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·临床研究·

隐形矫治拔牙与非拔牙患者牙弓三维形态差异

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【摘要】 目的 探讨隐形矫治拔牙与非拔牙患者下颌Spee曲线和下颌Wilson曲线整平的准确率、下颌后牙冠倾斜度、上下颌牙弓宽度及下颌切牙唇倾度变化，为研究隐形矫治器的治疗效果提供依据。**方法** 本研究已获得单位医学伦理委员会批准。选取2016至2023年间使用隐形矫治器治疗的成人骨性Ⅰ类患者，分为拔除4颗第一前磨牙组32例和非拔牙组33例。采集初始扫描模型（T1）、矫治方案设计模型（T2）、排齐整平后的扫描模型（T3），将不同时间点的扫描数据导出为STL格式文件，使用GOM Inspect 2019软件进行分析测量，临床效果（T1-T3）定义为AC，预期结果（T1-T2）定义为CC。探讨下颌Spee曲线、下颌Wilson曲线的整平准确率（AC/CC×100%）、下颌后牙冠倾斜度的变化、上下颌牙弓宽度的变化及下颌切牙唇倾度的变化。使用R4.3.2软件进行统计分析。**结果** 拔牙组和非拔牙组下颌Spee曲线的整平准确率分别为3.2%和10.1%；拔牙组和非拔牙组下颌第一磨牙的整平准确率分别为9.5%和4.2%，下颌第二前磨牙的整平准确率分别为32.8%和25%。拔牙组下颌Wilson曲线的整平准确率为126%，而非拔牙组为704%。拔牙组和非拔牙组下颌后牙牙冠倾斜度的AC最大值均出现在第一磨牙，第二前磨牙最小（$P<0.05$）；拔牙组第二前磨牙的CC最大，第一磨牙最小（$P<0.05$）；非拔牙组第二磨牙的CC最大，第二前磨牙最小（$P<0.05$）。拔牙组上下颌牙弓宽度变化差异无统计学意义（$P>0.05$）；非拔牙组上颌第一磨牙处及下颌第二前磨牙、第一磨牙处的牙弓宽度AC明显大于CC（$P<0.05$）。非拔牙组下颌第二前磨牙冠倾斜度的AC大于拔牙组（$P<0.05$），表现为更明显的牙冠颊向倾斜，而两组的下颌磨牙牙冠倾斜度AC与CC差异无统计学意义（$P>0.05$）；拔牙组的下颌Spee曲线的CC大于非拔牙组（$P<0.05$），而两组的下颌Spee曲线的AC差异无统计学意义（$P>0.05$）。拔牙组和非拔牙组下颌切牙唇倾度的AC均小于CC，但均为正值，表示下颌切牙唇倾的程度增加。**结论** 隐形矫治器下颌Spee曲线整平表达欠佳，下颌Wilson曲线整平存在过度表达趋势，患者下颌切牙唇倾度均增加；拔牙组牙弓宽度预测精准，非拔牙组牙弓宽度存在超预期扩展。

【关键词】 隐形矫治器；　下颌骨；　Spee曲线；　Wilson曲线；　牙弓宽度；　下颌牙冠倾斜度；　下颌切牙唇倾度

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Three-dimensional arch morphology differences in the invisible orthodontic treatment of extracted and non-extracted patients

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【Abstract】 Objective To investigate the accuracy of the mandibular curve of Spee and mandibular curve of Wilson curve, mandibular posterior crown inclination, maxillary and mandibular arch width, and mandibular incisor labial incli-

