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·临床研究·

成人正畸治疗患者下颌切牙骨缺损的回顾性研究

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【摘要】　目的　探讨成人错𬌗畸形未正畸治疗患者与正畸治疗结束患者下颌切牙骨缺损的发生率及牙槽骨厚度的变化，为成人正畸治疗发生下颌切牙骨缺损的防治提供参考。**方法**　本研究已通过单位医学伦理委员会审查批准。收集150例未正畸治疗成人错𬌗畸形患者及150例正畸治疗结束成人患者的临床病历、全口曲面体层片、头影测量侧位片及锥形束CT（CBCT）图像，并获得患者知情同意。未正畸治疗患者及正畸治疗结束患者分别分为骨性Ⅰ类、Ⅱ类、Ⅲ类3个亚组，每个亚组各50例。同时，从150例正畸治疗结束患者中根据正畸治疗前后资料完整性纳入60例患者，其中骨性Ⅰ类、Ⅱ类和Ⅲ类各20例。将头影测量侧位片导入Dolphin软件测量颌骨参数，将CBCT图像导入Mimics软件分析150例未正畸治疗患者、150例正畸治疗结束患者及其中60例正畸患者治疗前后下颌前牙区牙槽骨缺损发生情况及牙槽骨厚度。**结果**　在未正畸治疗患者中，骨性Ⅰ、Ⅱ、Ⅲ类患者下颌切牙唇侧骨开裂、骨开窗发生率均高于舌侧；骨性Ⅰ、Ⅱ、Ⅲ类患者下颌切牙牙槽骨厚度有统计学差异。在正畸治疗结束患者中，骨性Ⅰ、Ⅱ类下颌拔牙组患者下颌切牙舌侧骨开裂发生率均显著高于非拔牙组患者，牙槽骨舌侧骨板厚度小于非拔牙组患者；骨性Ⅱ类非拔牙组患者下颌切牙唇侧骨开窗发生率显著高于下颌拔牙组患者，舌侧骨开窗率低于下颌拔牙组患者；骨性Ⅲ类正畸正颌联合治疗组患者下颌切牙唇、舌侧骨开裂发生率均显著高于正畸掩饰治疗组患者，骨性Ⅲ类正畸正颌联合治疗组患者下颌切牙多个位点牙槽骨厚度显著小于掩饰治疗组患者。成人患者正畸治疗前后下颌切牙骨缺损与骨厚度的对比：骨性Ⅰ、Ⅱ类下颌拔牙组患者、骨性Ⅲ类正畸正颌联合治疗组患者正畸治疗后下颌切牙舌侧骨开裂发生率升高，舌侧骨板显著吸收变薄。在非拔牙组中，正畸治疗后，骨性Ⅰ类患者根颈部唇侧骨板、根尖部舌侧骨板吸收变薄；正畸治疗后，骨性Ⅱ类患者下切牙根颈部及根中部唇侧骨板变薄，唇侧骨开裂发生率升高。**结论**　错𬌗畸形成人患者未正畸治疗前下颌切牙即存在广泛的牙槽骨缺损；正畸治疗结束患者下颌切牙骨缺损发生率及牙槽骨厚度与治疗方案及骨性畸形类型有关。

【关键词】　骨开裂；　骨开窗；　骨缺损；　牙槽骨厚度；　骨性畸形；　正畸治疗；　正畸掩饰治疗；　正畸正颌联合治疗
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Retrospective study on bone defects of mandibular incisors in adult orthodontic patients

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【Abstract】　Objective　To explore the prevalence of bone defect and alveolar bone thickness changes in the man-

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dibular incisors of untreated adults and post-orthodontic treatment adults, with the aim of providing strategies for preventing and managing alveolar bone defects during orthodontic treatment. **Methods** This study was reviewed and approved by the Medical Ethics Committee. Clinical records, panoramic radiographs, cephalometric radiographs, and cone beam computed tomography (CBCT) images and informed consent were obtained for 150 untreated adults and 150 post-orthodontic adults. The untreated adults and post-orthodontic adults were respectively divided into three subgroups: skeletal Class Ⅰ, Class Ⅱ and Class Ⅲ, with 50 cases per subgroup. Meanwhile, 60 cases with completeness of pre- and post-orthodontic data were enrolled from 150 post-orthodontic adults, including 20 cases each of skeletal Class Ⅰ, Class Ⅱ, and Class Ⅲ. Cephalometric radiographs were imported into Dolphin software to measure skeletal parameters. CBCT images were imported into Mimics software to assess alveolar bone defects and to measure alveolar bone thickness of mandibular incisors among three groups: 150 untreated adult groups, 150 post-orthodontic groups and the pre- and post-treatment status of 60 patients selected from the latter group. **Results** Untreated adult patients: the prevalence of labial dehiscence and fenestration in the mandibular incisors was higher than that on the lingual side among skeletal Class Ⅰ, Ⅱ, and Ⅲ malocclusion patients, and there was a statistically significant difference in the alveolar bone thickness of the mandibular incisors among the three classes. Post-orthodontic treatment adults: for skeletal Class Ⅰ and Ⅱ patients, the prevalence of lingual bone dehiscence in the mandibular incisors was significantly higher in the extraction groups than in the non-extraction groups; correspondingly, the lingual alveolar bone was also thinner in the extraction groups; Class Ⅱ non-extraction patients showed a higher prevalence of labial bone fenestration but a lower prevalence of lingual bone fenestration in mandibular incisors compared to Class Ⅱ extraction patients; the orthodontic-orthognathic combined treatment group showed significantly higher prevalence of labial/lingual bone dehiscence and thinner alveolar bone at multiple sites in the mandibular incisors compared to the camouflage group in skeletal Class Ⅲ patients. Comparison of mandibular incisor bone defects and thickness before and after orthodontic treatment in adult patients: in skeletal Class Ⅰ and Ⅱ patients treated with premolar extraction and Class Ⅲ patients treated with orthodontic-orthognathic combined treatment, the lingual alveolar bone of mandibular incisors exhibited significant resorption and thinned after treatment, and this was accompanied by an increased prevalence of dehiscence; in non-extraction patients, Class Ⅰ non-extraction patients showed thinning of the crestal-labial bone and apical-lingual bone, Class Ⅱ patients showed thinning of the crestal-labial bone and middle-labial bone of the mandibular incisors, along with an increased prevalence of dehiscence. **Conclusion** In malocclusion adults, alveolar bone defects were already present in the mandibular incisors before orthodontic treatment. The alveolar bone defects and thickness in mandibular incisors among post-orthodontic adults were influenced by the treatment plan and Class of skeletal malocclusion.

