and 48.82±13.72ml vs 74.35±18.64ml, respectively, and the differences were with statistical significance($P<0.05$). The accuracy of screw placement was 97.54% of the guide plate group with 119 screws of grade 0 and 3 screws of grade 1, which was higher than that of the freehand group of 92.09% with 128 screws of grade 0, 10 screws of grade 1, and 1 screw of grade 2, and the difference was statistically significant ($P<0.05$). The anterior height of the vertebral body, sagittal index of the vertebral body, and Cobb angle of the two groups after operation were improved significantly compared with those before operation($P<0.05$), and no significant difference was found between the two groups at the same time points($P>0.05$). The VAS score, JOA score and ODI of the two groups after operation were significantly improved compared with those before operation($P<0.05$), and there was no statistical difference between the two groups at the same time points($P>0.05$). The injured vertebrae in patients of both groups achieved bone healing after operation, and no postoperative complications occurred. **Conclusions:** 3D printed external guide plate assisted percutaneous pedicle screw fixation can achieve good results in the treatment of single-segment thoracolumbar fractures, which can improves the screw placement accuracy significantly, shortens the operative time, and reduces the intraoperative radiation exposures comparing with freehand percutaneous pedicle screw fixation.

【**Key words**】Thoracolumbar fracture; 3D printed external guide plate; Pedicle screw; Minimally invasive

【**Author's address**】1. Department of Orthopedics, Guiyang First People's Hospital, Guiyang, 550000; 2. Department of Orthopedics, First People's Hospital of Zunyi City, 563000; 3. Department of Laboratory Medicine, Guiyang First People's Hospital, Guiyang, 550000

脊柱爆裂骨折以胸腰段骨折最为常见[1,2],往往需要手术治疗。经椎弓根螺钉固定是治疗胸腰椎骨折最常用的手术方法[3]。然而,传统的开放式手术创伤较大,术后功能恢复慢,与当前的快速康复理念相悖[4]。随着脊柱微创技术的发展,经皮椎弓根螺钉内固定在胸腰椎骨折的治疗中越来越多地被临床医生选择[5]。但经皮椎弓根螺钉内固定需要在 X 线透视下反复调整进针角度和进针距离,以确保椎弓根螺钉置入的准确性[6,7],增加了术者和患者的射线暴露剂量,且反复调整置钉位置可能降低钉道抗拔出强度,甚至造成周围重要脏器或血管损伤[8,9]。有报道称计算机导航[10,11]、机器人辅助[12,13]椎弓根螺钉置入可有效提高椎弓根螺钉置入的准确性和安全性,但学习曲线长、设备成本高,在一些基层医院或医疗条件欠发达地区难以推广应用。3D 打印的引导模板可以安全、准确地辅助椎弓根螺钉置入[14,15],但传统的贴骨导板是根据骨的表面形态设计的,操作时需要去除皮肤和肌肉,否则会降低椎弓根螺钉置入的准确性,如导板置入切口小,皮肤肌肉去除困难,骨表面暴露困难均会导致螺钉置入产生偏差,主要应用于脊柱开放手术,在经皮微创置钉手术中应用的相关报道较少。我们通过患者的 CT 影像学数据设计出 3D 体外导板模型,打印出 3D 个性化体外导板,在其辅助下进行经皮椎弓根螺钉置入手术,取得了较好的疗效,总结报告如下。

1 资料与方法

1.1 纳入及排除标准

纳入标准:(1)外伤性胸腰椎骨折,胸腰椎脊柱脊髓损伤程度的评分 (thoracolumbar injury classification and severity score,TLICS)≥5 分、胸腰椎骨折载荷分享评分 (load sharing classification,LSC)≤6 分;(2)单节段胸腰椎骨折;(3)无脊

髓、神经损伤等。排除标准：(1)合并严重的骨质疏松者；(2)合并脊柱侧凸等脊柱畸形者；(3)病理性骨折者。

1.2 一般资料

2017 年 8 月~2020 年 8 月共有 47 例符合纳入与排除标准的胸腰椎骨折患者在贵阳市第一人民医院行经皮椎弓根螺钉内固定术，男 13 例，女 34 例；年龄 21~69 岁；均为单节段骨折，骨折部位：T12 11 例，L1 26 例，L2 7 例，L3 2 例，L4 1 例。均无脊髓及神经根损伤表现。其中 22 例术前制作 3D 打印个体化体外导板，术前模拟置钉，术中辅助置钉(导板组)；25 例术中采用 X 线透视辅助下直接徒手置钉(徒手组)。两组患者的性别比、年龄、体重指数(BMI)、伤椎置钉数量和骨折节段均无显著性差异(表 1，P>0.05)。

表 1 两组患者一般资料对比

Table 1 Comparison of general data of the two groups of patients

	导板组 Guide plate group	徒手组 Freehand group	*P*值 *P* value
性别(男/女) Sex(Male/Female)	7/15	6/19	>0.05
年龄(岁) Age(years)	47.59±8.35	49.42±6.92	>0.05
体重指数(kg/m^2) BMI	22.71±2.67	21.69±3.41	>0.05
伤椎置钉数量 Number of screws placed on injured vertebrae			>0.05
1 枚 1 piece	10	11	
2 枚 2 pieces	12	14	
骨折节段 Fracture segment			>0.05
T12	6	5	
L1	11	15	
L2	3	4	
L3	1	1	
L4	1	0	