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nation changes in the invisible orthodontic treatment of extracted and non-extracted patients to provide a basis for the study of the therapeutic efficacy of the invisible aligner. **Methods**　This study was approved by the Unit Medical Ethics Committee. Adult bony Class I patients treated with invisible aligners between 2016 and 2023 were selected and categorized into 32 cases in a group with four first premolar extractions and 33 cases in a non-extraction group. The initial scanning model (T1), the orthodontic plan design model (T2), and the scanning model after alignment and leveling (T3) were collected, and the scanning data at different time points were exported to STL format files. They were then analyzed and measured using GOM Inspect 2019 software; the clinical effect (T1-T3) was defined as AC, and the expected result (T1-T2) was defined as CC. To explore the mandibular curve of Spee, the leveling accuracy of the mandibular Wilson curve (AC/CC×100%), the change in mandibular posterior crown inclination, the change in maxillary and mandibular arch width and the change in mandibular incisor labial inclination. The results were tallied using R4.3.2 software. **Results**　The leveling accuracy of the mandibular curve of Spee was 3.2% and 10.1% in the extraction and non-extraction groups, respectively; the leveling accuracy of the mandibular first molar in the extraction and non-extraction groups was 9.5% and 4.2%, respectively, and the leveling accuracy of the mandibular second premolar was 32.8% and 25%, respectively. The leveling accuracy of the mandibular curve of Wilson was 126% in the extraction group compared to 704% in the non-extraction group. The maximum values of AC for crown inclination of the mandibular posterior teeth were all found in the first molar and the minimum values in the second premolar ($P < 0.05$); CC was the greatest in the second premolar and the least in the first molar in the extraction group ($P < 0.05$), and in the second molar and the least in the second premolar in the non-extraction group ($P < 0.05$). There was no significant difference in the change of maxillary and mandibular arch widths in the extraction group ($P > 0.05$); the AC of the arch widths at the maxillary first molar and at the mandibular second premolar and first molar in the non-extraction group was significantly greater than the CC ($P < 0.05$). The AC of the mandibular second premolar crown inclination was significantly greater in the non-extraction group than in the extraction group ($P < 0.05$), showing a more pronounced buccal inclination of the crowns; in contrast, there was no significant difference between the mandibular molar crown inclination AC and CC in the two groups ($P > 0.05$). The CC of mandibular curve of Spee in the extraction group was significantly greater than that in the non-extraction group ($P < 0.05$), whereas there was no significant difference in AC between the two groups ($P > 0.05$). In addition, the AC of the labial inclination of the mandibular incisors in the extraction group and the non-extraction group was smaller than the CC, but both were positive, indicating an increase in the degree of labial inclination of the mandibular incisors. **Conclusion**　The invisible aligner mandibular curve of Spee leveling was poorly expressed, and there was a tendency for overexpression of the mandibular curve of Wilson leveling. Increased labial inclination of the mandibular incisors was observed in patients. The extraction group was accurately predicted in arch width control, there was overexpansion in the non-extraction group.

【Key words】 invisible orthodontic appliances; mandible; curve of Spee; curve of Wilson; arch width; mandibular crown inclination; labial inclination of mandibular incisors

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隐形矫治技术经过不断改进，可较精确实现牙齿移动，但对垂直向控制仍存在不足。垂直向牙齿移动比横向牙齿移动更难实现[1]，伸长运动实现率最低，仅为29.6%，前牙压低平均准确率为41.3%[2]。下颌Spee曲线代表咬合平面（occlusion plane，OP）的曲率，深Spee曲线是Ⅱ类错𬌗畸形和Ⅰ类错𬌗伴拥挤畸形的特征之一。随着时间的推移，Spee曲线会自然地加深，从而导致下颌切牙拥挤[3]。OP平坦可以减少咬合干扰从而实现安氏Ⅰ类牙尖交错关系。Spee曲线的整平是正畸治疗中的重要临床阶段，是咬合的第六个关键[4]，因此临床医生应将整平下颌Spee曲线作为矫治目标之一[5]。Wilson曲线是牙弓后段颊舌侧的咬合曲线，与理想的牙尖交错𬌗有关。正常情况下，下颌后牙牙冠向舌侧倾斜，若其过于直立，下颌Wilson曲线曲度平坦，则会妨碍形成理想牙弓间接触，产生侧

向干扰[6]。对于骨性Ⅰ类，安氏Ⅰ、Ⅱ类错𬌗伴拥挤的患者，根据拥挤程度不同，可选择拔牙或非拔牙的策略进行矫治，而非拔牙病例解除拥挤通常由磨牙远移、扩大牙弓实现[7]。

有关隐形矫治器对下颌牙列横向和纵向控制的研究较少，因此，本研究通过分析牙弓扫描数据，探讨隐形矫治器在整平下颌曲线（Wilson曲线和Spee曲线）、改善下颌磨牙冠倾斜度、调整上下颌牙弓宽度及下颌切牙唇倾度变化等方面的实际效果及准确率。

