[DOI]10.12016/j.issn.2096-1456.2020.01.005　　·临床研究·

虚拟手术设计在双颌正颌手术中的精准性研究

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【摘要】 **目的**　评估虚拟手术设计在双颌正颌手术中的精准性，以期为临床提供参考。**方法**　纳入需行双颌正颌手术的患者30例，利用CT数据和牙弓平面扫描数据建立复合颅骨模型，在Dolphin Imaging 11.7 Premium软件上模拟上颌骨LeFort Ⅰ型骨切开术和双侧下颌支矢状骨劈开术，必要时行颏成形术，利用3D打印的手术导板将虚拟手术设计转移到术中。选择3个平面：眶耳平面(FHP)、面中平面(垂直于FHP且通过鼻根点)和冠状面(垂直于FHP且通过蝶鞍点)。选择6个标志点：上、下颌中切牙的近中接触点(UI、LI)以及上下颌第一磨牙的近中颊尖(U6-R、U6-L、L6-R、L6-L)。在虚拟手术模型和真实术后模型上测量选定标志点和对称平面之间的距离，并计算两模型之间的线性差异和总体平均线性差异(UI、LI、U6-R、U6-L、L6-R、L6-L分别与眶耳平面、面中平面和冠状面之间距离的平均差异)。确定由咬合平面、腭平面和下颌平面分别与眶耳平面和面中平面构成的角度值，并计算虚拟手术模型和真实术后模型之间的角度差异和总体平均角度差异。**结果**　借助3D打印手术导板，虚拟手术设计被成功转移至实际手术中，所有患者术后对面型和咬合都很满意。虚拟与真实模型间的总体平均线性差异为0.81 mm(上颌骨0.71 mm，下颌骨0.91 mm)；总体平均角度差异为0.95°(相对于眶耳平面的平均角度差异为1.10°，相对于面中平面的平均角度差异为0.83°)。**结论**　虚拟手术设计有助于牙颌面畸形的诊断和治疗计划的制定，可以增加双颌正颌手术中骨块定位的精准性。

【关键词】 虚拟手术设计；　牙颌面畸形；　正颌手术；　骨块定位；　LeFort Ⅰ型骨切开术；　下颌支矢状骨劈开术；　颏成形术；　手术导板；　3D打印；　精准医学

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Research on the precision of virtual surgical planning in two-jaw orthognathic surgery

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【Abstract】 **Objective**　To provide a clinical reference by evaluating the precision of virtual surgical planning in two-jaw orthognathic surgery. **Methods**　Thirty consecutive patients who required two-jaw orthognathic surgery were included. A composite skull model was reconstructed using data from spiral computed tomography scan and surface scanning of the dental arch. LeFort I osteotomy of the maxilla and bilateral sagittal split ramus osteotomy of the mandible were simulated using Dolphin Imaging 11.7 Premium. Genioplasty was performed if indicated. Virtual plan was then transferred to operation room using 3D-printed surgical templates. Frankfort horizontal plane (FHP), midfacial plane (perpendicular to the FHP through the nasion), and coronal plane (perpendicular to the FHP through the sella point) were the selected three symmetry planes.Midpoint of the contact of the maxillary and mandibular central incisors (UI, LI), and the mesio-buccal cusp of the first maxillary and mandibular molars (U6-R,U6-L, L6-R, L6-L) were the six chosen volu-

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metric landmarks. To calculate the linear difference and overall mean linear difference (mean difference of the distance between UI, LI, U6-R, U6-L, L6-R, L6-L to FHP, midfacial and coronal plane) between simulated and postoperative models, the distance between selected landmarks and symmetry planes was measured. To calculate the angular difference and overall mean angular difference, values of the angles constructed by the occlusal, palatal, and mandibular plane to FHP and midfacial plane respectively were determined on simulated and postoperative models. **Results** The virtual surgical planning was successfully transferred to actual surgery with the help of 3D-printed surgical templates. All patients were satisfied with the postoperative facial profile and occlusion. The overall mean linear difference was 0.81 mm (0.71 mm for maxilla and 0.91 mm for mandible); and the overall mean angular difference was 0.95° (the mean angular difference relative to FHP was 1.10°, and that relative to midfacial plane was 0.83°). **Conclusion** Virtual surgical planning facilitated the diagnosis, treatment planning, and precise bony segments repositioning in two-jaw orthognathic surgery.