1.3 方法

1.3.1 术前准备 患者入院后完善影像学及相关术前检查，明确伤椎及上下相邻椎体，评价患者的心肺功能情况、手术风险及手术可行性。采用日本骨科协会(Japanese Orthopedic Association，JOA)评分、疼痛视觉模拟评分量表 (visual analog scale，VAS) 评分和 Oswestry 功能障碍指数(Oswestry disability index，ODI)评估患者术前神经功能、疼痛程度及脊柱功能障碍情况。

3D 体外导板构建及打印：(1) 模拟手术体位(俯卧位)，完成术前手术体位下的胸腰椎 CT 薄层扫描，获取患者 CT 数据，以 Dicom 格式存储。(2)在患者骨折 3D 模型上行模拟置钉，选择最适宜内固定物，在 3D 模型上设计术中置钉位置及角度，记录相关数值，制订出适宜且完整的手术方案。(3)选取局部增长和阈值划分进行三维重建，初步完成计算机三维重建模型，应用网格化及平滑处理工具对计算机三维模型进行进一步精细处理。根据手术设计，分别建立椎弓根置钉通道。以伤椎上位椎双侧椎弓根上缘连线为 X 轴，以棘突中心线为 Y 轴，进行导板放置区定位，便于术中精准定位。以伤椎及上下椎为范围模拟出患者胸腰部软组织三维形态，确保制成的体外导板与皮肤充分贴附。进行体外导板设计，生成体外导板三维重建模型，以 STL 格式保存。(4)将模型数据导入到 3D 打印机(型号：Ultimaker 3D，中国)，打印格式设置层厚 0.1mm，应用聚乳酸材料打印出 1:1 导板模型(图 1)，低温高压消毒备用。(5)对 3D 导板进行彻底消毒灭菌，严格遵守无菌原则。

1.3.2 手术方法 采用气管插管全麻、俯卧位。常规消毒、铺巾后，导板组先放置无菌 3D 体外导板及定位针，G 型臂透视下定位导板放置位置(同导板设计时相同，X 轴位于伤椎上位椎体双侧椎弓根上缘连线、Y 轴位于置钉节段棘突中心线)，并确认导板与皮肤贴附良好后，3D 打印导板引导下先完成对角两个穿刺点穿刺，透视确认位置满意，在 3D 打印的体外导板辅助引导下依次置入其余穿刺针，G 型臂透视确认各穿刺点和穿刺深度准确。依次置入导丝，去除导板和穿刺针，常规行经皮椎弓根螺钉置入(图 2)和复位内固定手术。徒手组在 G 型臂透视定位下，徒手直接经皮置入穿刺针，G 型臂透视确认各穿刺点和穿刺深度准确，依次置入导丝，去除穿刺针，常规行经皮椎弓根螺钉置入和复位内固定手术。两组手术均为同一手术团队实施，主刀为同一骨科高年资主任医师。

1.4 疗效评价指标

记录手术时间、置钉时间、术中 X 线透视次数、术中出血量、术后并发症发生率。术后第 1 天、1 周、1 年进行 VAS 评分，评估腰背部疼痛情况；通过 JOA 评分和 ODI 评估患者功能改善情况。术后 1 周行 X 线片、CT 检查，评估椎弓根螺钉置入情况(采用 Neo 分级标准)、椎体前缘高度变化、椎体矢状面指数(sagittal index，SI)、Cobb 角矫正