【Key words】 dehiscence; fenestration; bone defect; alveolar bone thickness; skeletal malocclusion; orthodontic treatment; camouflage orthodontic treatment; orthodontic-orthognathic combined treatment

【Trial registration】 West China School of Stomatology, Sichuan University (Registration Number: ChiCTR2500108107)

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【Competing interests】 The authors declare no competing interests.

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牙根表面牙槽骨缺损主要表现为骨开裂和骨开窗，前者指骨缺损呈Ⅴ型并延伸至牙槽嵴顶，后者指骨缺损未达牙槽嵴顶[1]。牙槽骨缺损的牙根表面仅有骨膜或者牙龈覆盖，甚至出现软组织缺如而导致牙根外露的情况，这严重削弱了牙周组织的支持作用，影响正畸治疗的安全性和稳定性[2-3]。骨开裂、骨开窗的发生取决于多个因素，其中牙槽骨厚度是牙槽骨缺损的影响因素，是临床评估的关键指标[4]。研究表明，在牙槽骨骨量不足情况下进行正畸治疗会增加骨缺损的风险[5]。因此，牙槽骨缺损严重程度及牙槽骨厚度是影响正畸方案制订的两大重要考量因素。随着年龄的增长，牙槽骨对生物力学的细胞反应能力降低，从而影响正畸牙移动期间的骨塑建过程[6-7]。青少年患者因处于生长发育期，其牙槽骨可塑性强[8-9]。因此，成年患者正畸治疗中牙槽骨缺损风险较青少年显著增加[10]。另一方面，下颌牙槽骨解剖学基础较上颌更为薄弱，且骨量从后向前逐渐变薄，使

得下颌前牙区的骨缺损更为常见[11]。

既往研究大多数聚焦于成人上颌前牙区，对成人下颌切牙骨缺损的研究较少，且由于采用不同的骨缺损评价方法和诊断阈值，不同研究关于牙槽骨缺损的发生率存在显著差异。基于以上，本研究以成年错𬌗畸形患者为研究对象，系统分析未正畸治疗患者与正畸治疗结束患者下颌切牙骨开裂、骨开窗的发生率及牙槽骨厚度的差异，以期为临床上骨开裂与骨开窗的风险评估与防治策略提供更精准的临床依据。

1　资料和方法

1.1　研究对象

本研究已获得华西口腔医院医学伦理委员会审核批准（审批号：WCHSIRB-D-2025-368），研究对象均已签署知情同意书。本研究收集2021年1月—2025年7月于四川大学华西口腔医院正畸科就诊的成年患者临床资料。

1.1.1　未正畸治疗患者组　①纳入标准：无正畸治疗史的成人错𬌗畸形患者（≥18岁）；除第三磨牙外，下颌恒牙列完整，无缺失牙、埋伏牙、畸形牙；下颌前牙区无外伤及手术史，无其他口腔颌面部病变、畸形；正畸治疗前临床治疗及影像学资料完整。②排除标准：下颌切牙出现临床及影像学上可诊断的牙周病、根尖周病变等；临床病历资料缺失或影像学图像模糊；拒绝参与本研究。

1.1.2　正畸治疗结束患者组　①纳入标准：完成正畸治疗的成人患者，骨性Ⅰ类、Ⅱ类错𬌗患者仅接受正畸治疗，按照拔牙方案分为对称拔除下颌第一前磨牙及下颌非拔牙；骨性Ⅲ类错𬌗患者的治疗方案分为正畸掩饰治疗和正畸正颌联合治疗，正畸掩饰治疗为下颌非拔牙、下颌切牙代偿性舌倾；正畸正颌联合治疗采用下颌非拔牙、下颌切牙唇倾去代偿的正畸治疗方式；整个正畸治疗过程中未进行任何牙周手术及骨增量手术；下颌前牙无严重牙根吸收、无牙周病和根尖周病；下颌前牙区无外伤及手术史，无其他口腔颌面部病变、畸形；治疗结束时临床资料及影像学资料完整。②排除标准：未完成正畸治疗或未达到正畸治疗结束的标准而自行要求结束治疗的患者；拔牙方案为非拔除下颌双侧第一前磨牙的患者；临床病历资料缺损或影像学图像模糊；拒绝参与本研究。

1.2　样本量估算与分组

基于预试验结果（未正畸治疗及正畸治疗结束成人骨性Ⅰ类、Ⅱ类、Ⅲ类患者各10例，每组下颌切牙40颗），使用PASS 16.0.4软件（NCSS公司，美国）计算样本量（双侧α=0.05、1−β=0.9）。考虑可能的混杂因素对结果的影响，增加10%的样本量，最终决定纳入150例未正畸治疗成人患者（骨性Ⅰ类、Ⅱ类、Ⅲ类各50例，每组下颌切牙各有200颗）及150例正畸治疗结束成人患者（骨性Ⅰ类、Ⅱ类、Ⅲ类各50例，每组下颌切牙各有200颗）；同时，对150例正畸治疗结束成人患者根据其治疗前后资料的完整性纳入60例患者比较正畸治疗前、后下颌切牙骨缺损发生情况及牙槽骨厚度，其中骨性Ⅰ类、Ⅱ类和Ⅲ类各20例，骨性Ⅰ类、Ⅱ类根据下颌拔牙与否分为拔牙组与非拔牙组，骨性Ⅲ类根据是否接受正颌手术治疗分为正畸掩饰治疗组与正畸正颌联合治疗组，共6个亚组，每个亚组各40颗下颌切牙。

