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·综述·

骨皮质切开术及改良术式加速正畸牙移动的临床研究进展

钟恺靖，　李博
口腔疾病防治全国重点实验室　国家口腔医学中心　国家口腔疾病临床医学研究中心　四川大学华西口腔医院口腔正畸科，四川　成都（610041）

【摘要】 加速正畸牙移动的辅助干预技术一直是正畸领域关注的热点。较长的正畸治疗周期常伴随多种潜在并发症，例如脱矿、龋坏、牙根吸收和牙龈炎症等。因此，使用加速正畸牙移动的辅助干预技术，缩短正畸治疗周期，可以为患者提供诸多益处，具有重要的临床意义。目前，加速正畸牙移动的辅助干预措施主要可以分为手术干预和非手术干预。其中，手术干预又以骨皮质切开术及其改良术式在临床最为常见，可以显著减少治疗时间，实现牙槽骨增量，扩大牙移动范围，但是会不可避免地造成创伤，存在诸多风险及限制因素，因而未能在临床上得到广泛应用。近年来，多种骨皮质切开术的改良术式不断涌现，如微创骨皮质切开术、压电切开术、骨微穿孔术和盘状切开术等，有效减少了软、硬组织损伤，降低了术后并发症发生率，且临床操作较为简便。皮质切开及改良术式均能在一定程度上缩短正畸治疗的时间，并对牙周健康的恢复有促进作用，且其对牙周、牙体及牙髓组织不会造成不利影响，但是在临床应用时仍需要对牙周组织损伤、牙根吸收、牙髓活力丧失等潜在副作用及不足进行重点关注和长期随访。

【关键词】 正畸；　骨皮质切开术；　加速；　正畸牙移动；　局部加速现象；　牙槽骨改建；　牙周加速成骨正畸；　牙根吸收
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Clinical research progress on corticotomy and modified techniques for accelerating orthodontic tooth movement

ZHONG Kaijing, LI Bo.　State Key Laboratory of Oral Diseases & National Center for Stomatology & National Clinical Research Center for Oral Diseases & Department of Orthodontics, West China Hospital of Stomatology, Sichuan University, Chengdu 610041, China
Corresponding author: LI Bo, Email: libo.scu@foxmail.com, Tel: 86-28-85503645

【Abstract】 Adjunctive interventions for accelerating orthodontic tooth movement have been a hot topic of interest in orthodontics. Prolonged orthodontic treatment is often associated with multiple potential complications, such as decalcification, caries, root resorption, and gingival inflammation. Therefore, applying adjunctive interventions that accelerate orthodontic tooth movement and reduce the duration of orthodontic treatment can provide patients with numerous benefits that are of profound clinical significance. Currently, adjunctive interventions for accelerating orthodontic tooth movement can be divided into two main categories: surgical and nonsurgical. Surgical interventions, represented by corticotomy and modified corticotomy procedures, are the most common in clinical practice and can minimize the treatment duration, augment alveolar bone, and expand the range of orthodontic tooth movement. However, these procedures are inevi-

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【作者简介】钟恺靖，本科，学士，Email：1257706330@qq.com
【通信作者】李博，主治医师，博士，Email：libo.scu@foxmail.com，Tel：86-28-85503645

tably traumatic and have many risks and limitations that prevent them from being widely used in clinical practice. In recent years, multiple modified corticotomy techniques, such as corticision, piezocision, micro-osteoperforation, and discision, have been proposed; these techniques can reduce soft and hard tissue damage and the incidence of postoperative complications and are relatively easy to perform in the clinic. Corticotomy and other improved surgical techniques can shorten the duration of orthodontic treatment to a certain extent and promote the recovery of periodontal health with no adverse effects on periodontal, dental, or pulp tissues. However, in clinical application, several potential side effects (such as periodontal tissue damage, root resorption, loss of pulp vitality, etc) and shortcomings need further research with long-term follow-up.

【Key words】 orthodontic; corticotomy; acceleration; orthodontic tooth movement; regional acceleratory phenomenon; alveolar bone reconstruction; periodontal accelerated osteogenesis orthodontic; root resorption

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正畸治疗周期通常为2～3年，而复杂的错𬌗畸形、较差的依从性等因素会导致治疗时间显著延长[1-2]。正畸牙移动速度过慢、疗程过长常伴随多种并发症，如疼痛不适、龋坏、牙龈炎症、牙根吸收等[3-4]。提高正畸效率、缩短正畸治疗时间有利于减少患者不适，显著降低不良反应的发生率及其严重程度[5-7]。总体而言，正畸治疗时间与牙移动效率成反比，正畸牙移动速度越快，则正畸治疗周期越短。我国正畸专家共识指出，正畸牙移动是以牙槽骨塑建（bone modeling）和骨重建（bone remodeling）为基础的力学生物学过程，受骨塑建与重建效率的直接影响，其限速环节是压力侧骨吸收[8-10]。而外科手术对于加速正畸牙移动有一定的效果，即通过人为介导的可逆性牙槽骨损伤，降低局部骨密度，诱导骨塑建与重建相关细胞变为更加活跃的状态，即局部加速现象（regional acceleratory phenomenon，RAP），RAP是加速正畸牙移动的手术干预措施的生理基础[11-13]。基于此，探讨安全有效的辅助干预措施，加速牙齿移动并缩短正畸治疗周期具有重要的临床意义。