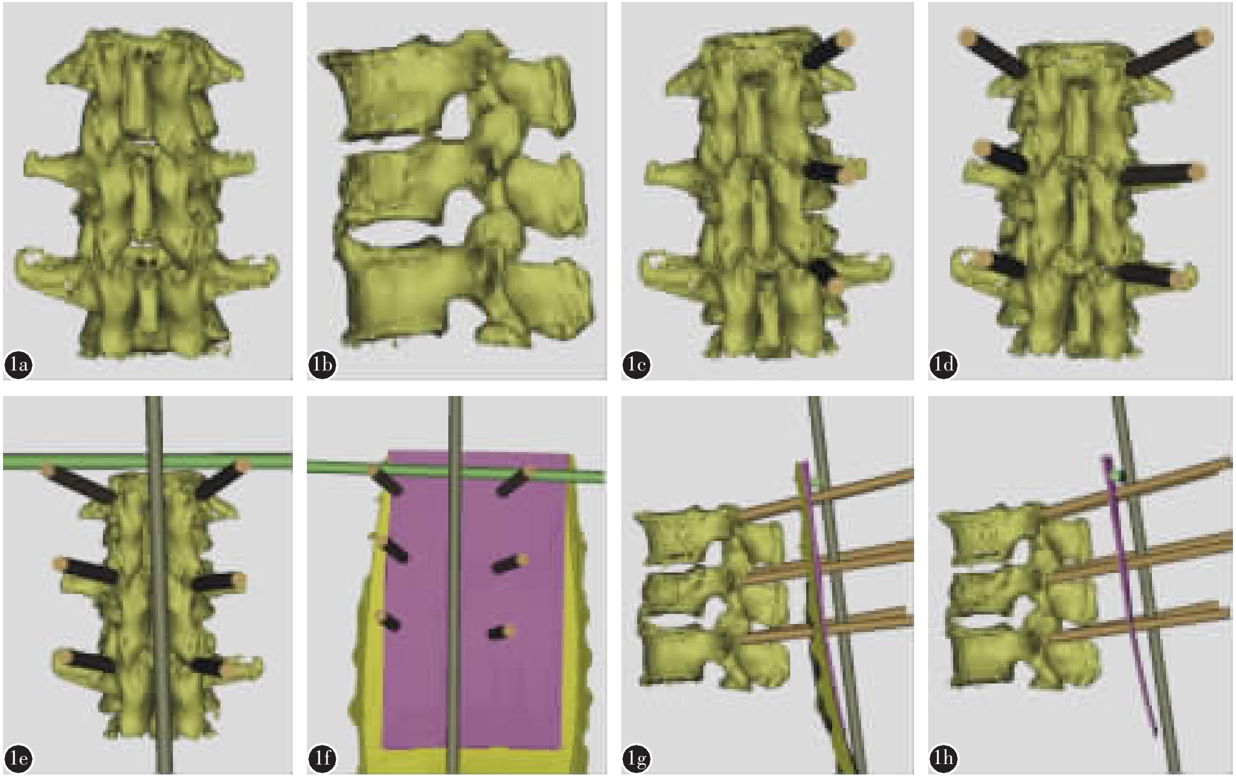


图 1 3D 体外导板构建及打印过程 **a**、**b** 骨折 3D 模型正面及侧面观 **c**、**d** 在患者骨折 3D 模型上建立椎弓根置钉通道 **e** 以伤椎上位椎体双侧椎弓根上缘连线为 X 轴，以棘突中心线为 Y 轴，制作定位针通道 **f** 皮肤界面贴附导板制作及 3D 打印体外导板后面观(紫色为导板，绿色为皮肤) **g** 3D 打印体外导板侧面观 **h** 导板制作完成，剔除皮肤的打印模式

Figure 1 Construction and printing process of 3D external guide plate **a, b** Front and side views of 3D fracture model **c, d** Establishing pedicle screw channels on the 3D fracture models **e** Taking the line connecting the upper edges of the pedicles on both sides of the upper vertebral body of the injured vertebra as the X-axis and the center line of the spinous process as the Y-axis to make a positioning needle channel **f** The skin interface attachment guide plate production and back view of 3D printed in vitro guide plate (purple, the guide plate, and green, the skin) **g** Side view of the 3D printed guide plate **h** The printing mode of the guide plate without skin

情况、骨折愈合情况，SI=椎体前缘高度/椎体后缘高度[16]。

1.5 统计学分析

使用 SPSS 22.0 统计软件进行分析。计量资料采用均数±标准差($\bar{x}\pm s$)表示，符合正态分布、方差齐性的计量资料两组间比较采用独立样本 t 检验，多组间比较采用方差分析。各组间率的比较采用卡方(χ^2)检验。$P<0.05$ 为差异有统计学意义。

2 结果

2.1 术中一般情况及术后并发症

两组患者的手术时间、置钉时间、X 线透视次数及出血量见表 2。导板组的手术时间、置钉时间、X 线透视次数及出血量较徒手组均显著性缩短或减少($P<0.05$)。两组患者术后均未出现切口感染、脊髓神经损伤、肺部感染、褥疮、断钉、断棒等并发症。

2.2 椎弓根螺钉置入情况

共置入椎弓根螺钉 261 枚，导板组中 10 例患者伤椎置钉 1 枚，12 例伤椎置钉 2 枚，共置钉 122 枚；徒手组中 11 例患者伤椎置钉 1 枚，14 例伤椎置钉 2 枚，共置钉 139 枚。两组椎弓根螺钉置钉等级和准确率见表 3，导板组置钉准确率显著性高于徒手组(97.54% vs 92.09%，$P<0.05$)，术后复查 CT 显示椎弓根螺钉位置良好(图 3)。

2.3 骨折复位情况

两组术前和术后 1 周时的椎体前缘高度、椎体矢状面指数和 Cobb 角见表 4，两组术后 1 周与术前比均有显著性改善($P<0.05$)，提示骨折复位及后凸矫正效果良好；两组同时间点比较均无显