【Key words】 virtual surgical planning; dento-maxillofacial deformities; orthognathic surgery; bony segments reposition; LeFort I osteotomy; sagittal split ramus osteotomy; genioplasty; surgical templates; 3D-printed; precision medicine

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双颌正颌手术，即上颌骨LeFort I型骨切开术联合下颌支矢状骨劈开术（sagittal split ramus osteotomy，SSRO）或垂直骨切开术（intraoral vertical ramus osteotomy，IVRO），是一种矫治严重牙颌面畸形的有效方法[1]。手术的成功取决于准确的手术设计和外科技术。双颌手术的传统治疗方案包括二维头影测量诊断分析、面弓转移、石膏模型外科以及制作中间和终末咬合板。这些方案通常能获得令人满意的效果，但有许多限制，比如耗时性、复杂性，甚至不准确性。虚拟手术设计和快速成型技术为治疗方案提供了新的可能性：全面三维分析牙弓和周围骨骼结构，从而模拟不同手术设计并预测相应结果，并使用3D打印导板将虚拟手术设计转移到实际手术当中[2-3]。已发表的有关虚拟手术设计的文献多为研究可行性的病例报告或是强调虚拟手术设计相对于传统方法的潜在优势[4-5]，少有文献报道关于虚拟手术设计在双颌手术中的精准性。本研究收集30例行双颌正颌手术患者的术前虚拟手术结果与术后真实手术结果，定量比较两者之间的差异，评价以虚拟手术设计和3D打印导板应用于数字化正颌外科手术的精准性。

1 资料和方法

1.1 临床资料

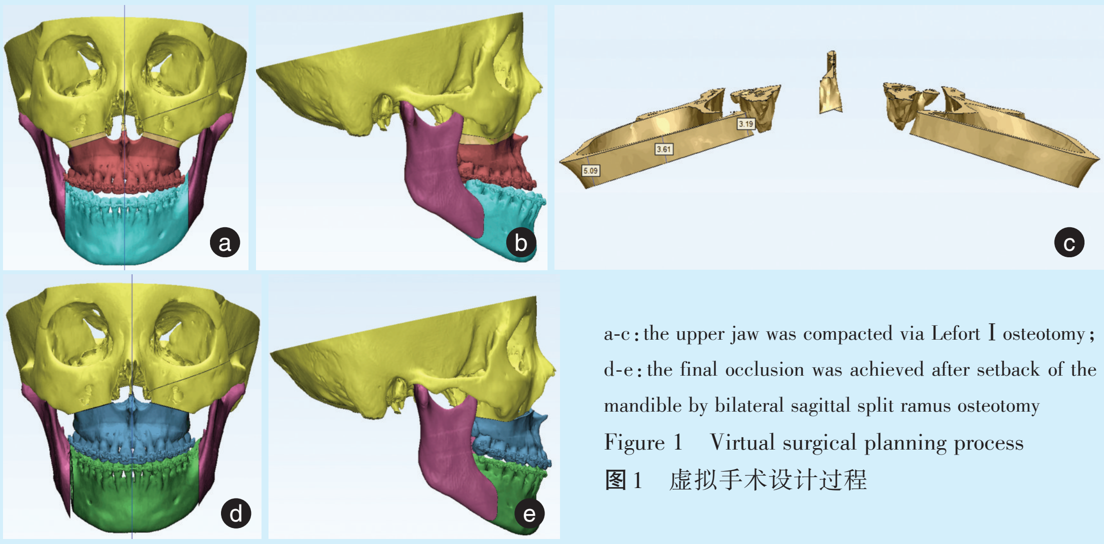
本研究纳入2018年1月1日～2018年6月30日四川大学华西口腔医院收治的需行双颌正颌手术的30个连续病例。纳入病例均为19～30岁骨性错𬌗畸形患者，男女比例近似1∶1，其中大多数为安氏Ⅲ类错𬌗畸形，少数患者伴有上颌骨垂直向发育过度、面部不对称或前牙开𬌗。研究方案经华西口腔医院伦理审查委员会批准，所有参与者均签署知情同意书。每例患者都接受了上颌骨LeFort Ⅰ型骨切开术联合双侧下颌支矢状骨劈开术，必要时行颏成形术。