1.3　影像学资料采集

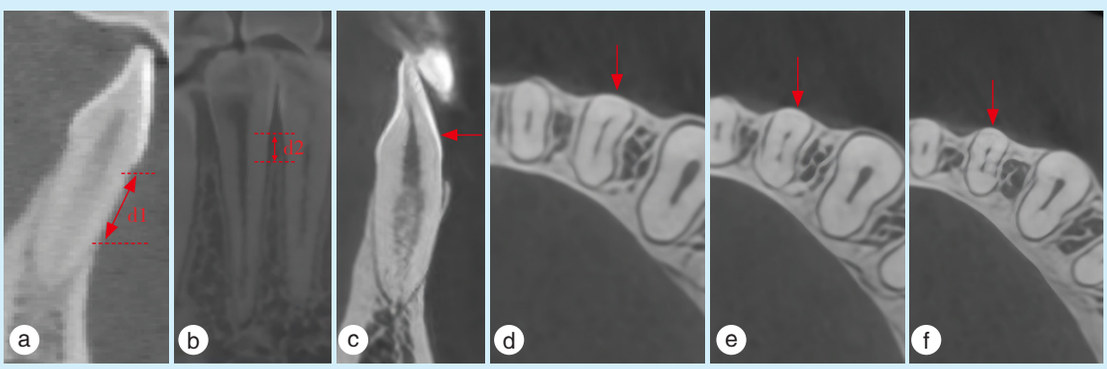
所有研究对象的曲面体层片和头影测量侧位片均采用华西口腔医院放射科的X光机（VERAVIEWEPOCS 2D，MORITA，日本）拍摄，拍摄时患者取直立位，调整患者眶耳平面与地面平行，矢状面与地面垂直。CBCT图像均采用华西口腔医院放射科的CBCT扫描仪（3D Accutomo CBCT，MORITA公司，日本）进行扫描。扫描参数为：85.0 kV，5.0 mA，视野20 cm×19 cm，扫描时间17.5 s，扫描层厚0.25 mm。扫描时患者采用端坐位，用颏兜和头架固定头颅，调节头颅固定装置及光标定位系统，使研究对象面部左右对称。将扫描获得的X线片以JPG图片格式存储，CBCT图像以DICOM格式存储。

1.4　测量方法

1.4.1　头影测量侧位片的测量参数　将患者的头影测量侧位片导入Dolphin软件，测量以下参数：∠SNA、∠SNB、∠ANB。

1.4.2　CBCT的测量参数及下颌切牙骨缺损的评估　将患者CBCT图像的DICOM数据导入Mimics软件，重建下颌骨及下颌切牙。骨开裂的诊断标准为牙齿颊舌向剖面和/或轴面上观察到牙槽骨呈V型缺损，且缺损累及牙槽嵴顶。逐层浏览三维CBCT图像，在矢状面上沿牙体长轴方向测量骨开裂最深处牙槽嵴顶到釉牙骨质界（cementoenamel junction，CEJ）的距离为d1，在冠状面测量近、远中邻面牙槽嵴顶到釉牙骨质界的距离，取较小值为d2，当d1−d2差值≥3 mm，即诊断为骨开裂[12]。骨

开窗的诊断标准为牙齿颊舌向剖面和/或横截面上观察到牙根唇/舌侧表面牙槽骨缺损，但缺损未累及牙槽嵴顶，且连续出现在3个及以上层面，即诊断为骨开窗（图1）。

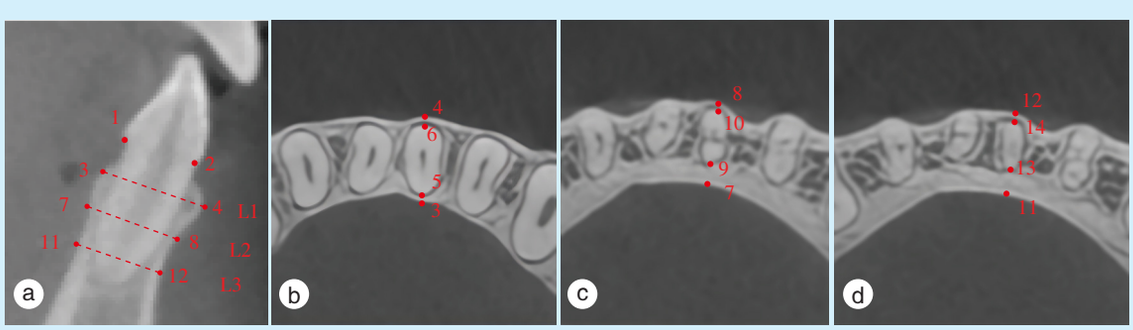


a: the CBCT images identify the sagittal section with the most severe dehiscence, along the axis of the tooth; the distance from the alveolar crest to the cementoenamel junction (CEJ) was measured and recorded as d1; b: on the coronal plane, the distance from the interproximal alveolar crest to the CEJ was measured, with the smaller value defined as d2, which represents the height of the interproximal alveolar bone; c: bone fenestration on the labial root surface in the sagittal plane; d-f: labial fenestration: the coordinate axis was moved upward and downward in the cross-sectional window; the absence of alveolar bone coverage on the labial root surface was observed across at least three consecutive layers