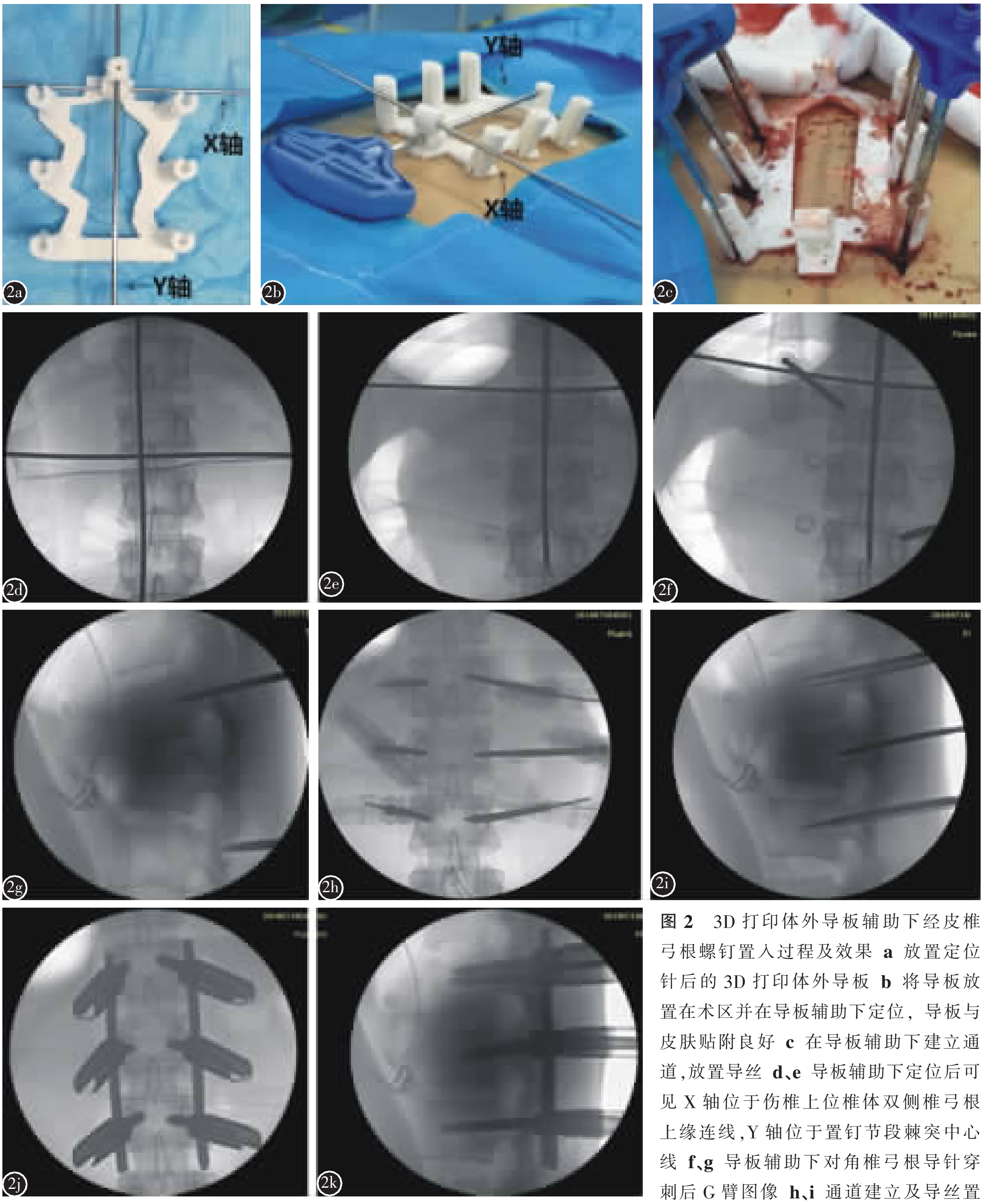


图 2 3D 打印体外导板辅助下经皮椎弓根螺钉置入过程及效果 **a** 放置定位针后的 3D 打印体外导板 **b** 将导板放置在术区并在导板辅助下定位，导板与皮肤贴附良好 **c** 在导板辅助下建立通道，放置导丝 **d**、**e** 导板辅助下定位后可见 X 轴位于伤椎上位椎体双侧椎弓根上缘连线，Y 轴位于置钉节段棘突中心线 **f**、**g** 导板辅助下对角椎弓根导针穿刺后 G 臂图像 **h**、**i** 通道建立及导丝置入后 G 臂图像 **j**、**k** 椎弓根螺钉置入后 G 臂图像

Figure 2 The procedure of 3D printed external guide plate assisted percutaneous pedicle screw placement and effect **a** 3D printed extracorporeal guide plate after placing positioning needles **b** Placing the guide plate on the surgical area and positioning with the help of the guide plate, where it attached well to the skin **c** Establishing a channel with the aid of the guide plate and placing a guide wire **d, e** After positioning with the aid of the guide plate, it could be seen that the X axis was located on the line connecting the upper edges of the bilateral pedicles of the upper vertebral body of the injured vertebra, and the Y axis was located on the center line of the spinous process of the screw placement segment **f, g** G-arm images after guide-assisted diagonal pedicle screw puncture **h, i** G-arm images after channel establishment and guide wire placement **j, k** G-arm images after pedicle screw placement

表 2 两组患者的手术时间、置钉时间、透视次数及出血量 ($\bar{x}\pm s$)

Table 2 The operative time, screw placement time, number of fluoroscopy, and blood loss of the two groups of patients

	导板组 Guide plate group	徒手组 Freehand group
手术时间(min) Operative time	63.57±12.18①	85.56±16.27
置钉时间(min) Screw placement time	23.69±3.63①	41.36±8.12
X线透视次数(次) X-ray fluoroscopy times	15.26±4.15①	26.93±6.93
出血量(ml) Intraoperative blood loss	48.82±13.72①	74.35±18.64

注:①与徒手组相比 $P<0.05$

Note: ①Compared with the freehand group, $P<0.05$

表 3 两组患者手术的置钉等级和置钉准确率

Table 3 The screw placement grade and accuracy of the two groups of patients

	置钉等级 Screw placement grade				置钉准确率(%) Screw placement accuracy
	0	1	2	3	
导板组(n=122) Guide plate group	119	3	0	0	97.54①
徒手组(n=139) Freehand group	128	10	1	0	92.09

