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· 基础研究 ·

不同全瓷材料和厚度的种植牙冠应力分布有限元分析

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【摘要】 目的 通过有限元方法比较不同全瓷材料和厚度在种植牙冠修复的应力分布情况,为临床冠部修复材料的选择和设计提供参考。**方法** 建立下颌第一磨牙种植牙冠修复有限元模型,并进行6种冠厚度和4种不同冠修复材料,即树脂基陶瓷(Lava Ultimate和Vita Enamic)、二硅酸锂玻璃陶瓷(IPS e.max CAD)和氧化锆陶瓷(Cercon)进行组合。在下颌第一磨牙殆面加载600 N,使用有限元软件ANSYS 10.0分析应力分布。**结果** 冠部应力分析显示,4 mm-Cercon组156.05 MPa最高,1 mm-Lava Ultimate组18.85 MPa最低。树脂水门汀应力分析显示,4 mm-Lava Ultimate组62.52 MPa最高,1 mm-IPS e.max CAD组16.74 MPa最低。使用成品基台时,Lava Ultimate组在冠修复体、树脂水门汀中的应力集中较相同冠厚度的个性化基台高。**结论** 随着冠厚度增加,冠修复体和树脂水门汀中的最大主应力集中呈现上升趋势;树脂基陶瓷使用个性化基台更有利于减少应力集中。

【关键词】 树脂基陶瓷; 氧化锆; 冠修复体厚度; 树脂水门汀; 种植牙; 有限元; 应力分布; 基台设计; 个性化基台

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Finite element analysis of the stress distribution of dental implant crowns with different all-ceramic materials and thicknesses LI Jieshen¹, LIN Zhenxiang², WU Dong¹, ZHENG Zhiqiang¹, LIN Jie¹. 1. Department of VIP Dental Service, School and Hospital of Stomatology, Fujian Medical University, Fuzhou 350002, China; 2. Department of Stomatology, Hospital of Fujian Provincial Authorities, Fuzhou 350001, China

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【Abstract】 Objective To compare the stress distribution of different all-ceramic restoration materials and thicknesses in dental crown restorations using the finite element method and provide a reference for the selection and design of clinical crown restoration materials. **Methods** A finite element model of mandibular first molar implant crown restoration was created, and 6 crown thickness designs and 4 different crown restoration materials were evaluated, namely, resin-based ceramics (Lava Ultimate and Vita Enamic), lithium disilicate glass-ceramics (IPS e.max CAD), and zirconia ceramic (Cercon) designs. The mandibular first molars were loaded at 600 N, and the stress distribution was analyzed by using the finite element software ANSYS 10.0. **Results** The crown stress analysis showed that 156.05 MPa was the highest in 4 mm Cercon group and 18.85 MPa was the lowest in 1 mm Lava Ultimate group. The stress analysis of resin cement showed that 62.52 MPa was the highest in the 4 mm Lava Ultimate group and 16.74 MPa was the lowest in 1 mm IPS e.max CAD group. During the use of the finished platform, the stress concentration of the Lava Ultimate group in the crown prosthesis and resin cement was higher than that of the personalized platform with the same crown thickness. **Conclusion** With increasing crown thickness, the maximum principal stress concentration in crown restoration

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and resin cement increases. Personalized abutments are more conducive to reducing stress concentrations for resin-based ceramics.

【Key words】 resin-based ceramics; zirconia; crown restoration thickness; resin cement; dental implant; finite element; stress distribution; abutment design; personalized abutment

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近年来,随着计算机辅助设计和计算机辅助制造(computer aided design/computer aided manufacturing, CAD/CAM)技术在口腔领域的发展,氧化锆、二硅酸锂玻璃陶瓷等美观、生物相容性好的全瓷材料得到广泛推广,但陶瓷的高脆性和高硬度限制了这类材料的临床应用^[1]。相对于传统全瓷材料,树脂基陶瓷具有物理性能接近天然牙、加工性能好的优点,但相对强度较低^[2-3]。本实验分别选择二硅酸锂玻璃陶瓷(IPS e.max CAD)、氧化锆(Cercon)、树脂纳米陶瓷(Lava Ultimate)和树脂渗透基质玻璃陶瓷(Vita Enamic)进行研究,通过有限元分析,比较不同全瓷修复材料和厚度在种植牙冠修复的应力分布情况,为临床冠部修复材料的选择和设计提供参考。