在过去的十年中，涌现了多种用于加速正畸牙移动的手术辅助干预技术，其中又以骨皮质切开术及其改良术式在临床最为常见，包括但不限于传统的牙周加速成骨正畸（periodontally accelerated osteogenic orthodontics，PAOO）、骨皮质切开术（corticotomy），以及近年来新涌现的压电切开术（piezocision）和骨微穿孔术（micro-osteoperforations，MOP）等；其主要临床应用场景包括：加速尖牙与磨牙远中移动[14-17]、加速前牙内收及关闭拔牙间隙[18-19]、辅助拥挤牙列排齐及扩弓治疗[20]和扩大错𬌗畸形患者的牙移动范围[21-24]等。本文拟对临床上常见的骨皮质切开加速正畸牙移动的术式进行总结比较，以期为临床应用提供依据。

1　骨皮质切开术及改良术式的具体应用场景及优势

1.1　骨皮质切开术（Corticotomy）

1893年，Bryan等首次提出骨皮质切开术可以加速牙齿移动[25]。然而直到1959年，骨皮质切开术辅助正畸治疗（corticotomy-assisted orthodontic treatment）才作为一种加速牙齿移动的治疗手段被学界所熟知和接受[26]。具体而言，在需要加速移动的正畸牙根方的颌骨行骨皮质切开术，由颊舌侧从皮质骨切至松质骨深度，且不造成松质骨损伤[7]。传统皮质切开术首先需要在牙根之间进行垂直切口，然后使用手机和车针等器械在牙根周围的骨面磨出凹槽，因此组织创伤较大。1994年，Yaffe等[27]首次报道了发生于下颌骨黏骨膜瓣切开术后的RAP。术后10 d可观察到RAP，在3周达到高峰，并在120 d后基本完成。当在舌侧和颊侧行黏骨膜瓣切开术后，RAP效应则更为明显。

2001年，Wilcko等[28]研究认为牙齿移动加速

与RAP密切相关，骨皮质切开术引起的牙齿移动不是由骨块整体移动导致的，而是由骨皮质切开术周围骨组织的脱矿与再矿化过程引发的。基于此，该研究提出了PAOO，这是一种将颌骨的骨皮质切开并在骨面置入人工骨材料的术式，能够加速正畸牙移动、缩短治疗时间，同时扩大牙齿可移动范围[29]，常用于患者唇颊侧和/或舌腭侧多个牙位，适用于牙周组织条件较差、骨皮质较薄、需要牙槽骨增量的患者。该技术于术前1周施加正畸力，术中在牙根之间作垂直切口，包括颊侧和舌侧，行骨皮质切开术并在牙龈顶端连接，放置人工骨移植物，最后缝合皮瓣。通过去除骨皮质，诱导RAP的发生，在骨愈合期间促使局部破骨活性提升，改善骨代谢及重建情况，同时促进牙齿的移位，从而实现加速正畸牙移动、增加手术区域牙槽骨量、扩大牙齿可移动范围的目的。研究表明，相较传统的骨皮质切开术，PAOO更加安全有效，显著缩短正畸治疗时间，减少正畸治疗的副作用如牙根吸收等，同时扩大单纯正畸治疗的适应证，甚至在某些情况下能避免正颌手术的介入[28]。PAOO的另一个显著优势在于，其可以在手术过程中置入人工骨材料，治疗已有的骨开窗和骨开裂，并防止新的骨开窗和骨开裂的形成[30]，同时使牙槽骨量增加，在重建牙槽骨周围软组织方面有重要意义，对牙周健康恢复有促进作用[31-32]。然而，相较于其他术式，PAOO存在手术时间长、范围广、创伤较大的缺点。此外，常见的术后并发症，如瘀伤和疼痛，亦降低了患者对此技术的接受度。