注:①与徒手组相比 $P<0.05$

Note: ①Compared with the freehand group, $P<0.05$

著性差异($P>0.05$)。

2.4 临床疗效

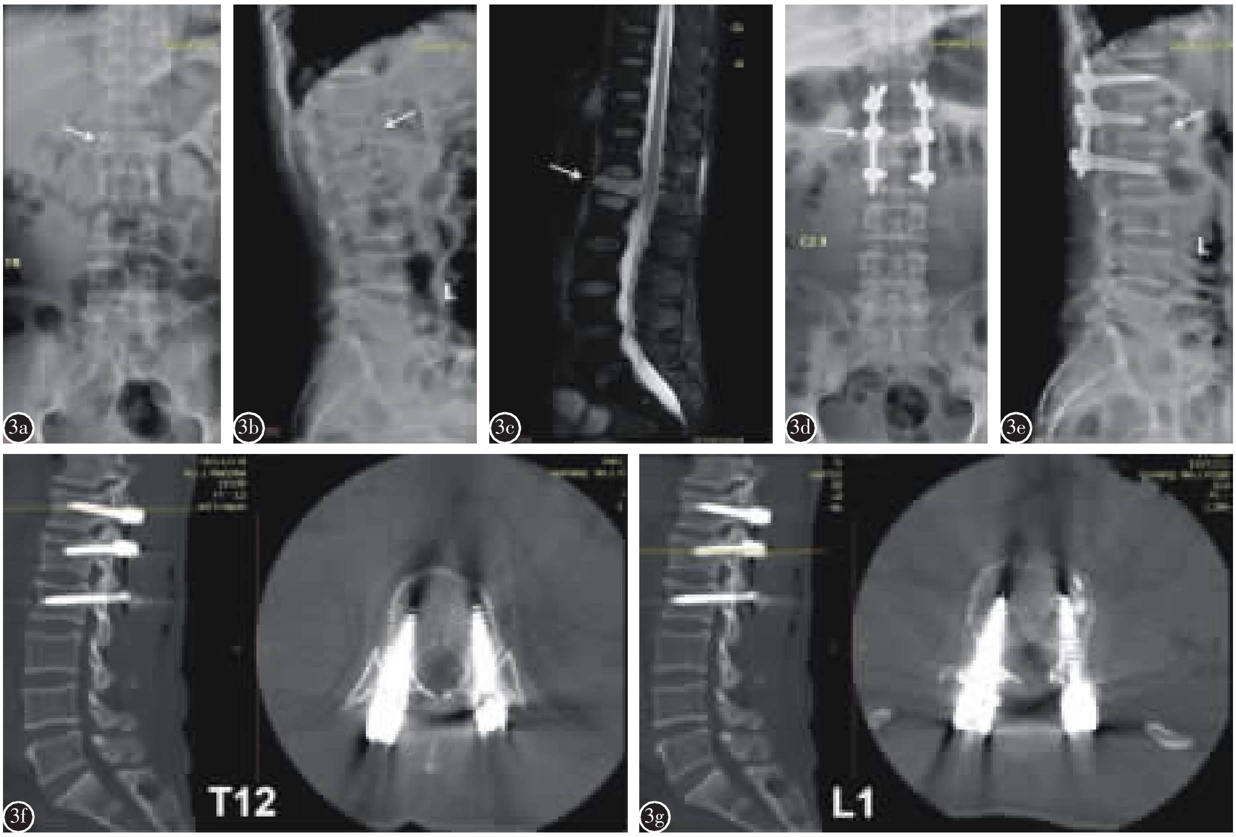
两组术前和术后不同时间点的 VAS 评分、JOA 评分和 ODI 见表 5。两组患者术后疼痛程度均明显改善;术后 1 周及 1 年时 JOA 评分明显增高,ODI 明显下降($P<0.05$);两组同时间点的 VAS 评分、JOA 评分和 ODI 均无显著性差异($P>0.05$)。术后 1 年复查腰椎 X 线及 CT 提示两组患者伤椎均已骨性愈合,愈合率均为 100%,均未出现椎体塌陷、骨折不愈合、断钉、断棒等情况(图 4)。

3 讨论

经皮椎弓根螺钉固定治疗胸腰椎骨折逐渐被推广应用,因其具有手术创伤小、恢复快、治疗效果好等优势[17],尤其在减少软组织损伤和术后并发症方面具有显著优势[18]。但传统的 3D 打印贴骨导板需要根据骨的表面形态去除皮肤和肌肉,带来一定损伤。“个体化”“1:1”的 3D 打印体外导板更能体现上述优势,其具有价格低廉、操作方便等特点,可微创、精准、快速建立椎弓根通道[19],进而减少手术创伤、降低手术风险、加快术后康复。有研究显示,个体化 3D 打印导向模板辅助强直性脊柱炎患者颈椎椎弓根螺钉置入可显著提高置钉的准确性和安全性,降低螺钉置入的风险[20];在 3D 打印导板辅助下,可提高经腰椎后路椎弓根螺钉置钉的精准度[21],减少手术并发症,显著改善患者临床症状[22]。

本研究采用患者的 CT 数据建立模型,通过个体化 3D 模型设计,制作新型 3D 打印个性化体外导板,并进行胸腰椎骨折治疗的临床应用,取得了良好的临床疗效。本研究中,导板组的手术时间、置钉时间、X 线透视次数及出血量均明显低于徒手组,并且未出现切口感染、脊髓神经损伤、肺部感染、褥疮、断钉、断棒等术后并发症,可能与微创经皮置钉创伤小、术后恢复快、可早期下床活动有关。提示 3D 打印体外导板辅助置钉可减少术中出血、手术创伤、术中辐射及术后并发症,充分体现了其微创性和安全性。但本研究病例数较少,尚需后续临床中进一步验证。导板组置钉准确率高达 97.54%,明显高于徒手组,说明术前在体外 3D 数字化模型上模拟置钉,并制作相应经皮置钉导板,通过与患者体型及骨骼形态精确匹配,达到精准置钉,体现 3D 打印体外导板的精准性;导板组术后的椎体前缘高度、椎体矢状面指数和 Cobb 角较术前均有显著性改善,与徒手组比较均无显著性差异,说明 3D 体外导板辅助下经皮椎弓根螺钉内固定能够获得良好的胸腰椎骨折复位及后凸矫正。与传统徒手经皮置钉相比,3D 打印体外导板辅助置钉具有同等的术后疗效,其术后疼痛、神经功能及胸腰椎功能均明显改善,术后 1 年两组患者伤椎均已骨性愈合,并且未出现椎体塌陷、骨折不愈合、断钉、断棒等情况,说明术后疗效优良,充分体现了其有效性。