1　材料和方法

1.1　一般资料

本研究经哈尔滨医科大学医学伦理委员会批准（伦理号：2024385）。选取2016至2023年于哈尔滨医科大学口腔医院正畸科就诊的患者，均由1名经验丰富的医生使用同一种品牌的隐形矫治器进行治疗，品牌名称：Invisalign（隐适美，爱齐，美国），且均使用SmartTrack材料[8]。采集初始扫描模型（T1）、矫治方案设计模型（T2）、排齐整平后的扫描模型（T3），将不同时间点的扫描数据导出为STL格式文件，使用GOM Inspect 2019软件进行分析测量，临床效果（T1-T3）定义为AC，预期结果（T1-T2）定义为CC，准确率=AC/CC×100%。纳入拔除4颗第一前磨牙者32例和非拔牙者33例，均为骨性Ⅰ类错𬌗畸形，无正畸治疗史。

1.2　纳入与排除标准

1.2.1　纳入标准　第一次就诊时年龄为18~28岁的患者、0°<ANB≤5°、22°≤FMA<32°，安氏Ⅰ、Ⅱ类错𬌗畸形；采用隐形矫治器治疗，每天佩戴22 h以上，每副佩戴两周；初始Spee曲线深度为2~5 mm；完整恒牙列（不包括第三磨牙）且无正畸治疗史，牙周状况良好；临床资料完整；拔牙组矫治方案为拔除14、24、34、44；非拔牙组牙列轻度至中度拥挤；两组均把下颌Spee曲线整平和控制Wilson曲线作为矫治目标之一。

1.2.2　排除标准　锁𬌗；牙列缺损；使用特殊打开咬合的措施；安氏Ⅲ类错𬌗畸形、骨性Ⅱ类、Ⅲ类错𬌗畸形；有严重牙周组织疾病；依从性差；患有影响颅颌面部发育或影响骨代谢的疾病等。

1.3　方法

使用iTero Element扫描仪（爱齐，美国）扫描患者口腔，收集患者T1、T2、T3的扫描模型，将STL格式文件导入GOM Inspect 2019软件分析。

咬合平面（OP）：下颌中切牙切缘中点、左右侧下颌第二磨牙远颊尖的连线形成的平面[9]。测量指标：①下颌Spee曲线：测量两侧下颌尖牙牙尖，第一、二前磨牙颊尖，第一、二磨牙近中颊尖到OP的垂直距离，两侧最大的垂直距离取平均值。各牙相对OP的整平情况由两侧第二前磨牙颊尖，第一、二磨牙近中颊尖到OP的垂直距离的平均值表示。②下颌Wilson曲线：测量两侧下颌第二前磨牙颊、舌尖；第一、二磨牙近中颊尖、舌尖到OP的垂直距离；两侧的颊尖距之和减舌尖距之和的差值。③下颌后牙牙冠倾斜度：下颌牙弓两侧后牙颊尖到OP的垂直距离减舌尖到OP的垂直距离的差值。④上下颌牙弓宽度：以双侧尖牙牙尖、双侧前磨牙颊尖、双侧第一磨牙近中颊尖之间距离来分别评估前、中、后段牙弓。⑤下颌切牙唇倾度：双侧下颌第一前磨牙的牙长轴（拔牙病例为第二前磨牙）所在平面与通过下颌中切牙FA点的切线所形成的角度，见图1。

1.4　统计学方法

本研究使用R4.3.2进行数据分析，利用Shapiro wilk检验对数据进行正态分布检验，数据符合正态分布，两组间比较采用t检验。P<0.05为差异具有统计学意义。