Figure 1　Diagnostic for alveolar bone defects in adult mandibular incisors

图1　成人下颌切牙骨缺损的诊断

牙槽骨厚度的测量示意图见图2。在切牙最大唇舌截面上标记舌侧釉牙骨质界点1与唇侧釉牙骨质界点2，沿牙长轴自釉质牙骨质界点连线向根尖方向每隔3 mm作1个与釉牙骨质界点连线平行的平面，记为L1、L2、L3，分别对应牙根颈部、根中部、根尖部水平。L1、L2、L3平面与舌、唇侧骨皮质交点分别标为点3、4、7、8、11和12；点3-4、点7-8、点11-12连线为根颈部、根中部、根尖部牙槽骨厚度。在L1、L2、L3水平面上分别标记牙根表面至骨皮质表面的最短距离为点3-5、4-6，7-9、8-10，11-13、12-14，分别代表根颈部、根中部、根尖部舌/唇侧骨板厚度[13]。



a: the maximal buccolingual section of CBCT images mark the lingual cementoenamel junction (CEJ) point (Point 1) and the labial CEJ point (Point 2); reference planes L1, L2, and L3 parallel to the CEJ line were constructed, spaced 3 mm apart from the CEJ toward the apex (L1 = cervical root, L2 = middle root, and L3 = apical root). The intersection points of planes L1, L2, and L3 with the lingual and labial alveolar bone are labeled 3, 4, 7, 8, 11, and 12, respectively. b-d: the shortest distance 3-5/4-6 (figure b), 7-9/8-10 (figure c), 11-13/12-14 (figure d) represent lingual/labial alveolar bone thickness at level L1, L2, and L3 of the incisor at the horizontal section, respectively

Figure 2　Diagram of the method for measuring alveolar bone thickness of mandibular incisors in adults in CBCT images

图2　成人下颌切牙牙槽骨厚度的CBCT测量示意图

1.5　统计学分析

本研究中的所有数据由一位经过严格培训的研究者独立完成。使用SPSS 29.0.2.0（SPSS公司，美国）进行统计学分析。经Shapiro-Wilk检验，牙槽

骨厚度不服从正态分布，以四分位数[*M*(*IQR*)]描述，采用非参数检验分析不同矢状骨面型组间牙槽骨厚度的差异。骨缺损发生率的比较采用卡方检验和Fisher确切概率法。

2　结　果

2.1　研究对象基本信息

未正畸治疗患者组与正畸治疗结束患者组在年龄和性别分布上无统计学差异。对正畸治疗结束患者组不同治疗方式亚组的人口学特征进一步分析发现，仅在骨性Ⅱ类患者中，非拔牙组的男性比例高于拔牙组；其余各亚组间的年龄与性别分布均无统计学差异。

2.2　未正畸治疗患者组下颌切牙骨缺损发生率及牙槽骨厚度的分析

骨性Ⅰ、Ⅱ、Ⅲ类患者下颌切牙唇侧骨开裂、骨开窗发生率高于下颌切牙舌侧，其中骨性Ⅱ类患者下颌切牙舌侧无骨开裂发生，唇侧骨开窗发生率低于骨性Ⅰ、Ⅲ类患者（表1）。

如表2所示，骨性Ⅰ、Ⅱ、Ⅲ类患者下颌切牙牙槽骨唇侧骨板，从根颈部到根中部逐渐变薄，舌侧骨板从根颈部到根尖部逐渐增厚。3组患者根颈部、根中部、根尖部牙槽骨厚度有统计学差异，但差值较小。骨性Ⅲ类患者下颌切牙根尖部舌侧骨板厚度大于骨性Ⅰ类与Ⅱ类患者，根尖部唇侧骨板厚度小于后两类患者，这与Ⅲ类患者下颌切牙代偿性舌倾相关。

表1　未正畸治疗患者组下颌切牙骨开裂、骨开窗的发生率

Table 1　Prevalence of dehiscence and fenestration in mandibular incisors among the untreated adult orthodontic patients group　*n* (%)

Mandibular incisors	Alveolar bone dehiscence					
	Class Ⅰ	Class Ⅱ	Class Ⅲ	χ^2	*P*	*Post hoc*
Labial (*n* = 200)	27 (13.5)	25 (12.5)	34 (17.0)	1.819	0.403	–
Lingual (*n* = 200)	8 (4.0)	0	12 (6.0)	11.586	0.003	Ⅰ > Ⅱ Ⅲ > Ⅱ
Mandibular incisors	**Alveolar bone fenestration**					
	Class Ⅰ	Class Ⅱ	Class Ⅲ	χ^2	*P*	*Post hoc*
Labial (*n* = 200)	65 (32.5)	39 (19.5)	59 (29.5)	9.367	0.009	Ⅰ > Ⅱ Ⅲ > Ⅱ
Lingual (*n* = 200)	3 (1.5)	1 (0.5)	3 (1.5)	1.239	0.709	–

Each skeletal Class comprised 50 cases in the untreated adult orthodontic patients group. In *post hoc* tests, the symbol "–"indicates that no further analysis was conducted as *P*>0.05. Pairwise comparisons of the prevalence of labial and lingual bone dehiscence and fenestration of mandibular incisors in adults with skeletal Class Ⅰ, Ⅱ, and Ⅲ, respectively, showed *P*<0.05

表2　未正畸治疗患者组下颌切牙不同水平面的牙槽骨厚度

Table 2　Alveolar bone thickness at different levels of mandibular incisor roots among the untreated adult patients group *IQR* (P_{25}, P_{75})

Bnoe thickness /mm	Crestal-total	Crestal-labial	Crestal-lingual	Mid-total	Mid-labial	Mid-lingual	Apical-total	Apical-labial	Apical-lingual
Class Ⅰ (*n* = 200)	6.3 (5.4, 6.9)	0.6 (0.2, 0.9)	0.6 (0.3, 0.8)	6.2 (5.7, 6.9)	0.3 (0, 0.5)	1.1 (0.9, 1.6)	6.5 (5.6, 7.4)	2.9 (2.4, 3.6)	3.9 (3.3, 4.8)
Class Ⅱ (*n* = 200)	6.5 (6.0, 7.0)	0.7 (0.3, 0.9)	0.5 (0.3, 0.7)	6.3 (5.9, 6.8)	0.4 (0.1, 0.7)	1.0 (0.8, 1.4)	6.1 (5.6, 6.9)	2.9 (2.2, 3.4)	3.8 (3.2, 4.7)
Class Ⅲ (*n* = 200)	6.6 (5.9, 7.2)	0.5 (0.1, 0.8)	0.6 (0.4, 0.9)	6.6 (5.8, 7.3)	0.3 (0, 0.5)	1.3 (0.8, 1.8)	6.9 (6.0, 7.9)	2.6 (2.0, 3.3)	4.9 (4.0, 5.8)
H	12.230	9.232	8.049	6.372	15.671	11.374	33.062	16.833	70.738
P	0.002	0.010	0.018	0.041	< 0.001	0.003	< 0.001	< 0.001	< 0.001
Post hoc	Ⅱ > Ⅰ Ⅲ > Ⅰ	Ⅱ > Ⅲ	Ⅲ > Ⅱ	Ⅲ > Ⅰ	Ⅱ > Ⅰ Ⅱ > Ⅲ	Ⅲ > Ⅱ	Ⅲ > Ⅰ Ⅲ > Ⅱ	Ⅰ > Ⅲ Ⅱ > Ⅲ	Ⅲ > Ⅰ Ⅲ > Ⅱ