1.2　微创骨皮质切开术

正畸医师和患者常认为传统皮质切开术的侵入性太大，故其临床普及度和接受度仍然很低，微创骨皮质切开术作为传统骨皮质切开术的一种微创改良术式应运而生。该技术可以在不翻开皮瓣的情况下对皮质骨进行手术，适用于牙周条件良好、无植骨需求的患者。Kim等[33]使用一把锤形手术刀从牙龈乳头以下5 mm处穿过牙龈和松质骨，抵达皮质骨下约10 mm处，保存了牙龈的完整性，显著减少了软组织创伤。临床实践表明，微创性皮质切开术造成的损伤足以诱发颌骨RAP效应，从而加速正畸牙移动。同时，与传统骨皮质切开术相比，该术式的优势在于避免了手术翻瓣造成的创伤，利于软组织恢复，患者接受度更高；但也存在术中不能移植软、硬组织或人工材料以弥补牙周组织不足的缺点。此外，为了进一步减轻术区创伤，各种各样的新型手术设备已逐步投入临床使用，如压电设备[34]、激光[35-36]、牙骨锤[33]等。

1.3　压电切开术

压电切开术是将无需翻瓣的骨皮质切开术与可移植人工骨材料的PAOO的技术优势相结合，在颊龈侧作微切口，使用压电装置切割牙槽骨，从而引发目标区域RAP效应。因此，该技术虽然是微创的，但可移植软、硬组织或人工材料，以改善牙龈退缩或填补牙槽骨缺损。具体而言，该技术利用超声波微振动，选择性切割矿化组织，保留软组织；由于压电装置的微创性和选择性切割骨组织的特性，故可以更加安全、精确地切割牙槽骨，显著降低了骨坏死的发生率[37]。压电切开术还消除了传统皮质切开术中牙槽骨过度受力的潜在副作用，显著降低患者的不适感。与其他术式相比，该技术手术时间短，手术创伤小，术后不适感较低，患者接受度较高。但是，由于手术过程切口小且不涉及翻瓣，不适用于对软、硬组织或人工材料有大量移植需求的患者；且存在术区轻微瘢痕的风险，因此也不适用于高笑线的患者[38]。此外，由于切割牙槽骨的操作无法在直视下进行，因此需要使用内窥镜辅助以避免损伤牙根。

为进一步减轻患者在手术过程中的疼痛与不适，Kim等[39]提出了一种名为压电穿刺术（Piezopuncture）的新方法，临床多用于辅助尖牙远中移动，适用于牙周条件较好、不需要植骨的患者。该术式使用一种新型超声手术工具——压电刀（piezotome），根据治疗计划利用压电刀尖端在牙龈与颌骨进行多次皮质穿刺。动物研究结果表明，压电穿刺术能显著加速比格犬的牙齿移动和颌骨代谢活动，并避免了皮瓣与切口等造成的软组织损伤。研究表明，压电穿刺术能有效加速正畸牙移动，减少手术时间与患者的恐惧和不适，减轻组织创伤，但其诱发的颌骨RAP的范围和持续时间不足以覆盖整个正畸治疗周期，故需要在一定的时间间隔进行多次压电穿刺术[40]。

此外为了使临床操作更加便捷，一种新型的盘状切开术（discision）于近年被提出[41]。该方法利用连接到牙科手机（微马达装置）的圆盘锯等设备进行垂直皮质切开术，便于日常临床操作，设备简化、价格便宜、易于携带；且圆盘锯相较于压电手术刀，更加轻薄、尺寸更小，故更加微创。临床研究表明，该技术有效促进了正畸牙的快速移

动[42]，但仍有待更多的临床随机对照试验证实并明确其具体临床应用场景。

1.4　骨微穿孔术（MOP）

MOP也被称为牙槽骨穿刺术，于2013年首次提出，其技术优势在于可将术创降至最低，通过最小的手术创伤引发RAP效应，从而实现加速正畸牙移动[43]。Propel（PROPEL Orthodontics，美国）是一种可以在不翻开牙龈和黏骨膜瓣的情况下作牙槽骨穿孔用以辅助MOP的设备，有效避免了翻瓣造成的损伤[43]。临床试验表明，将患者分为Propel治疗组与传统治疗组，再将患者自身左右侧设置为加力侧与未加力侧：与未加力侧相比，Propel治疗组的加力侧与传统治疗组的加力侧在差异基因表达谱方面无统计学差异；但与治疗组相比，正畸牙移动过程中应用Propel可以显著上调参与骨重建的炎性基因表达水平[44-45]。该术式优势在于操作简单，且出现术后瘢风险更低；不足之处在于，虽然该技术对患者造成的损伤较小，但RAP持续时间亦较短，加速牙移动的效果与其他技术相比较弱，且不适用于需要植骨的患者。由于下颌骨皮质较厚，需要反复穿刺，存在术中牙根损伤的潜在风险，故术前需拍摄X线片、锥形束CT（cone beam CT，CBCT）等，精确设计术区穿刺方向与位置，指导临床操作。此外，相对其他骨皮质切开术式而言，可能增加治疗时间和费用。