2　结　果

符合条件的拔牙受试者平均年龄23.9岁，平均排齐整平时长为18.6个月；非拔牙受试者平均年龄为29.6岁，平均排齐整平时长16.1个月。

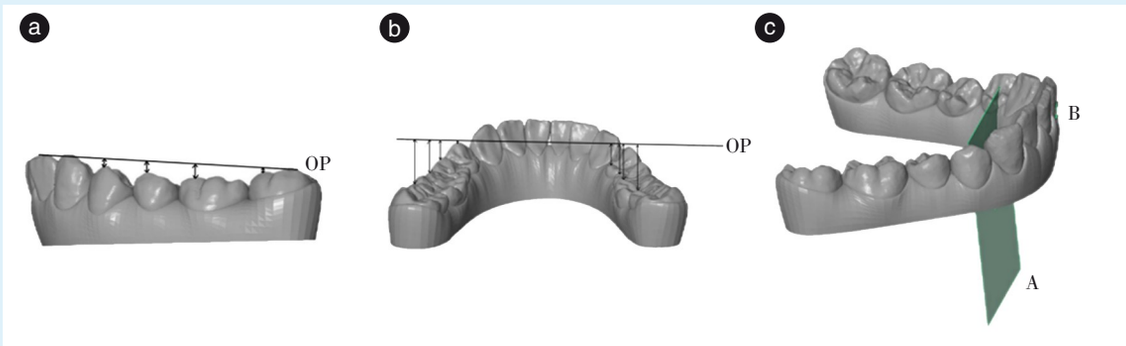
2.1　拔牙组临床效果和预期效果比较

下颌Spee曲线的AC比CC高1.30 mm（P<0.001），拔牙组隐形矫治器下颌Spee曲线的整平准确率仅为3.2%（表1）。

下颌第二前磨牙、下颌第一磨牙、下颌第二磨牙相对OP整平情况结果分析显示，矫治初始Spee曲线最深处位于下颌第一磨牙近中颊尖，平均1.97 mm。比较AC与CC，下颌前磨牙、下颌磨牙明显整平不足，下颌第一磨牙整平准确率最低，为9.5%，下颌第二前磨牙最高，为32.8%（P<0.05，表1）。

初始下颌Wilson曲线平均深度为-4.43 mm，CC变平0.84 mm，AC变平1.06 mm，隐形矫治器下颌Wilson曲线的整平准确率为126%（表1）。

下颌后牙牙冠倾斜度初始均为负值（即牙冠舌向倾斜）；AC和CC均表现出牙冠颊向倾斜，CC



The definition of the occlusal plane (OP) was based on the midpoint of the incisal margin of the mandibular mesial incisors, the distal buccal cusp of the left mandibular second molar, and the distal buccal cusp of the right mandibular second molar. a: measurement methods of the mandibular curve of Spee: the maximum value of the left and right sides are averaged. b: measurement methods of the mandibular curve of Wilson: the sum of the buccal apical distance minus the sum of the lingual apical distance. c: measurement methods of the labial inclination of mandibular incisors: the angle formed by plane A, in which the long axis of the teeth of the bilateral mandibular first premolar (second premolar in the case of tooth extraction) is located, and tangent B through the facial-axis point of the mandibular mesial incisor

Figure 1　Measurement of the mandibular curve of Spee, the mandibular curve of Wilson, and labial inclination of the mandibular incisors

图1　下颌Spee曲线、下颌Wilson曲线、下颌切牙唇倾度的测量方法

下颌第二前磨牙最大，下颌第一磨牙最小；AC下颌第一磨牙最大，下颌第二前磨牙最小；下颌第一磨牙AC与CC偏差0.76 mm（P<0.05，表1）。

分析上下颌牙弓宽度，发现尖牙、第二前磨牙、第一磨牙处AC与CC无明显差异（P>0.05，表1）。

表1　隐形矫治拔牙组的Spee曲线、Wilson曲线、冠倾斜度、牙弓宽度的CC、AC比较

Table 1　Comparison of CC and AC for the curve of Spee, curve of Wilson, crown inclination, and arch width in the invisible orthodontic treatment of the extraction group　n=32, mm