1.2 虚拟手术设计

在术前和术后1个月（术后正畸前），对每例患者进行CT扫描和牙弓激光扫描（3 shape，哥本哈根，丹麦）。将来自CT扫描的DICOM数据和来自牙弓扫描的STL数据拟合，构建精确的颅颌面-牙列模型。在全面三维分析后，运用Dolphin Imaging 11.7 Premium（Dolphin Imaging and Management Solutions，Chatsworth，美国）和Mimics 10.01（Materialise，比利时）软件进行虚拟手术设计和模拟（图1）。

1.3 使用3D打印导板转移

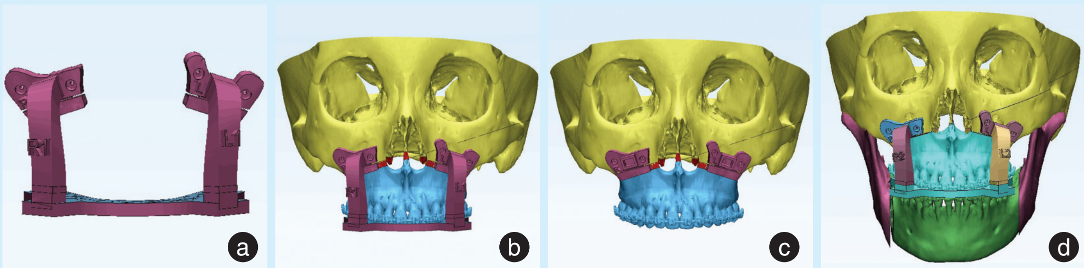
借助系列外科导板将虚拟设计转移至手术中（图2），所用手术导板包括一个终末咬合板、两对连接杆以及一对定位板（图3a）。终末咬合板和第一对连接杆在上颌截骨术之前用于确定定位板的位置（图3b），然后用微型螺钉将定位板固定在上颌骨，取出咬合板和连接杆（图3c），切开上颌骨后（图3d），连接终末咬合板、第二对连接杆和定位板，确定上颌骨新的三维空间位置（图3e）。确定上颌骨最终位置后，进行双侧下颌支矢状骨劈开术并借助终末咬合板获得正确咬合（图3f）。



a-c: the upper jaw was compacted via Lefort Ⅰ osteotomy; d-e: the final occlusion was achieved after setback of the mandible by bilateral sagittal split ramus osteotomy

Figure 1　Virtual surgical planning process

图1　虚拟手术设计过程



a-c: bone attachments were fixed on the surface of maxilla using miniscrews with the support of the occlusion plate and the first pair of 3D arms; d: the new 3D position of the maxilla was determined by the occlusion splint and a second pair of 3D arms, and the final occlusion was determined by the same occlusion splint

Figure 2　Design of a series of surgical guides to help the virtual design transfer to the actual operation

图2　设计系列手术导板以帮助虚拟设计转移到实际手术中

1.4　虚拟外科手术设计的精准性评估

选择3个平面：眶耳平面（FHP）、面中平面（垂直于FHP且通过鼻根点）和冠状面（垂直于FHP且通过蝶鞍点）。

选择6个标志点：上、下颌中切牙的近中接触点（UI、LI）以及上下颌第一磨牙的近中颊尖（U6-R、U6-L、L6-R、L6-L）（图4）。

在虚拟手术模型和真实术后模型上测量选定标志点和对称平面之间的距离，并计算两模型之间的线性差异。

总体平均线性差异：UI、LI、U6-R、U6-L、L6-R、L6-L分别与眶耳平面、面中平面和冠状面之间距离的平均差异。

上颌标志点的平均线性差异：UI、U6-R、U6-L分别与眶耳平面、面中平面和冠状面之间距离的平均差异。下颌标志点的平均线性差异：LI、L6-R、L6-L分别与眶耳平面、面中平面和冠状面之间距离的平均差异。