1 材料和方法

1.1 建立二维有限元模型

参考《中国人牙体测量和统计资料表》数据^[4],在有限元软件 ANSYS 10.0(ANSYS, 美国)中建立近远中向的二维下颌第一磨牙种植牙修复模型。模型全长 20.5 mm,冠高 7.5 mm,冠颊舌向宽 10.5 mm,基台穿龈高度 2.0 mm,种植体长 11.0 mm,种植体颈部宽 4.0 mm。分别建立冠修复体、树脂水门汀、基台、种植体、牙槽骨和食团结构的有限元模型。如图 1 所示,进行 6 种冠设计,即个性化基台(冠修复体厚 1 mm、2 mm、3 mm 和 4 mm)和成品基台(冠修复体厚 3 mm 和 4 mm);共使用 4 种不同冠修复材料:树脂纳米陶瓷(Lava Ultimate, 3M, 美国)、树脂渗透基质玻璃陶瓷(Vita Enamic, Vita, 德国)、二硅酸锂玻璃陶瓷(IPS e.max CAD, Ivoclar-Vivadent, 列支敦士登)和氧化锆陶瓷(Cercon, Dentsply, 美国),有 24 种组合。个性化基台设计成牙体解剖缩小形态,成品基台设计成接近圆柱形态,基台保持 6~8°聚合角,设计深凹面(deep chamfer)形肩台,宽度随冠厚度变化。个性化基台的牙冠厚

度指在牙尖斜面和轴面的厚度,成品基台指在轴面的厚度,在肩台和牙尖处随牙体形态和基台种类有所减少和增加,但不同厚度组间区别明显。树脂水门汀厚度设定为 0.08~0.10 mm^[3]。牙槽骨设定为力学性质良好的 II 类骨。假设修复体、树脂水门汀、基台界面完全粘接,种植体和牙槽骨完全骨整合。

1.2 材料性质,边界条件及加载载荷

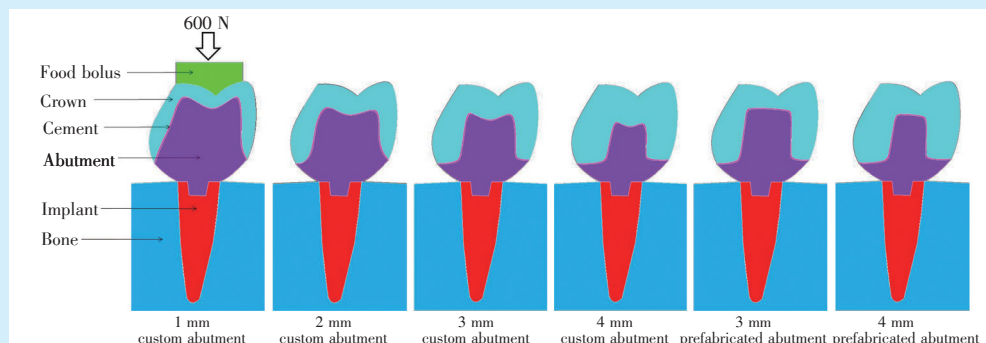
表 1 中列出有限元分析实验所用的材料性质^[5-9],分析中的材料均被假设为等方、同质和线弹性的材料。图 1 中显示分析用模型的几何情况。应用有限元分析软件 ANSYS 10.0 在计算机上划分二维四节点的四边形结构单元(PLANE42),这种单元的每个节点在平面内分别有 2 个自由度。将牙槽骨底部和两侧节点的水平 and 垂直方向自由度进行刚性约束。在下颌第一磨牙殆面食团上沿牙体长轴殆龈向加载 600 N 均布荷载,以模拟最大咬合力^[6],加载方式为静态加载。使用有限元软件 ANSYS 10.0 分析应力分布,评估最大主应力。