Item	Dental position	Initial(95% *CI*)	CC(95% *CI*)(T1-T2)	AC(95% *CI*)(T1-T3)	Accuracy	*t*	*P*
Curve of Spee	/	2.15 (1.78, 2.52)	−1.26 (−1.61, −0.92)	0.04 (−0.34, 0.41)	3.2%	22.450	<0.001
Curve of Wilson	/	−4.43 (−5.72, −3.14)	0.84 (−0.28, 1.97)	1.06 (0.23, 1.89)	126%	0.391	0.681
Vertical distance from each tooth position to OP	Second premolars (B cusp)	1.75 (1.36, 2.14)	−1.25 (−1.63, −0.86)	−0.41(−0.78, −0.05)	32.8%	16.050	<0.001
	First molars (MB cusp)	1.97 (1.60, 2.34)	−1.26 (−1.58, −0.94)	0.12 (−0.22, 0.46)	9.5%	24.400	<0.001
	Second molars (MB cusp)	0.89 (0.68, 1.10)	−0.47 (−0.68, −0.26)	−0.08 (−0.29, 0.13)	17%	7.180	<0.001
Crown tilt	Second premolars	−1.86 (−2.39, −1.33)	0.41 (−0.16, 0.98)	−0.11 (−0.52, 0.30)	/	2.515	0.014
	First molars	−0.81 (−1.30, −0.32)	0 (−0.42, 0.43)	0.76 (0.46, 1.06)	/	3.199	0.002
	Second molars	−1.67 (−2.28, −1.05)	0.32 (−0.15, 0.79)	0.46 (0.00, 0.93)	/	0.890	0.376
Width of maxillary arch	Canines	36.76 (35.47, 38.04)	2.48 (1.51, 3.46)	2.03 (0.91, 3.15)	/	1.660	0.101
	Second premolars	48.38 (46.7, 50.06)	−0.50 (−1.97, 0.96)	−0.83 (−2.05, 0.40)	/	0.972	0.334
	First molars	53.38 (52.11, 54.65)	0.20 (−0.60, 1.00)	0.22 (−0.51, 0.94)	/	0.081	0.936
Width of mandibular arch	Canines	26.98 (26.21, 27.75)	2.43 (1.61, 3.25)	2.38 (1.50, 3.26)	/	0.311	0.757
	Second premolars	40.17 (38.58, 41.77)	−1.78 (−3.22, −0.34)	−1.87 (−3.24, −0.49)	/	0.364	0.717
	First molars	45.65 (44.48, 46.83)	−1.28 (−2.07, −0.49)	−0.81 (−1.60, −0.02)	/	1.965	0.053

Positive values indicate an increase in distance, while negative values indicate a decrease in distance. AC: T1-T3 (clinical effects), CC: T1-T2 (expected results). Accuracy=AC/CC×100%. The "/" indicates the tooth position was not statistically recorded. Crown tilt: a negative initial value represents a lingual tilt of the crown; OP: occlusion plane

2.2　非拔牙组临床效果和预期结果比较

非拔牙组下颌Spee曲线的AC比CC高0.71 mm（P<0.001），下颌Spee曲线的整平准确率为10.1%（表2）。

下颌第二前磨牙、下颌第一磨牙、下颌第二磨牙相对OP整平情况结果分析显示，矫治初始Spee曲线最深处位于下颌第一磨牙近中颊尖，平均1.94 mm。比较AC与CC，下颌前磨牙、下颌磨牙明显整平不足，与拔牙组结果一致，下颌第一磨牙整平准确率最低，仅为4.2%；但下颌第二前磨牙准确率最高，为25%（P<0.001，表2）。

下颌Wilson曲线初始平均深度为-4.93 mm，CC变平0.27 mm，AC变平1.9 mm，AC明显大于CC（P<0.001），下颌Wilson曲线的整平准确率为704%（表2）。

下颌后牙牙冠倾斜度初始均为负值（即牙冠舌向倾斜），AC和CC也均表现为牙冠颊向倾斜；与拔牙组不同，CC下颌第二磨牙最大，下颌第二前磨牙最小；AC与拔牙组结果相同，下颌第一磨牙最大，下颌第二前磨牙最小（P<0.001，表2）。

分析上下颌牙弓宽度，发现上颌第一磨牙处，下颌第二前磨牙、第一磨牙处AC明显大于CC（P<0.05，表2）。

表2　隐形矫治非拔牙组的Spee曲线、Wilson曲线、冠倾斜度、牙弓宽度等指标的CC、AC比较

Table 2　Comparison of CC and AC for the curve of Spee, curve of Wilson, crown inclination, and arch width in the invisible orthodontic treatment of the non-extraction group　n=33, mm