Each skeletal Class comprised 50 cases in the untreated adult patients group. The Kruskal-Wallis *H* test was used for intergroup comparisons

2.3　正畸治疗结束患者组下颌切牙骨缺损发生率及牙槽骨厚度的分析

骨性Ⅰ类与Ⅱ类拔牙组患者下颌切牙舌侧骨开裂发生率均显著高于其非拔牙组。骨性Ⅱ类患者中，非拔牙组的下颌切牙唇侧骨开窗发生率高于拔牙组，而舌侧骨开窗发生率低于拔牙组。骨性Ⅲ类成年患者中正畸正颌联合治疗组下颌切牙唇、舌侧骨开裂发生率均显著高于正畸掩饰治疗组；然而，两组间下颌切牙骨开窗的发生率无统计学差异（表3）。

骨性Ⅰ、Ⅱ类拔牙组患者下颌切牙牙槽骨舌侧骨板厚度小于非拔牙组患者。骨性Ⅲ类正畸正

表3　正畸治疗结束患者组下颌切牙骨开裂、骨开窗的发生率

Table 3　Prevalence of alveolar bone dehiscence and fenestration of mandibular incisors among the post-orthodontic treatment adult patients group　*n* (%)

	Mandibular incisors	Alveolar bone dehiscence		Alveolar bone fenestration	
		Labial	Lingual	Labial	Lingual
Class Ⅰ	Extraction group (*n*=128)	26(20.3)	45(35.2)	24(18.8)	5(3.9)
	Non-extraction group (*n*=72)	17(23.6)	1(1.4)	8(11.1)	5(6.9)
	χ^2	0.297	29.668	2.001	0.895
	P	0.586	<0.001	0.157	0.500
Class Ⅱ	Extraction group (*n*=108)	24(22.2)	32(29.6)	11(10.2)	6(5.6)
	Non-extraction group (*n*=92)	26(28.3)	6(6.5)	32(34.8)	0
	χ^2	0.966	17.237	17.81	5.269
	P	0.326	<0.001	<0.001	0.032
Class Ⅲ	Camouflage group (*n*=96)	21(21.9)	31(32.3)	12(12.5)	3(3.1)
	Orthodontic-orthognathic group (*n*=104)	54(51.9)	58(55.8)	12(11.5)	0
	χ^2	19.231	11.141	0.044	3.299
	P	<0.001	0.001	0.834	0.109

Each skeletal Class comprised 50 cases in the post-orthodontic treatment adult patients group. The skeletal Class Ⅰ group comprised 32 patients in the extraction group and 18 adults in the non-extraction group. The skeletal Class Ⅱ group comprised 27 patients in the extraction group and 23 patients in the non-extraction group. The skeletal Class Ⅲ group comprised 24 patients in the camouflage group and 26 patients in the orthodontic-orthognathic group

颌联合治疗组患者下颌切牙在多个位点上牙槽骨厚度显著小于掩饰治疗组患者，甚至部分联合治疗组患者出现根颈部唇、舌侧骨板缺如的现象(表4)。

表4　正畸治疗结束患者组下颌切牙不同水平面的牙槽骨厚度

Table 4　Alveolar bone thickness at different levels of mandibular incisor roots among post-orthodontic treatment adult patients group　*IQR* (P_{25}, P_{75})

	Bnoe thickness/mm	Crestal-total	Crestal-labial	Crestal-lingual	Mid-total	Mid-labial	Mid-lingual	Apical-total	Apical-labial	Apical-lingual
Class Ⅰ	Extraction group (*n*=128)	6.2 (5.4,6.9)	0.4 (0,0.6)	0.2 (0,0.7)	6.3 (5.4,7.2)	0.5 (0.3,1.0)	0.5 (0,1.0)	6.9 (5.9,8.0)	4.4 (3.4,5.9)	3.1 (2.4,3.9)
	Non-extraction group (*n*=72)	6.3 (5.8,7.0)	0.3 (0,0.6)	0.6 (0.3,0.9)	6.9 (6.0,7.7)	0.5 (0.1,1.0)	1.1 (0.8,1.7)	7.5 (6.2,9.5)	4.0 (2.9,6.9)	3.7 (3.0,4.3)
	U	4 177.0	4 470.5	3 012.5	3 483.0	4 378.0	2 563.5	3 737.0	4 415.5	3 478.0
	P	0.273	0.721	<0.001	0.004	0.557	<0.001	0.027	0.624	0.004
Class Ⅱ	Extraction group (*n*=108)	6.3 (5.6,7.1)	0.5 (0,0.8)	0.3 (0,0.7)	6.3 (5.6,7.2)	0.5 (0.2,0.9)	0.5 (0,1.1)	6.7 (5.8,8.1)	4.0 (3.0,5.2)	3.0 (1.9,4.1)
	Non-extraction group (*n*=92)	7.1 (6.1,7.7)	0.4 (0,0.8)	0.9 (0.5,1.3)	7.1 (6.4,7.7)	0.2 (0,0.6)	1.5 (1.0,2.1)	7.4 (6.8,8.3)	3.3 (2.5,4.5)	4.4 (3.6,5.3)
	U	3 414.5	4 562.0	2 312.5	3 447.5	3 563.0	2 061.5	3 842.0	3 859.0	2 480.5
	P	<0.001	0.287	<0.001	<0.001	<0.001	<0.001	0.005	0.006	<0.001
Class Ⅲ	Camouflage group (*n*=96)	6.1 (5.6,6.9)	0.4 (0,0.7)	0.3 (0,0.6)	6.2 (5.5,6.8)	0.3 (0.1,0.5)	0.7 (0.1,1.2)	6.5 (5.7,7.6)	3.1 (2.4,4.1)	3.9 (2.9,4.9)
	Orthodontic-orthognathic group (*n*=104)	5.5 (4.7,6.5)	0 (0,0.3)	0 (0,0.2)	5.3 (4.7,6.3)	0.1 (0,0.6)	0.3 (0,0.6)	5.8 (5.0,6.7)	3.3 (2.4,4.0)	2.8 (2.1,4.0)
	U	3 193.5	2 992.0	3 562.0	3 185.0	4 311.0	3 281.0	3 236.5	4 953.0	3 083.5
	P	<0.001	<0.001	<0.001	<0.001	0.089	<0.001	<0.001	0.924	<0.001