表 1 材料性质
Table 1 Material properties

Item	Young's modulus (GPa)	Poisson ratio
Lava Ultimate	12.70	0.45
Vita Enamic	37.80	0.24
IPS e.max CAD	95.00	0.25
Cercon	205.20	0.24
Resinous cement	7.50	0.30
Cortical bone	10.40	0.34
Implant/Abutment (Ti-6Al-4V)	120.00	0.33
Food bolus	3.41×10^{-3}	0.10

2 结果

最大主应力有限元分析结果见表 2,冠部应力分析显示,4 mm-Cercon 个性化基台组 156.05 MPa 最高,1 mm-Lava Ultimate 个性化基台组 18.85 MPa 最低;随着冠厚度的增加,Lava Ultimate 组、Vita Enamic 组和 IPS e.max CAD 组的冠修复体应力均呈上



The model structure included crown, resin cement, abutment, implant, bone and food bolus. From left to right, the custom abutment included the design of 1 mm, 2 mm, 3 mm and 4 mm crown restoration thickness, and the prefabricated abutment included the design of 3 mm and 4 mm crown restoration thickness, the arrow on the occlusal surface indicated that a uniform load of 600 N was applied along the long axis of the tooth

Figure 1 The stress loading model and six crown designs in this experiment

图1 本实验中使用的应力加载模型与6种冠设计

升趋势。树脂水门汀应力分析显示,4 mm-Lava Ultimate 个性化基台组 62.52 MPa 最高,1 mm-IPS e.max CAD 个性化基台组 16.74 MPa 最低,各材料树脂水门汀中的应力均呈上升趋势。基台应力分析显示,4 mm-Lava Ultimate 个性化基台组 187.22 MPa 最高,2 mm-Cercon 个性化基台组 49.14 MPa 最低。各材料组的种植体的应力均呈下降趋势。使用成品基台时,Lava Ultimate 组在冠修复体、树脂水门汀中的应力集中较相同冠厚度的个性化基台高。周围牙槽骨中的应力在 41.06 ~ 41.11 MPa 范围,变化较小。

最大主应力云图见图 2,由图可知,冠厚度从 1 mm 到 4 mm,各材料组的冠部高应力区逐渐增大,基台高应力逐渐减少;当冠厚度为 4 mm 时,各组均可见基台高应力区转移到肩台处。