Item	Dental position	Initial(95% *CI*)	CC(95% *CI*)(T1-T2)	AC(95% *CI*)(T1-T3)	Accuracy	t	P
Curve of Spee	/	2.06 (1.8, 2.32)	−0.79 (−0.99, −0.59)	−0.08 (−0.36, 0.2)	10.1%	11.923	<0.001
Curve of Wilson	/	−4.93 (−5.86, −4)	0.27 (−0.53, 1.06)	1.9 (1.29, 2.51)	704%	12.155	<0.001
Vertical distance from each tooth position to OP	Second premolars (B cusp)	1.67 (1.39, 1.95)	−0.92 (−1.15, −0.69)	−0.23 (−0.53, 0.06)	25%	19.530	<0.001
	First molars (MB cusp)	1.94 (1.72, 2.16)	−0.71 (−0.88, −0.53)	−0.03 (−0.28, 0.21)	4.2%	19.870	<0.001
	Second molars (MB cusp)	0.86 (0.73, 0.98)	−0.30 (−0.39, −0.20)	−0.06 (−0.19, 0.07)	20%	6.950	<0.001
Crown tilt	Second premolars	−1.98 (−2.40, −1.56)	0.08 (−0.32, 0.48)	0.53 (0.15, 0.90)	/	8.700	<0.001
	First molars	−0.97 (−1.29, −0.64)	0.18 (−0.04, 0.41)	0.99 (0.74, 1.24)	/	12.040	<0.001
	Second molars	−2.34 (−2.73, −1.95)	0.24 (−0.09, 0.57)	0.93 (0.48, 1.38)	/	9.626	<0.001
Width of maxillary arch	Canines	34.65 (33.83, 35.47)	1.69 (1.06, 2.32)	1.22 (0.71, 1.74)	/	5.481	0.006
	First premolars	42.81 (42.21, 43.42)	2.08 (1.57, 2.58)	1.89 (1.50, 2.28)	/	1.008	0.370
	Second premolars	47.60 (46.62, 48.57)	2.89 (1.97, 3.81)	2.96 (2.08, 3.84)	/	0.248	0.781
	First molars	52.59 (51.73, 53.46)	2.09 (1.61, 2.58)	2.59 (2.08, 3.09)		3.466	0.037
Width of mandibular arch	Canines	25.97(25.46, 26.48)	1.21 (0.70, 1.71)	1.14 (0.74, 1.55)	/	0.498	0.610
	First premolars	34.15 (33.33, 34.97)	1.86 (1.06, 2.66)	1.77 (0.99, 2.56)	/	0.231	0.794
	Second premolars	40.22 (39.22, 41.21)	1.75 (0.91, 2.59)	2.42 (1.66, 3.18)	/	6.759	0.002
	First molars	44.94 (44.01, 45.86)	1.35 (0.73, 1.97)	2.51 (1.85, 3.17)	/	9.585	<0.001

Positive values indicate an increase in distance, while negative values indicate a decrease in distance. AC: T1-T3 (clinical effects), CC: T1-T2 (expected results). Accuracy=AC/CC×100%. The "/" indicates the tooth position was not statistically recorded. Crown tilt: a negative initial value represents a lingual tilt of the crown; OP: occlusion plane

2.3　拔牙组和非拔牙组临床效果和预期结果比较

非拔牙组下颌第二前磨牙冠倾斜度的AC明显大于拔牙组（P<0.05），表现为更明显的牙冠颊向倾斜；而两组的下颌磨牙牙冠倾斜度AC与CC无明显差异。拔牙组的下颌Spee曲线的CC明显大于非拔牙组（P<0.05），而AC的Spee曲线整平两组差异无统计学意义（P>0.05，表3）。

拔牙组和非拔牙组的下颌切牙唇倾度的CC、AC均为正值，这表示下颌切牙表现为唇向倾斜的程度增加，但对比两组的下颌切牙唇倾度变化无显著差异（P>0.05）。

表3　隐形矫治拔牙组和非拔牙组CC和AC比较

Table3　Comparison of CC and AC in the invisible orthodontic treatment of extraction and non-extraction groups

Item	Dental position	Group	CC(95% *CI*)(T1-T2)	AC(95% *CI*)(T1-T3)
Curve of Spee	/	Extraction group(*n*=32, mm)	−1.26 (−1.61, −0.92)	0.04 (−0.34, 0.41)
		Non-extraction group(*n*=33, mm)	−0.79 (−0.99, −0.59)	−0.08 (−0.36, 0.2)
		t	2.28	0.470
		P	0.024	0.639
Curve of Wilson	/	Extraction group(*n*=32, mm)	0.84 (−0.28, 1.97)	1.06 (0.23, 1.89)
		Non-extraction group(*n*=33, mm)	0.27 (−0.53, 1.06)	1.9 (1.29, 2.51)
		t	0.814	1.576
		P	0.417	0.117
Crown tilt	second premolars	Extraction group(*n*=32, mm)	0.41 (−0.16, 0.98)	−0.11 (−0.52, 0.3)
		Non-extraction group(*n*=33, mm)	0.08 (−0.32, 0.48)	0.53 (0.15, 0.9)
		t	0.935	2.233
		P	0.351	0.027
	First molars	Extraction group(*n*=32, mm)	0.00 (−0.42, 0.43)	0.76 (0.46, 1.06)
		Non-extraction group(*n*=33, mm)	0.18 (−0.04, 0.41)	0.99 (0.74, 1.24)
		t	0.729	1.150
		P	0.467	0.252
	Second molars	Extraction group(*n*=32, mm)	0.32 (−0.15, 0.79)	0.46 (0, 0.93)
		Non-extraction group(*n*=33, mm)	0.24 (−0.09, 0.57)	0.93 (0.48, 1.38)
		t	0.268	1.395
		P	0.798	0.165
Labial inclination of mandibular incisors	/	Extraction group(*n*=32, °)	0.49 (−0.37, 1.35)	0.15 (−0.26, 0.55)
		Non-extraction group(*n*=33, °)	4.46 (3.59, 5.33)	3.76 (2.72, 4.79)
		t	1.180	2.030
		P	0.313	0.139