Each skeletal Class comprised 50 cases in the post-orthodontic treatment adult patients group. The skeletal Class Ⅰ group comprised 32 patients in the extraction group and 18 adults in the non-extraction group. The skeletal Class Ⅱ group comprised 27 patients in the extraction group and 23 patients in the non-extraction group. The skeletal Class Ⅲ group comprised 24 patients in the camouflage group and 26 patients in the orthodontic-orthognathic group

2.4　成人正畸治疗前后下颌切牙骨缺损发生率及牙槽骨厚度的比较

对比分析成人正畸治疗前后下颌切牙骨缺损及牙槽骨厚度的变化。骨性Ⅰ、Ⅱ类拔牙组患者、骨性Ⅲ类正畸正颌联合治疗组患者正畸治疗后下颌切牙舌侧骨开裂发生率显著上升，骨性Ⅱ类非拔牙组患者正畸治疗后下颌切牙唇侧骨开裂发生率升高；而骨性Ⅰ类非拔牙组、骨性Ⅲ类正畸掩饰治疗组患者下颌切牙骨缺损发生率在正畸矫治前后无显著差异。术前正畸治疗去除下颌切牙代偿性舌倾，改善牙根位置，骨性Ⅲ类正畸正颌联合治疗患者唇侧骨开窗发生率降低（表5）。

表5　60例成人正畸治疗前后下颌切牙骨开裂、骨开窗发生率

Table 5　Prevalence of alveolar bone dehiscence and fenestration of mandibular incisors before and after orthodontic treatment in 60 cases adult patients　*n* (%)

Mandibular incisors		Class Ⅰ	Extraction group (*n*=40)			Class Ⅰ	Non-extraction group (*n*=40)		
		T0	T1	χ^2	*P*	T0	T1	χ^2	*P*
Alveolar bone dehiscence	Labial	4(10.0)	10(25.0)	3.117	0.077	6(15.0)	12(30.0)	2.581	0.108
	Lingual	3(7.5)	22(55.0)	21.004	<0.001	1(2.5)	1(2.5)	0	1.000
Alveolar bone fenestration	Labial	11(27.5)	7(17.5)	1.147	0.284	6(15.0)	7(17.5)	0.092	1.000
	Lingual	0	1(2.5)	1.013	1.000	0	0	–	–
Mandibular incisors		Class Ⅱ	Extraction group (*n*=40)			Class Ⅱ	Non-extraction group (*n*=40)		
		T0	T1	χ^2	*P*	T0	T1	χ^2	*P*
Alveolar bone dehiscence	Labial	1(2.5)	1(2.5)	0	1.000	3(7.5)	12(30.0)	6.646	0.010
	Lingual	0	15(37.5)	18.462	<0.001	0	2(5.0)	2.051	0.494
Alveolar bone fenestration	Labial	13(32.5)	11(27.5)	0.238	0.626	14(35.0)	15(37.5)	0.054	0.816
	Lingual	0	0	–	–	0	0	–	–
Mandibular incisors		Class Ⅲ	Camouflage group (*n*=40)			Class Ⅲ	Orthodontic-orthognathic group (*n*=40)		
		T0	T1	χ^2	*P*	T0	T1	χ^2	*P*
Alveolar bone dehiscence	Labial	7(17.5)	10(25.0)	0.672	0.412	8(20.0)	15(37.5)	2.990	0.084
	Lingual	0	4(10.0)	4.211	0.116	3(7.5)	24(60.0)	24.654	<0.001
Alveolar bone fenestration	Labial	9(22.5)	7(17.5)	0.313	0.576	18(45.0)	7(17.5)	7.400	0.007
	Lingual	0	0	–	–	1(2.5)	0	1.013	1.000

Class Ⅰ, Class Ⅱ, Class Ⅲ, 20 cases adults patients separately. Chi-square test was used to analyze the incidence of dehiscence and fenestration in the mandibular incisor region among patients with different skeletal malocclusions

骨性Ⅰ、Ⅱ类拔牙组患者、骨性Ⅲ类正畸掩饰治疗组患者正畸治疗后下颌切牙舌侧骨板在根颈部、根中部、根尖部均显著吸收变薄；骨性Ⅲ类正畸正颌联合治疗组患者正畸治疗后下颌切牙唇、舌侧骨板在多个水平面存在更严重的吸收。在非拔牙组中，正畸治疗后骨性Ⅰ类患者根颈部唇侧骨板、根尖部舌侧骨板吸收变薄，骨性Ⅱ类患者根颈部及根中部唇侧骨板变薄，而其他部位牙槽骨基本稳定（表6）。