与传统徒手经皮置钉比较,3D 打印导板辅助经皮椎弓根螺钉固定的主要优点如下:(1)可提高椎弓根螺钉置钉精准度,降低置钉难度,缩短手术时间,体现了手术微创性;(2)可降低手术风险,提高手术安全性;(3)可明显改善患者术后胸腰椎功能,手术疗效优良。但是,本研究所设计制作的 3D 打印个性化体外导板只适用个体化,不同患者需重复设计及打印,有待开发出可调节角度的个性化导板,适用于更多患者,提高临床工作效率;(2)



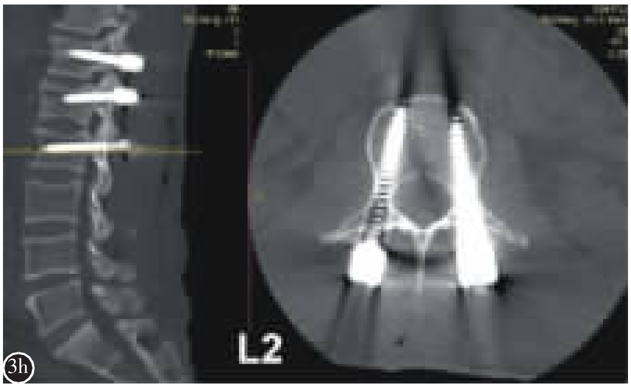


图 3 导板组患者，男，52 岁，L1 骨折，TLICS 评分 5 分，LSC 评分 5 分 **a**、**b** 术前腰椎正侧位 X 线片示 L1 椎体压缩骨折 **c** 术前 MRI 矢状位，T2WI 抑脂像示 L1 椎体骨折并骨髓水肿 **d**、**e** 术后腰椎正侧位 X 线片示椎弓根钉、棒固定在位，椎体高度及腰椎序列较术前恢复 **f~h** 术后 1 周复查腰椎 CT 显示 T12、L1、L2 椎弓根螺钉位置良好

Figure 3 A male patient in guide plate group, 52 years old, L1 fracture, TLICS score of 5, LSC score of 5 **a**, **b** Preoperative AP and lateral X-rays of the lumbar spine showed L1 compression fracture **c** Preoperative MRI sagittal, T2WI fat-suppressed image showed L1 vertebral fracture and bone marrow edema **d**, **e** Postoperative X-rays of the lumbar spine showed that the pedicle screws and rods were fixed in place, and the height of the vertebral body and the vertebral alignment were recovered compared with those before operation **f-h** Postoperative one week lumbar CT showed that T12, L1, and L2 pedicle screws were well positioned

表 4 两组患者胸腰椎骨折复位及矫正情况 ($\bar{x}\pm s$)

Table 4 The reduction and correction of thoracolumbar fractures in the two groups

	导板组 Guide plate group		徒手组 Freehand group	
	术前 Preoperation	术后 1 周 Postoperative 1 week	术前 Preoperation	术后 1 周 Postoperative 1 week
椎体前缘高度(%) Anterior vertebral height	56.24±7.45	92.87±10.13①	57.86±8.26	91.68±8.67①
椎体矢状面指数(%) Vertebral sagittal index	59.44±5.68	85.84±14.64①	60.07±6.74	86.58±13.24①
Cobb角(°) Cobb angle	15.14±4.15	5.02±2.23①	13.85±5.28	4.74±1.87①

注：①与术前比较 $P<0.05$

Note: ①Compared with preoperation, $P<0.05$

本研究仅涉及胸腰椎单椎体骨折，对于复杂的多节段、跨节段椎体骨折以及合并椎弓根骨折等类型的脊柱骨折，仍需进一步深入探索及研究；(3)本组研究病例数相对较少，需扩大样本量，证实研究结论。

本研究制备的基于 3D 打印技术的经皮椎弓根螺钉个性化体外导板在胸腰椎骨折行经皮椎弓根螺钉手术中应用效果优良，可更大限度减少术

表 5 两组患者手术前后 VAS 评分、JOA 评分和 ODI ($\bar{x}$±s)

Table 5 VAS score, JOA score and ODI before and after surgery in the two groups

	VAS评分 VAS score		JOA评分 JOA score		ODI(%)	
	导板组 Guide plate group	徒手组 Freehand group	导板组 Guide plate group	徒手组 Freehand group	导板组 Guide plate group	徒手组 Freehand group
术前 Preoperation	7.86±2.56	7.75±2.14	8.96±1.28	8.87±1.52	86.69±12.61	85.27±13.85
术后 1 天 Postoperative 1 day	4.12±1.43①	4.34±1.92①	—	—	—	—
术后 1 周 Postoperative 1 week	2.68±0.23①	2.81±0.64①	18.12±1.98①	17.25±1.32①	35.32±6.86①	38.65±8.32①
术后 1 年 Postoperative 1 year	1.12±0.22①	1.15±0.19①	27.69±0.85①	27.52±1.12①	8.53±4.42①	9.28±3.84①