A positive change indicates labial inclination. A negative change indicates a lingual incination. AC: T1-T3 (clinical effects), CC: T1-T2 (expected results). The "/" indicates the tooth position was not statistically recorded. Crown tilt: a negative initial value represents a lingual tilt of the crown

3　讨　论

错𬌗畸形在口腔疾病中发病率位居第三,仅次于龋病和牙周疾病,咬合不正是最常见的牙齿问题之一[10],可能会影响患者颌面部美学外观、功能和社会心理健康等方面[11-12]。正畸治疗的主要目的是矫正咬合不正,治疗过程会因佩戴矫治器产生口腔不适及出现暂时性的容貌改变、疼痛、发音和咀嚼功能不良等问题,患者会因此而对矫治产生抗拒,从而降低了治疗效果[13]。近年来,随着人们生活水平的提高以及对美观、舒适的要求越来越高,人们对口腔健康相关生活质量的关注日益增加[14],隐形矫治器正逐步替代金属固定矫治器成为更多患者的选择。

正畸矫治器较难完全表达既定的牙齿运动[15]。本研究表明,隐形矫治器实际整平下颌Spee曲线的能力低于预测。拔牙组整平准确率仅为3.2%,说明拔除下颌第一前磨牙后,矫治过程中出现了下颌第一磨牙近中倾斜及下颌切牙舌侧倾斜[16-17]。Dai等[18]研究证实,使用隐形矫治器治疗拔除四颗第一前磨牙的患者,第一磨牙出现比预测更多的近中端倾斜及压低,伴随中切牙冠舌向转矩增加;成人与青少年的牙齿移动对比,前者存在生理性支抗丧失,年龄是第一磨牙支抗丧失的重要影响因素[19]。对于拔除第一前磨牙的病例,马艳宁等[20]认为隐形矫治器由于材料特性,刚性不足,容易在前牙回收时出现覆𬌗加深,前牙转矩丢失等问题;在拔牙病例设计时,牙套的长度随着拔牙间隙的缩小而缩短,对后牙产生近中推力,使

得后牙更容易出现近中倾斜与压低，导致垂直向的失控。这些研究可以解释两组的CC与AC有明显差异，可能是由于拔除下颌第一前磨牙后，下颌后牙近中倾斜移动导致下颌Spee曲线较深[7,18]，而下颌磨牙长轴的近中倾斜也导致咀嚼肌功能异常，继而促进Spee曲线 的加深[21-22]。

本研究表明，相较于下颌第二前磨牙处较高的Spee曲线整平准确率，下颌第一磨牙处存在明显整平不足，这与Goh等[23]研究一致。有研究表明，男性和女性咬合力从切牙到磨牙逐渐增大，第一磨牙处咬合力最大[24]。Spee曲线的发展可能是由于对侧后牙的萌出时间不同、颅面变化和神经肌肉系统的发展；一旦在青春期建立，它就会在成年早期保持相对稳定[25]。Talens-Cogollos等[26]发现，隐形矫治器治疗骨性Ⅰ类错𬌗，矫治后下颌磨牙平均压低0.84 mm，下颌第一磨牙近中颊尖明显降低。本试验中第一磨牙处整平效果差，因其在牙弓中承担最大咀嚼负荷和隐形矫治器具有“𬌗垫效应”[27-28]。Talens-Cogollos等[26]认为由“𬌗垫效应”造成的磨牙压低具有自限性，因为患者的神经肌肉适应使磨牙趋向恢复原始高度。因此，在临床医生进行方案设计时，应注意对整平下颌Spee曲线设计过矫正，尤其是下颌第一磨牙区。