确定由咬合平面、腭平面和下颌平面分别与眶耳平面和面中平面构成的角度值，并计算虚拟手术模型和真实术后模型之间的角度差异。

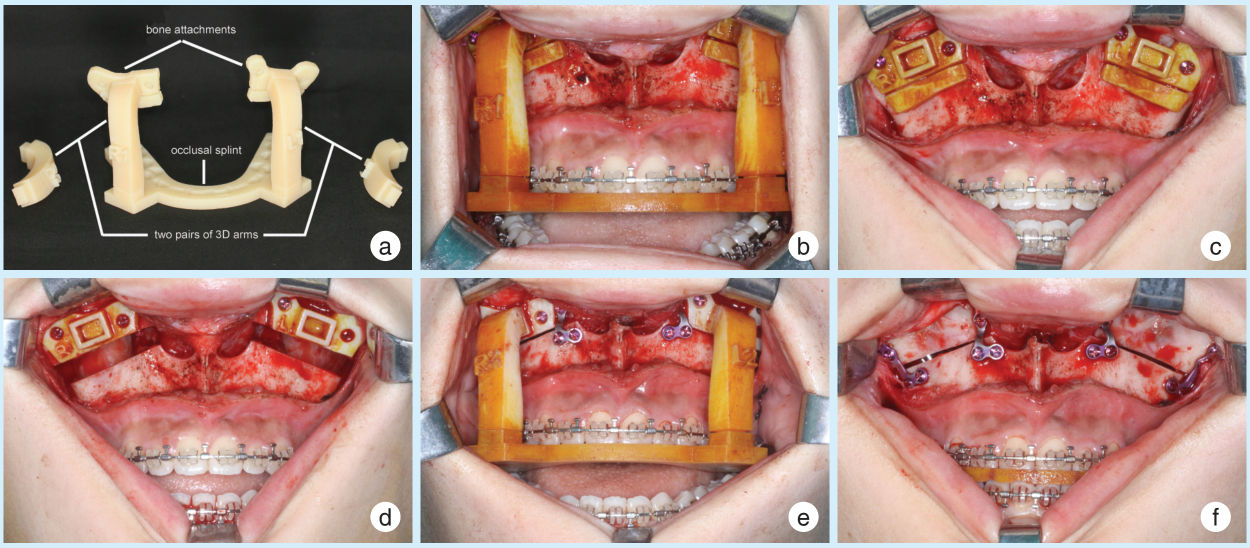
1.5　数据分析

使用SPSS 12.0版本（SPSS，Chicago，IL，SA）分析所有数据，利用配对 t 检验分析颌骨和牙的虚拟位置与实际位置之间的差异，检验水平为双侧 α = 0.05。

2　结　果

2.1　整体结果

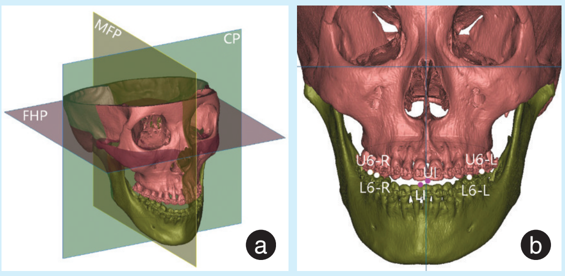
在3D系列外科手术导板的辅助下，虚拟手术



a: the surgical templates consisted of three parts: a occlusion splint, two pairs of 3D arms, and a pair of bone attachments; b-c: bone attachments were fixed on the surface of maxilla using mini screws with the support of the occlusion plate and the first pair of 3D arms; d: LeFort Ⅰ osteotomy and impaction of the upper jaw were then performed according to the indication line of the bone attachments; e: the occlusion splint and a second pair of 3D arms were used to determine the new 3D position of the maxilla; f: subsequently, bilateral sagittal split ramus osteotomy of the mandible was performed and the final occlusion was determined by the occlusion splint

Figure 3 A series of surgical templates were fabricated by rapid prototyping technology to support the intraoperative translation of the virtual plan to actual surgery

图3 利用快速成型技术制作系列手术导板,在实际手术中实现虚拟设计的转移



a: symmetry planes, FHP: Frankfort horizontal plane; MFP: midfacial plane; CP: coronal plane

b: landmarks: UI: midpoint of the contact of the maxillary central incisors; LI: midpoint of the contact of the mandibular central incisors; U6-R & U6-L: the mesio-buccal cusp of the first maxillary molars; L6-R & L6-L: the mesio-buccal cusp of the first mandibular molars.