3　讨　论

严重的牙槽骨开裂、骨开窗可能导致牙根外露、牙龈退缩、牙周炎、牙髓炎等诸多不良反应。其中，正畸治疗引起的牙槽骨缺损削弱了牙周组织的支持作用，而天然牙列存在的骨缺损则增加了正畸治疗的潜在风险。因此，鉴于骨缺损的严重危害及潜在的治疗风险，正畸医生需对其加以警惕。CBCT克服了二维影像的缺点，对诊断骨开裂、骨开窗具有良好的重复性和准确性[14]。本研究借助CBCT探索不同骨性畸形未正畸治疗成人患者与正畸治疗结束成人患者下颌切牙骨开裂、骨开窗发生率及牙槽骨厚度的差异。

3.1　骨开窗与骨开裂的CBCT诊断

既往研究对骨开窗的诊断标准较为一致，对骨开裂的诊断标准尚未统一，其中，最经典的是Evangelista和Leung等的测量方法，然而，这两种诊断方法未将骨开裂与牙周病导致的牙槽骨吸收区分开来[15]。为了弥补这点不足，本研究采纳周琳等[12]和徐筱等[16]的改良标准，即沿牙长轴方向测量骨缺损最深处牙槽嵴顶至釉牙骨质界的距离与

邻面牙槽嵴顶高度之差≥3 mm。

3.2　未正畸治疗成人患者下颌切牙骨缺损及牙槽骨厚度

在未正畸治疗患者中，下颌切牙唇侧骨开裂与骨开窗的发生率普遍高于舌侧[17-18]，归因于生理状态下唇侧骨板比舌侧骨板更为薄弱[19]。Han等[19]发现骨性Ⅱ类与Ⅲ类错𬌗畸形成年患者下颌骨缺损发生率高于骨性Ⅰ类成年患者，而本研究发现骨性Ⅰ、Ⅲ类患者下颌切牙舌侧骨开裂及唇侧骨开窗发生率高于骨性Ⅱ类，前者可能与骨性Ⅱ类患者下颌切牙代偿性唇倾有关[20]，后者原因可能是本研究未对纳入患者的垂直骨面型、拥挤度等进行限制所致。在牙槽骨厚度方面，骨性Ⅲ类患者下颌切牙根尖部舌侧骨板厚度大于骨性Ⅰ类与Ⅱ类患者，根尖部唇侧骨板厚度小于后两类患者，这与Ⅲ类患者下颌切牙代偿性舌倾相关[17]。既往研究也表明，骨开裂和骨开窗在未接受正畸治疗患者中即普遍存在[14, 21]，因此，正畸医生在制定治疗计划时应仔细评估患者治疗前骨缺损的存在及严重程度，从而制订出合理、安全的治疗方案。

表6　60例成人正畸治疗前后下颌切牙牙槽骨厚度

Table 6　Alveolar bone thickness of mandibular incisors before and after orthodontic treatment in 60 cases adult patients　*IQR* (P_{25}, P_{75})

Bone thickness/mm	Class Ⅰ	Extraction group (n=40)			Class Ⅰ	Non-extraction group (n=40)		
	T0	T1	U	P	T0	T1	U	P
Crestal-total	6.6(6.2,7.4)	5.7(5.1,6.5)	435.0	<0.001	6.5(6.1,7.1)	6.4(5.1,7.2)	687.0	0.277
Crestal-labial	0.7(0.3,1.0)	0.3(0,0.8)	546.5	0.014	0.4(0.2,0.9)	0.1(0,0.8)	590.5	0.039
Crestal-lingual	0.7(0.2,0.8)	0(0,0.4)	392.0	<0.001	0.7(0.3,1.0)	0.5(0,0.9)	633.0	0.107
Mid-total	6.0(5.7,6.5)	6.0(5.0,6.5)	719.5	0.439	6.5(6.0,8.1)	6.5(6.0,8.2)	761.0	0.707
Mid-labial	0.3(0,0.7)	0.7(0,0.9)	584.0	0.035	0.4(0.3,0.9)	0.5(0,1.1)	787.0	0.900
Mid-lingual	1.0(0.7,1.2)	0.1(0,0.7)	278.5	<0.001	1.5(0.8,2.4)	1.3(0.9,1.9)	720.0	0.441
Apical-total	6.2(5.6,6.9)	6.8(5.4,7.4)	661.0	0.181	7.3(6.6,9.2)	7.0(6.5,9.8)	749.0	0.624
Apical-labial	0.7(0.7,1.4)	1.7(1.0,3.0)	454.5	0.001	1.2(0.9,2.2)	1.6(0.9,3.2)	723.5	0.462
Apical-lingual	1.7(1.2,2.2)	1.0(0,1.8)	447.5	0.001	2.7(1.6,4.2)	2.2(1.3,2.7)	558.5	0.020
Bone thickness/mm	Class Ⅱ	Extraction group (n=40)			Class Ⅱ	Non-extraction group (n=40)		
	T0	T1	U	P	T0	T1	U	P
Crestal-total	7.1(6.4,7.8)	6.4(5.6,7.2)	534.0	0.010	7.1(6.4,7.6)	7.1(6.7,8.0)	749.0	0.624
Crestal-labial	0.9(0.6,1.1)	0.6(0.3,0.8)	469.5	0.001	0.7(0.4,1.0)	0.3(0,0.7)	470.0	0.001
Crestal-lingual	0.6(0.4,1.0)	0.3(0,0.6)	438.0	<0.001	0.7(0.4,0.9)	0.9(0.5,1.5)	620.0	0.083
Mid-total	6.9(6.0,7.3)	6.3(5.8,7.7)	696.0	0.317	6.7(6.2,7.5)	7.0(6.7,7.6)	637.5	0.118
Mid-labial	0.4(0,0.7)	0.4(0.2,0.8)	731.5	0.508	1.5(1.2,1.9)	0(0,0.4)	586.5	0.031
Mid-lingual	1.5(1.2,1.9)	0.8(0.2,1.6)	401.5	<0.001	1.4(0.9,1.8)	1.6(1.0,2.2)	679.5	0.246
Apical-total	6.7(5.8,8.0)	7.3(5.9,8.1)	733.5	0.522	7.1(6.7,7.8)	7.4(6.9,7.9)	701.5	0.343
Apical-labial	1.0(0.6,1.6)	1.5(0.9,2.3)	506.0	0.005	1.0(0.6,1.6)	0.8(0.4,1.2)	667.0	0.200
Apical-lingual	2.7(2.1,3.4)	2.0(1.3,3.2)	544.5	0.014	2.2(1.9,3.1)	2.3(1.4,3.5)	792.0	0.939
Bone thickness/mm	Class Ⅲ	Camouflage group (n=40)			Class Ⅲ	Orthodontic-orthognathic group (n=40)		
	T0	T1	U	P	T0	T1	U	P
Crestal-total	6.8(6.2,7.4)	6.6(5.9,7.1)	662.0	0.184	6.2(5.7,6.8)	5.6(4.8,6.5)	492.5	0.003
Crestal-labial	0.5(0.1,0.8)	0.3(0,0.7)	674.5	0.222	0.4(0,0.6)	0(0,0.3)	511.5	0.004
Crestal-lingual	0.8(0.7,1.1)	0.5(0.3,0.7)	404.0	<0.001	0.4(0.1,0.6)	0(0,0.4)	452.0	<0.001
Mid-total	6.9(6.3,7.5)	6.7(6.0,7.6)	744.0	0.590	5.5(5.2,6.1)	5.3(4.7,6.1)	688.5	0.283
Mid-labial	0.3(0,0.6)	0.4(0.2,0.6)	759.5	0.695	0(0,0.3)	0.3(0,0.5)	533.5	0.007
Mid-lingual	1.8(1.4,2.2)	1.3(0.9,1.8)	462.5	0.001	0.6(0.3,1.0)	0.2(0,0.5)	367.0	<0.001
Apical-total	7.5(6.7,8.5)	7.2(6.5,8.4)	740.0	0.564	5.5(5.0,6.4)	5.4(4.5,5.8)	635.0	0.112
Apical-labial	1.0(0.8,1.3)	1.0(0.7,1.4)	788.5	0.912	0.5(0.3,0.8)	0.8(0.4,1.2)	534.0	0.010
Apical-lingual	3.1(2.3,3.6)	2.6(1.9,3.2)	588.0	0.041	1.3(0.9,2.2)	0.4(0.1,0.9)	242.0	<0.001