本研究中，两组下颌Wilson曲线均表现为AC>CC，表明隐形矫治器实际整平下颌Wilson曲线的能力超出预期，倾向于在下颌整平Wilson曲线过表达。非拔牙组下颌第一、二磨牙牙冠倾斜度AC相似，说明邻近牙齿颊尖受力转移。两组下颌第一磨牙牙冠倾斜度变化最大，表明下颌第一磨牙缺乏根颊向转矩，出现牙冠过度颊侧倾斜。研究指出隐形矫治器根颊向转矩表达有限，与下颌磨牙牙冠颊尖水平宽度的扩大相比，下颌牙龈水平的扩大较少[29-30]。Zhou等[31]总结隐形矫治器牙齿颊向整体移动表达率低，需预设足够根颊向转矩。基于本研究结果，方案设计建议设置更大的根颊向转矩、更小的冠颊侧转矩。

本研究表明，非拔牙组牙弓宽度在上颌第一磨牙处、下颌第二前磨牙和第一磨牙处AC>CC，说明实际中、后段牙弓宽度增加超过预测。上颌牙弓在尖牙、第一磨牙处宽度增加有统计学意义，因为前牙段拥挤解除，后牙牙冠颊倾。Santucc等[32]证实隐形矫治器扩弓效果主要靠牙齿倾斜运动，前磨牙区域最有效。Robertson等[33]也证实隐形矫治器通过牙冠颊侧倾斜矫治轻至中度拥挤，尖牙冠颊向转矩表达率几乎为100%。

拔牙组上下颌牙弓宽度的AC与CC在尖牙、第二前磨牙、第一磨牙处无明显差异，表明拔牙组隐形矫治器扩弓表达较好。Houle等[29]证实下颌牙弓在牙尖水平扩弓准确率较高，有报道称上颌牙弓前牙间宽度变化的可预测性也无明显差异[34]。研究发现，使用隐形矫治器进行牙弓扩展时，上牙弓的总准确率为67%，下牙弓的总准确率为64%；下颌牙弓中，尖牙处的的牙弓扩张效果最为可靠[35-36]。在本研究中，两组下颌尖牙处的牙弓扩展AC与CC均无明显差异，说明隐形矫治器对牙弓前段的扩展效果较好。拔牙组的上下颌牙弓宽度在第一磨牙处的扩展差异无统计学意义，说明此处有准确的牙弓扩张，结合第一磨牙具有最大的冠颊向倾斜（AC与CC之差），更加印证了其缺乏根颊向转矩[37]。

下颌切牙唇倾无明显差异，这说明隐形矫治器对下前牙的唇倾效果表达较好。据报道[38]，隐形矫治器对牙弓深度的控制效果和固定矫治器相当。这表明在本研究中，下颌Spee曲线的整平不足可能与下颌磨牙处的整平有关。下切牙唇倾度指标的测量增加了本研究的有效性。隐形矫治器的工作原理就像弓丝[23]，整平Spee曲线时，不管矫治方案设计磨牙伸长还是前牙压低，最终矫治器的形状都是相同的。有研究表明，在不导致前牙段牙弓宽度增大的前提下，切牙每唇倾4 °可整平1 mm曲线[39]。

综上，隐形矫治器对下颌Spee曲线整平准确率较低，倾向过度表达整平Wilson曲线。后牙相对于OP的整平情况中，下颌第一磨牙整平准确率最低。下颌第一磨牙出现最大的牙冠颊向倾斜，提示方案设计中对Spee曲线在下颌第一磨牙处整平进行过矫正，临床医师应预设更大根颊向转矩。隐形矫治器对拔牙组上下颌牙弓宽度、拔牙组和非拔牙组的下颌牙弓前部宽度表达较为准确。本研究讨论了隐形矫治器整平下颌Spee曲线、Wilson曲线的准确率，有助于完善隐形矫治器结合纵向和横向咬合曲线对Monson球体的研究，从而将牙齿排列与颅面结构相关联[21,40]。但本研究样本量相对较少，结果有一定局限性，未来仍需更多高质量样本进一步验证其观点。

【Author contributions】 Ren L designed the study, performed the experiments, analyzed the data and wrote the article. Zheng Z, Zhang JS analyzed the data, designed the research study and revised the article.

Zhang MM conceptualized and reviewed the article. All authors read and approved the final manuscript as submitted.

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