注：①与术前比较 $P<0.05$

Note: ①Compared with preoperation, $P<0.05$

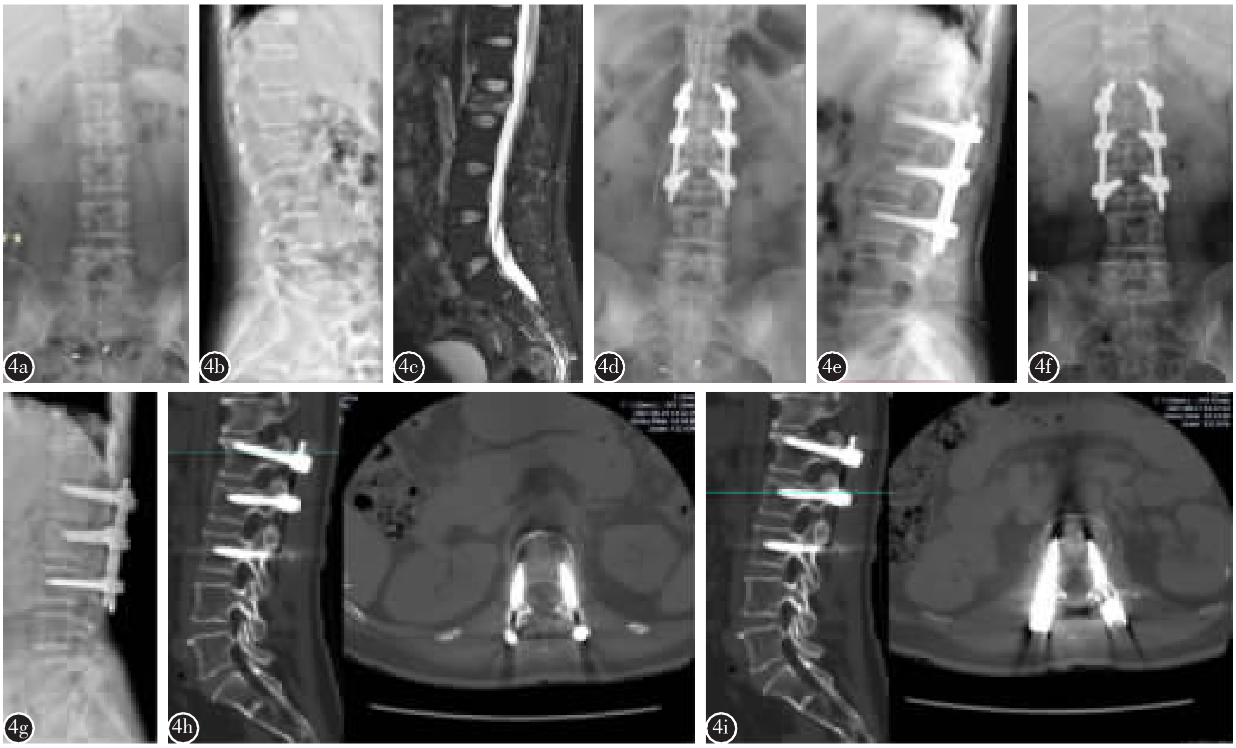


图 4 导板组患者，女，49 岁，L2 椎体骨折，TLICS 评分 5 分，LSC 评分 5 分 **a、b** 术前腰椎正侧位 X 线片示 L2 椎体压缩骨折 **c** 术前 MRI 矢状位，T2WI 抑脂像示 L2 椎体骨折并骨髓水肿 **d、e** 术后腰椎正侧位 X 线片示椎弓根钉、棒固定在位，椎体高度及腰椎序列较术前恢复 **f、g** 术后 1 年复查腰椎正侧位 X 线片示椎弓根钉、棒固定在位无松动，椎体高度及腰椎序列无明显变化，骨折已愈合 **h、i** 术后 1 年复查腰椎 CT 显示 L1、L2、L3 椎弓根螺钉位置良好，骨折已愈合

Figure 4 A female patient in guide plate group, 49 years old, L2 fracture, TLICS score of 5, and LSC score of 5 **a, b** AP and lateral X-rays of the lumbar spine before operation showed L2 compression fracture **c** Preoperative MRI sagittal, T2WI fat-suppressed image showed L2 vertebral fracture and bone marrow edema **d, e** Postoperative X-rays of the lumbar spine showed that the pedicle screws and rods were fixed in place, and the height of the vertebral body and the lumbar vertebral alignment were recovered compared with those before operation **f, g** One year after operation, X-ray images showed that the pedicle screws and rods were fixed in place without loosening, the vertebral body height and lumbar vertebral alignment did not change significantly, and the fracture had healed **h, i** One-year follow-up CT of the lumbar spine showed that the L1, L2, and L3 pedicle screws were in good positions and the fractures had healed