2　骨皮质切开术及改良术式的潜在副作用及不足

从早期的截骨术发展到如今的骨皮质切开术，加速正畸牙移动的手术辅助干预技术在减小术创、简化操作等方面均取得了长足进步，学界对于其潜在风险也进行了深入研究和评估。回顾已发表的系统评价，目前已建立了严格的评价标准，用于评估手术加速正畸牙移动的技术对牙周组织、牙根吸收和牙髓活力的影响[46]。然而，大部分研究仅为基于循证医学的外部证据，并没有报道不良影响[47-52]，即加速正畸牙移动的手术辅助干预措施基本不会对牙周、牙体及牙髓组织造成不利影响，但是在临床应用时仍需要对下列潜在副作用及不足进行重点关注和长期随访。

2.1　牙周组织损伤

回顾并分析大量相关研究[44-47]，发现在不翻瓣的情况下，手术干预加速组与未手术组相比，其牙周组织副作用没有明显差异，且术后牙槽骨厚度与密度明显增加，而若是加入手术翻瓣操作，则会使牙龈组织恢复情况受到较大不良影响。研究发现PAOO试验组与对照组在牙周探诊深度、菌斑数量、牙龈指数等方面差异均存在统计学意义，其中试验组的牙周组织恢复情况较好[53]。Khlef等[54]进行临床试验发现，有翻瓣操作的骨皮质切开术与无翻瓣操作的骨皮质切开术（压电切开术）相比，两组患者在正畸治疗前后的牙龈、乳头出血和菌斑指数方面存在显著差异，其中翻瓣操作组的牙龈恢复情况明显较差。有学者比较了骨皮质切开术后置入人工骨材料与否对骨密度的影响，其研究结果均表明，骨皮质切开术后进行人工骨材料移植，明显有助于增加牙槽骨的厚度和密度[55]。

2.2　牙根吸收

骨皮质切开术加速牙移动对牙根的影响目前尚存在争议。大多数学者认为，骨皮质切开术辅助正畸治疗的优点之一是防止牙根吸收[56]。然而，此方面亦存在矛盾的研究结果[57]，特别是在导致牙根吸收的原因方面，即术后牙根吸收究竟是由于手术对根面骨质吸收、重塑的影响，还是与手术操作不当导致牙根直接损伤有关。大多数评估牙根长度和牙根吸收潜在不良影响因素的研究表明，加速正畸牙移动的手术辅助干预技术通常不会引起牙根吸收[58-60]。

鉴于牙根吸收是一种三维现象，通过电子计算机断层扫描（computed tomography，CT）和CBCT（cone beam CT，CBCT）成像可以更加准确地测量牙根吸收的程度，具有较高的灵敏度和良好的特异性[61]。采用CBCT测量牙根长度为评估根尖吸收程度提供了可靠依据，消除了二维X线片测量时产生的误差[61]。有研究报道指出，在压电切开术过程中，当压电装置接近邻近牙根时，可能导致医源性牙根损伤[62]。因此当采用外科手术，特别是压电切开术，来加速正畸牙移动时，应当谨慎操作，避免造成医源性的牙根损伤。

2.3　牙髓活力丧失

现有相关研究证据表明，外科手术加速正畸牙移动对牙髓活力几乎不会产生不良影响。多项随机对照试验[48-49, 54]和非随机对照试验[36]分析了正畸治疗中行外科手术对牙髓活力的影响，分别比较了外科手术实验组与对照组中的牙髓状态，结果没有发现统计学差异。此外，也有针对骨皮质切开术的临床研究显示，骨皮质切开术不会导致牙髓损伤，也不会诱发牙髓炎症对牙周组织产

生不良影响，试验组与对照组所有牙齿在所有测量时间点均保持良好活力。上述研究表明，用于加速正畸牙移动的骨皮质切开术通常不会导致牙髓活力的丧失，然而仍需要进行更多高质量的临床随机对照试验，才能得出更明确的结论。

3　总结与展望

骨皮质切开及改良术式均能在一定程度上缩短正畸治疗的时间，并对牙周健康的恢复有促进作用。此外，在某些情况下，外科手术辅助加速正畸牙移动技术还可以作为拒绝接受正颌手术的正畸患者的替代治疗方案，通过扩大牙移动范围来实现轻度骨量不足患者的正畸掩饰性治疗。在未来的研究中，研究者应更多地关注如何提高困难牙移动的效率，如转矩移动、经上颌窦等特殊解剖结构的牙移动等；并且对加速正畸牙移动的手术辅助干预技术进行更多高质量的临床研究，通过多中心、大样本的随机对照试验来评估和比较不同骨皮质切开及改良术式的安全性、有效性、副作用和长期稳定性。

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