Class Ⅰ, Class Ⅱ, Class Ⅲ, 20 cases adults patients separately

3.3　正畸治疗结束成人患者下颌切牙骨缺损及牙槽骨厚度

在正畸治疗结束患者组中，与非拔牙组相比，骨性Ⅰ、Ⅱ类拔牙组患者下颌切牙舌侧骨开裂发生率升高，舌侧牙槽骨厚度变薄，这主要是由于前牙内收对舌侧牙槽骨板的直接压迫，导致舌侧牙槽骨吸收程度普遍大于唇侧[22]。骨性Ⅲ类正畸正颌联合治疗患者下颌切牙冠唇倾、根舌倾的去代偿治疗对唇侧牙槽骨造成压迫，使该类患者下颌切牙唇侧骨开裂发生率高于掩饰治疗患者[23-24]。本研究与Ma等[25-26]、Jiao等[27]和Liu等[28]的研究结果相似，骨性Ⅲ类正畸正颌联合治疗患者的下颌切牙唇、舌侧骨开裂发生率更高，牙根颈部唇、舌侧骨板厚度更薄。Iijima等[29]解释为，正畸正颌联合治疗患者在术前正畸阶段虽表现为下颌切牙唇倾，但实际机制以牙根舌向移动为主，而非牙冠唇向倾斜。

3.4　正畸治疗后成人患者下颌切牙骨缺损与骨塑建

既往研究表明，成人正畸治疗后下颌切牙骨缺损发生率增加[30-32]。骨缺损的发生与正畸牙移动方向、移动量、正畸力大小和牙槽骨结构等因素相关[10, 33]，其本质是牙根突出与牙槽骨吸收变薄共同作用的结果[11, 21]。成年患者拔牙矫治后，切牙舌侧骨板厚度显著下降，而对切牙唇侧骨板厚度的变化则尚未达成一致意见[22, 34-38]。本研究发现骨性Ⅰ、Ⅱ类拔牙矫治患者下颌切牙根颈部唇侧骨板变薄，根尖部唇侧骨板增厚而根中部唇侧骨板厚度存在差异：骨性Ⅰ类患者骨板增厚，骨性Ⅱ类患者骨板厚度无明显变化。该发现为理解唇侧不同层面的骨塑建规律提供了关键证据。关于牙槽骨塑建的稳定性，一些研究表明，在正畸治疗结束后的保持期间持续有骨改建发生，但成人骨塑建能力有限，无法恢复到治疗前水平[33, 39]。

3.5　本研究的局限性

本研究的局限性主要包括以下几个方面：尽管CBCT被许多学者证实对牙槽骨缺损具有较高的检出率，但当牙槽骨厚度小于0.5 mm或牙周膜间隙较宽时可能错误评估骨缺损的存在与范围[19, 23, 40]。本研究为回顾性研究，可能存在选择性偏倚的风险，研究样本由牙列拥挤、牙突、地包天等问题主动就诊的患者构成，这类患者往往存在更严重的牙颌面畸形，下颌切牙排列更靠近唇侧或舌侧骨皮质，因此，本研究结果无法代表未就诊的错𬌗畸形人群骨缺损的真实世界水平。此外，后续本课题组将通过高质量的纵向对照研究，系统分析不同治疗方案下颌切牙移动量及移动方向、生物力学大小等，全面分析治疗方案本身对骨缺损发生率和牙槽骨塑建过程的影响。

【Author contributions】 Yang HM designed the study, performed the experiments, collected and analyzed the data, wrote the article. Chen X verified the study method and results of the data analysis. Li XJ, Qiu WZ collected, organized, and stored the data. Chen S designed and guided the study, revised and reviewed the article. All authors read and approved the final manuscript as submitted.

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