Figure 4 The symmetry planes and landmarks on the surface of the skull

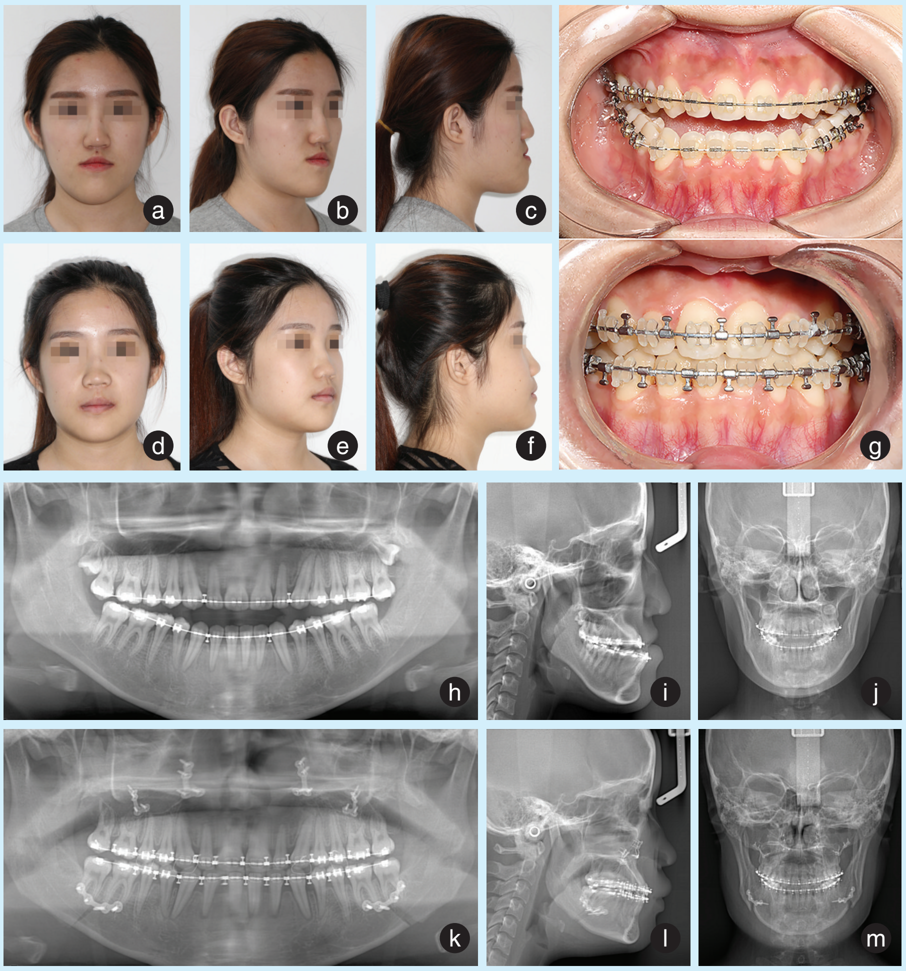
图4 颅骨表面的对称平面和标志点

设计被成功转移至所有患者的实际术中,所有患者对包括面型和咬合在内的术后效果表示满意。典型病例是诊断为安氏Ⅲ类错㓗伴开㓗的22岁女性(图5)。该患者进行了上颌LeFort I型骨切开术后的上颌上抬、前移和固定,以及下颌支矢状骨劈开术后的下颌骨后退,术后一个月的软组织肿胀仍然明显,但面型和咬合令人满意。

2.2 定量分析

表1展示了虚拟手术模型和真实术后模型之间的线性差异,总体平均线性差异是(0.81 ± 0.40) mm,上颌标志点的平均线性差异是(0.71 ± 0.30) mm,下颌标志点的平均线性差异是(0.91 ± 0.40) mm;上颌骨和下颌骨的标志点相对于眶耳平面的总体平均线性差异为(0.92 ± 0.40)mm,相对于面中平面是(0.55 ± 0.30)mm,相对于冠状面是(0.97 ± 0.40)mm。

表2为虚拟手术模型与真实术后模型的角度差异,总体平均角度差异为0.95° ± 0.50°,相对于眶耳平面的平均角度差异为1.10° ± 0.50°,相对于面中平面的平均角度差异为0.83° ± 0.40°。



a-c: the facial profile before surgery; d-f: the facial profile after surgery; g: the comparison of final occlusion before and after surgery; h-j: panoramic and cephalometric images before surgery; k-m: panoramic and cephalometric images after surgery

Figure 5 Images of representative patient

图 5 典型病例图片

表 1 虚拟手术模型和真实术后模型之间的线性差异定量比较结果

Table 1 Quantitative results of linear differences between virtually simulated and actual postoperative models $\bar{x}\pm s$,mm