中 X 线透视次数、缩短手术时间、提高术中置钉成功率、降低手术风险,使经皮椎弓根螺钉内固定术在治疗胸腰椎骨折中具有更佳精准性、微创性及有效性,值得临床推广应用。

4 参考文献

1. 宋超, 林斌, 陈志达, 等. 胸腰椎骨折合并椎间盘损伤的研究进展[J]. 中国脊柱脊髓杂志, 2019, 29(10): 932–935.
2. Santander XA, Rodríguez–Boto G. Retrospective evaluation of thoracolumbar injury classification system and thoracolumbar ao spine injury scores for the decision treatment of thoracolumbar traumatic fractures in 458 consecutive patients [J]. World Neurosurg, 2021, 153: e446–e453.
3. Li Y, Qian Y, Shen G, et al. Safety and efficacy studies of kyphoplasty, mesh–container–plasty, and pedicle screw fixation plus vertebroplasty for thoracolumbar osteoporotic vertebral burst fractures[J]. J Orthop Surg Res, 2021, 16(1): 434.
4. Modi HN, Suh SW, Fernandez H, et al. Accuracy and safety of pedicle screw placement in neuromuscular scoliosis with free–hand technique[J]. Eur Spine J, 2008, 17(12): 1686–1696.
5. Jin B, Su YB, Zhao JZ. Three–dimensional fluoroscopy–based navigation for the pedicle screw placement in patients with primary invasive spinal tumors[J]. Chin Med J, 2016, 129(21): 2552–2558.
6. El–Desouky A, Silva PS, Ferreira A, et al. How accurate is fluoroscopy–guided percutaneous pedicle screw placement in minimally invasive TLIF[J]. Clin Neurol Neurosurg, 2021, 205: 106623.
7. 金祺, 周逸驰, 赵祖发, 等. 经皮与经肌间隙入路椎弓根螺钉内固定术治疗单节段胸腰椎骨折疗效的 Meta 分析[J]. 中国脊柱脊髓杂志, 2020, 30(11): 991–1000.
8. Pijpker PAJ, Kuijlen JMA, Kraeima J, et al. A Comparison of drill guiding and screw guiding 3D–printing techniques for intra and extrapedicular screw insertion [J]. Spine (Phila Pa 1976), 2021, 7(10): E434–E441.
9. Hasanain M, Englisch CN, Garner M, et al. Radiological analyses of the dimensions of the pedicle and dorsal part of the transverse process of subaxial vertebrae in the context of cervical spine surgery[J]. Ann Anat, 2021, 238: 151790.
10. Coric D, Rossi VJ, Peloza J, et al. Percutaneous, navigated minimally invasive posterior cervical pedicle screw fixation[J]. Int J Spine Surg, 2020, 14(s3): s14–s21.
11. Charles YP, Cazzato RL, Nachabe R, et al. Minimally invasive transforaminal lumbar interbody fusion using augmented reality surgical navigation for percutaneous pedicle screw placement[J]. Clin Spine Surg, 2021, 34(7): E415–E424.
12. Park C, Crutcher C, Mehta VA, et al. Robotic–assisted percutaneous iliac screw fixation for destructive lumbosacral metastatic lesions:an early single–institution experience [J]. Acta Neurochir (Wien), 2021, 163(11): 2983–2990.
13. Katsevman GA, Spencer RD, Daffner SD, et al. Robotic–navigated percutaneous pedicle screw placement has less facet joint violation than fluoroscopy–guided percutaneous screws[J]. World neurosurg, 2021, 151: e731–e737.
14. Wu C, Deng J, Zeng B, et al. Three–dimensional anatomic analysis and navigation templates for C1 pedicle screw placement perpendicular to the coronal plane: a retrospective study[J]. Neurol Res, 2021, 43(12): 961–969.
15. Zhao Y, Liang J, Luo H, et al. Double–trajectory lumbar screw placement guided by a set of 3D–printed surgical guide templates: a cadaver study[J]. BMC Musculoskelet Disord, 2021, 22(1): 296.
16. 张剑锋, 吕世桥, 沈炳华, 等. 经皮椎体后凸成形术骨水泥位置对术后疗效影响的对比分析 [J]. 中国矫形外科杂志, 2010, 18(18): 1514–1517.
17. Phan K, Rao PJ, Mobbs RJ. Percutaneous versus open pedicle screw fixation for treatment of thoracolumbar fractures: systematic review and meta–analysis of comparative studies [J]. Clin Neurol Neurosurg, 2015, 135: 85–92.
18. 林书, 胡豇, 万仑, 等. 机器人辅助下经皮微创椎弓根螺钉内固定与传统开放内固定治疗胸腰椎骨折的短期疗效比较[J]. 中国修复重建外科杂志, 2020, 34(1): 76–82.
19. 许可, 蒲晓鹏, 郑旺, 等. 3D 打印个体化椎弓根导板研制及模拟置钉的准确性[J]. 中国组织工程研究, 2017, 21(23): 3724–3729.
20. 丁祥, 李超, 牛国旗, 等. 个体化 3D 打印导向模板辅助强直性脊柱炎颈椎椎弓根螺钉置入的实验研究 [J]. 实用医学杂志, 2020, 36(8): 1072–1076.
21. Marengo N, Matsukawa K, Monticelli M, et al. Cortical bone trajectory screw placement accuracy with a patient–matched 3D printed guide in lumbar spinal surgery: a clinical study [J]. World Neurosurg, 2019, 130: e98–e104.
22. 王雅辉, 刘正蓬, 褚立, 等. 3D 打印技术在椎弓根螺钉植入过程中的应用价值[J]. 实用医学杂志, 2019, 35(6): 931–935.

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(英文编审 谭 啸)

(本文编辑 卢庆霞)