3 讨论

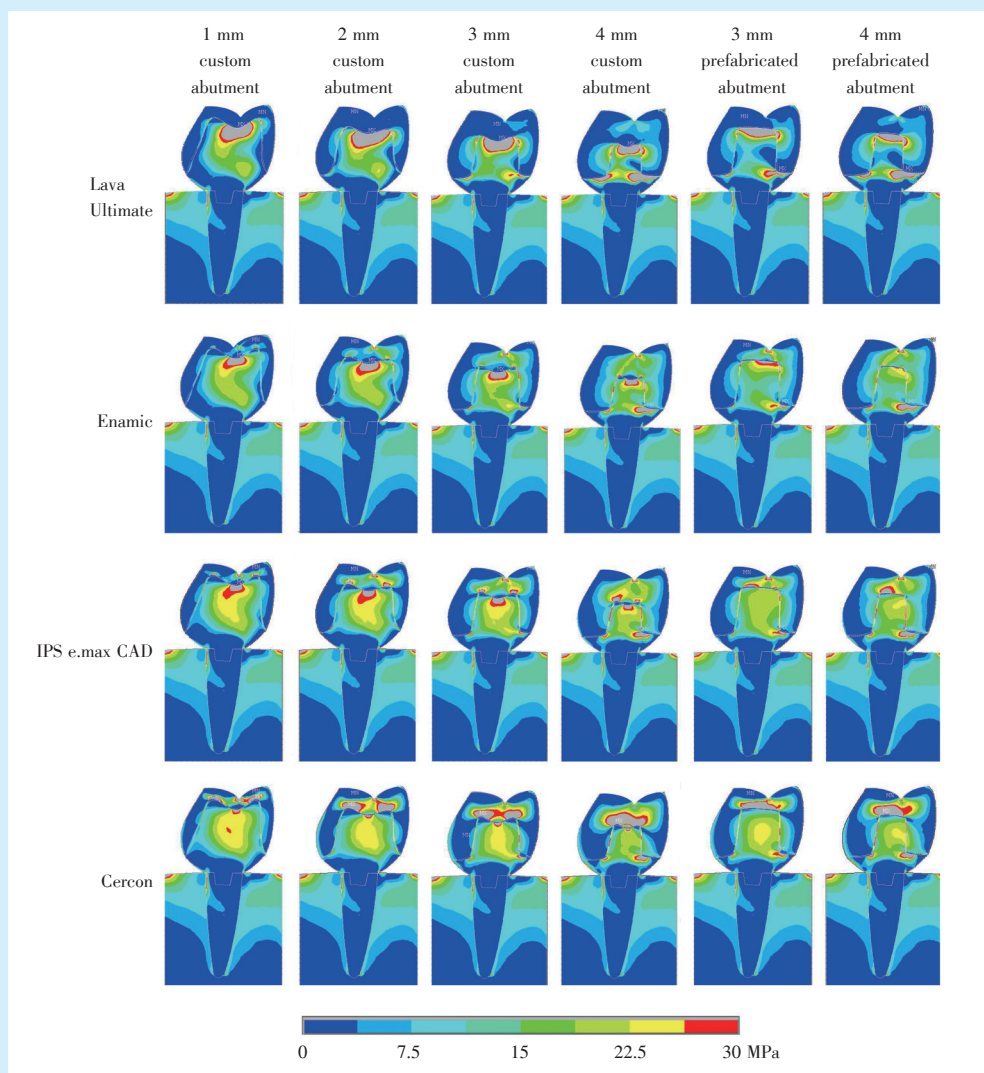
虽然下颌第一磨牙种植冠部修复本身是三维结构,但其主要特点在近远中向的二维模型中可以反映。二维平面模型与三维立体模型比较,虽在结构完整性方面有不足,但也有自身的优势,如建模快速简单、误差可控、易于发现问题本质等^[10]。三维模型分网所采用的四面体单元在精确性上不及平面的四边形单元,如在解析树脂水门汀等菲薄结构上,会划分出角度极小的单元,使有限元计算结果的精确性受到影响^[11]。由于冠部应力是主要观察指标之一,本实验参照 Ausiello 等^[12]和 Dal Piva 等^[6]方法,在下颌第一磨牙殆面食团上牙龈向加载 600 N 模拟最大咬合力,食团加载避免

表 2 不同全瓷材料和厚度的种植牙冠最大主应力

Table 2 Maximum principal stress value of dental implant crown with different all-ceramic materials and thickness MPa

Materials	Crown restoration thickness	Crown	Cement	Abutment	Implant	Bone	
Lava Ultimate	1 mm-custom	18.85	34.00	166.80	48.65	41.06	
	2 mm-custom	25.40	44.69	146.15	46.40	41.07	
	3 mm-custom	29.31	53.22	170.58	39.43	41.07	
	4 mm-custom	35.59	62.52	187.22	35.75	41.14	
	3 mm-prefabricated	37.37	68.18	94.70	48.92	41.02	
	4 mm-prefabricated	38.94	61.02	151.22	36.89	41.08	
	Vita Enamic	1 mm-custom	38.69	22.26	92.47	48.25	41.06
		2 mm-custom	52.73	28.47	79.31	46.36	41.07
3 mm-custom		66.52	32.95	89.38	41.48	41.07	
4 mm-custom		68.00	37.65	103.57	36.82	41.11	
3 mm-prefabricated		64.27	43.72	75.97	47.43	41.05	
4 mm-prefabricated		70.59	42.11	109.11	37.75	41.08	
IPS e.max CAD		1 mm-custom	68.57	16.74	72.44	46.39	41.08
		2 mm-custom	73.08	22.20	61.21	43.10	41.09
	3 mm-custom	76.31	26.14	74.89	38.77	41.09	
	4 mm-custom	94.46	31.50	95.32	36.50	41.11	
	3 mm-prefabricated	68.69	32.49	80.72	40.79	41.08	
	4 mm-prefabricated	74.45	33.76	101.98	36.71	41.11	
	Cercon	1 mm-custom	125.56	20.25	54.13	44.00	41.08
		2 mm-custom	133.92	25.90	49.14	42.30	41.09
3 mm-custom		130.91	32.14	80.69	38.32	41.10	
4 mm-custom		156.05	41.95	95.08	36.40	41.11	
3 mm-prefabricated		79.67	35.37	86.80	38.06	41.10	
4 mm-prefabricated		108.10	41.66	94.93	36.26	41.11	