Landmarks	Difference in the distance to FHP	t	P	Difference in the distance to midfacial plane	t	P	Difference in the distance to coronal plane	t	P
UI	0.7 ± 0.3	0.282	0.780	0.4 ± 0.1	0.694	0.493	0.8 ± 0.4	0.491	0.627
LI	1.1 ± 0.5	0.464	0.646	0.5 ± 0.3	0.076	0.940	1.0 ± 0.4	0.997	0.327
U6-R	0.8 ± 0.4	0.029	0.977	0.6 ± 0.2	0.487	0.630	0.9 ± 0.3	0.739	0.466
U6-L	0.7 ± 0.3	0.893	0.379	0.5 ± 0.2	0.667	0.510	1.0 ± 0.5	0.234	0.817
L6-R	1.0 ± 0.4	0.572	0.572	0.7 ± 0.3	1.364	0.183	1.1 ± 0.6	1.808	0.081
L6-L	1.2 ± 0.5	0.298	0.768	0.6 ± 0.3	2.717	0.011	1.0 ± 0.5	0.419	0.678

表 2 虚拟手术模型和真实术后模型之间的角度差异定量比较结果

Table 2 Quantitative comparison of angular differences between virtually simulated and actual postoperative models $\bar{x}\pm s$, °

Symmetry planes	Angular difference relative to FHP	t	P	Angular difference relative to midfacial plane	t	P
Occlusal plane	1.1±0.6	1.078	0.290	0.9±0.4	0.019	0.985
Palatal plane	0.8±0.3	0.665	0.511	0.6±0.2	0.952	0.349
Mandibular plane	1.3±0.6	0.930	0.360	1.0±0.6	1.550	0.132

3 讨 论

关于正颌外科手术中的虚拟手术设计文献资料，多为报告一个或几个病例以强调实践可行性。由于表示数据的差异，几乎不可能进行 meta 分析[6]。本研究通过比较 30 例患者的虚拟设计和实际结果之间的线性与角度差异，分析了正颌外

科手术中虚拟手术设计的精准性。利用系列手术导板使得上颌骨能够独立于下颌骨而固定在新的三维位置上。因此,不需要进行面弓转移、上颌架等复杂的操作,也不需要进行模型外科和制作中间咬合板。Lin等[7]回顾了过去十年间涉及正颌外科手术中使用计算机辅助技术的文献,包括虚拟手术设计、术中虚拟设计的转化以及术后评估分析,最后得出结论:在正颌外科手术中使用计算机辅助技术有利于提高手术的可预见性和精确度、提高患者满意度、降低手术难度。

双颌正颌手术后,将设计模型与实际模型进行比较,已报道的数据表示方式各不相同,比如组内相关系数、三维表面积差异、三维线性和角度差异[8-11]。本研究分析了虚拟结果与实际结果之间的线性和角度差异。多数文献将临床成功标准定为线性差异2 mm,角度差异4°[11-12]。本研究中,30例患者的总体平均线性差异为0.81 mm,角度差异为0.95°。笔者还发现虚拟设计和3D打印手术导板用于上颌(平均线性差异0.71 mm)的效果比下颌(平均线性差异0.91 mm)更好;在控制偏差方面,面中平面(0.55 mm)比眶耳平面(0.92 mm)和冠状面(0.97 mm)的效果更好。尽管虚拟手术设计被广泛报道,仍有其他方式可将治疗计划转移至术中。Mazzoni等[13]开发了计算机辅助设计(computer aided design, CAD)和计算机辅助制造(computer aided manufacturing, CAM)技术,可以制作外科手术切割导板和钛固定板,使正颌患者的上颌骨不借助于外科夹板也能够正确再定位。Kim等[14]开发了一种具有3D虚拟设计和图像引导传输的集成正颌外科手术系统,在虚拟设计中,参考点的位移通过传统文献中手术每个步骤的位移来确认,虚拟手术的结果直接通过图像引导被转移到物理模型上。虚拟手术设计有助于增加双颌正颌手术中骨块定位的精准性,其误差在临床上是可接受的。但将虚拟设计转移到实际手术的方法不同会影响最终实际结果的准确性,因此仍需进一步研究不同术中转移方法的优缺点。

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