了直接在牙冠上进行点状加载时发生的局部应力集中,有利于对有限元分析结果的判读。



Different colors represented different stress value ranges. With the increase of crown thickness, the crown high stress area increased, the abutment high stress area decreased. The high stress area of abutment was transferred to the shoulder when crown restoration thickness is 4 mm

Figure 2 Distribution of the maximum principal stress of dental implant crown with different all-ceramic materials and thickness

图2 不同全瓷材料和厚度的种植牙冠最大主应力分布云图

在CAD/CAM加工中小于1 mm的冠切割容易折裂,在磨牙冠留出中央螺丝孔和基台空间后,大于4 mm的冠厚度较为少见,因此本实验从1 mm到4 mm范围进行评价。临床中成品基台多为圆柱或圆台形状,粗细一定程度可调,咬合面为平面,不具备个性化基台的牙体缩小形态,因此设计为只调节轴面的厚度,以反映其特点。本实验结果显示,Lava Ultimate组的应力主要在基台集中,而Cercon组的应力主要在冠修复体集中,而且冠越厚越容易集中。临床上使用较厚的氧化锆冠和内核很小的基台组合很少发生冠折裂,主要由于氧化锆

的强度高。但在使用强度较低的树脂基陶瓷材料时,需要控制冠的厚度,否则可能会导致冠的折裂失败。这和金属烤瓷的饰瓷与底层冠的关系类似,强度较低的表层要有强度高的内核支撑,表层材料过厚容易崩裂,过薄易产生磨损和颜色不佳的问题。

种植牙冠部修复和天然牙冠不同之处在于,种植冠部修复使用钛等较硬的基台内核,较天然牙的牙体内核弹性模量大,在应力分布上更容易向钛基台集中,这有利于使用树脂基陶瓷冠部修复。本实验结果可见Lava Ultimate组、Vita Enamic

组冠部修复体的应力集中较 Cercon 组低,特别是较薄的 1 mm 组,而树脂水门汀中的应力集中较氧化锆高,修复成功的关键在于粘接。Peumans 等^[13]和 Stawarczyk 等^[14]的研究结果表明,树脂水门汀与树脂基陶瓷成分近似,两者之间更易于形成化学结合。IPS e.max CAD 组树脂水门汀中应力集中最低,且二硅酸锂玻璃陶瓷粘接性能较好,在种植体冠修复的应用有待临床检验。树脂基陶瓷在用成品基台时,冠和树脂水门汀中的应力集中较个性化基台高。3 mm-Lava Ultimate 成品基台的树脂水门汀应力为 68.18 MPa,为树脂水门汀中最高。Ausiello 等^[12]使用冠厚度 6 mm,聚合角 6°的成品基台时,氧化锆的抗折力约为 Lava Ultimate 的 3 倍。较细而尖的成品基台容易造成基台尖端的应力集中,因此树脂基陶瓷材料在种植牙冠修复时使用个性化基台有利于应力分散。种植牙没有牙周膜,咬合时位置变化很小。当对颌磨牙也为种植修复体时,如果上下颌都采用氧化锆这类坚硬的材料进行冠部修复,对种植体稳定可能产生影响。此外,天然牙存在生理性磨耗,而氧化锆材料的强度高,磨耗较少;如果上下对颌种植牙均采用氧化锆冠修复,长期使用天然牙磨耗之后,容易形成高点,发生种植牙的颌创伤。

综上,树脂基陶瓷材料在种植牙冠修复时使用个性化基台有利于减少应力集中。此外,本实验为静态力学的有限元分析,实验中周围牙槽骨中的应力几乎没有变化,因此动态冲击对种植体以及周围骨的影响还有待进一步研究。

[Author contributions] Li JS performed the experiments and wrote the article. Lin ZX designed the study. Wu D and Zheng ZQ revised the article. Lin J designed the study, performed the experiments and reviewed the article. All authors read and approved the final manuscript as submitted.

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