Bending Resistance of Polylactic Acid Absorbable Root Canal Pile after Repairing Residual Roots

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As we all know, tooth growth is very important for children. Whether it is the growth of new teeth or the loss of deciduous teeth, the residual roots of deciduous teeth will affect the physiological replacement of permanent teeth, and the repair of non-absorbable retention posts will also participate. Therefore, the purpose of this article is to explore the polylactic acid can absorb the bending resistance of the root canal pile after repairing the residual root. The method adopted in this paper is to randomly select 24 isolated mandibular premolars to ensure the morphological similarity of the sample as much as possible. After routine root canal treatment and filling, the crown is removed, and the sample is divided into 3 groups on average., Respectively, polylactic acid absorbable root canal post, fiberglass post and composite resin short post retention, to perform post-core resin crown repair. Subsequently, the electronic universal material testing machine and formula were used to calculate the bending resistance of each material in the fracture mode, and then LSD two-sided inspection was used for comprehensive comparison. Corresponding conclusions are drawn through data comparison. The research results show that the bending strength of the polylactic acid absorbable root canal pile group is 1031.44±359.78N, the bending strength of the glass fiber pile group is 1121.34±193.50N, and the composite resin short pile The group was 1581.36±677.20N, and the differences were statistically significant (P<0.05). The three groups of samples in the experiment are all favorable tooth creases. Therefore, it can be concluded from the experimental results that the bending resistance of the polylactic acid absorbable root canal pile after restoring the residual root is lower than that of the composite resin short pile, which can also meet the clinical needs.

Key words: Polylactic Acid, Absorbable Root Canal, Restoration of Residual Roots, Bending Resistance
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With the rapid development of biomedical materials, orthopedic absorbable fixation materials have been widely used. When a large area of permanent tooth crown tissue is damaged, root canal treatment can be performed first, and then the fiber post core system or metal post core system can be used for repair. From the general clinical results, it is more common to choose metal or fiber posts (cores) to use root canal to enhance retention, which can quickly restore the original shape and inherent function of the tooth body. At present, the use of a brand new polylactic acid post membrane to repair the residual roots of deciduous teeth can achieve good clinical efficacy and play an important role in restoring oral physiology. Therefore, it will provide new research methods for repairing residual roots.

As a new type of biodegradable material, polylactic acid is more and more closely connected with people's production and life, and it has begun to be applied in the biomedicine industry. Polylactic acid, also known as polylactide, is a

polymer [1] obtained by polymerizing lactic acid as the main raw material. With its good biodegradability, polylactic acid does not damage the environment. After the degradation of microorganisms in the soil and the atmosphere, water and carbon dioxide are formed [2]. Therefore, in today's environment-saving society, it is not only beneficial to economic development, but also very friendly to the environment, so polylactic acid is very popular [3]. Polylactic acid is made by extracting starch from renewable plant resources, and then glucose is obtained through saccharification, and then fermented by special strains to produce high-purity lactic acid. Combined with chemical synthesis methods, polylactic acid of a certain molecular weight is finally formed. Industrial materials made of polylactic acid can be naturally degraded after they are scrapped. Most of the carbon dioxide produced can be absorbed by plants and decomposed by organic matter in the soil, and few are directly discharged into the atmosphere [4]. Compared with the traditional processing methods of ordinary plastics, the air freshness is protected and the normal atmospheric circulation is maintained. At present, there are more and more specialties in the production and processing of polylactic acid, and the application of related patents is also increasing [5]. More importantly, polylactic acid can be completely absorbed by human tissues during clinical use in medicine, without toxic and side effects, and has good physical and mechanical properties [6]. Polylactic acid the polylactic acid prepared by the solvent volatilization film forming method can absorb the root canal pile membrane and has good biocompatibility [7].

In the 1980s and 1990s, foreign scholars first applied absorbable internal fixation to the clinic [8]. Deciduous teeth are more susceptible to caries, and the tooth body can be transformed into residual crown and root in a short period of time. In the process of tooth transformation, residual roots will appear due to incomplete nutrients [9]. Therefore, most of the correction of caries is to use polylactic acid and other absorbable materials for repair and filling. With the development of absorbable biomaterials, polylactic acid has gradually become the most commonly used orthopedic absorbable internal fixation material in clinical practice [10]. The application of polylactic acid in the medical field can be combined into new polymer compounds through hydrolysis, and many types of treatments are commonly used [11]. Polylactic acid has a degradation rate similar to the physiological absorption rate of deciduous tooth roots, and has a good biocompatibility for the physiological replacement of deciduous permanent teeth, periodontal ligament cells and deciduous dental pulp cells of deciduous teeth [12]. The polylactic acid rod is made into a polylactic acid root canal pile for deciduous teeth, which is bonded with glass ionomer cement, which can be well used for the functional repair of severe infant caries [13]. However, the non-absorbability of glass ionomer cement has hidden dangers to the physiological replacement of primary permanent teeth, so the study of polylactic acid is an important breakthrough to improve the restoration of residual roots, and it is also the key to seeking retention materials that are synchronized with the roots of primary teeth [14].

In this study, the isolated mandibular premolars were used as the research object, and the method of electronic universal material testing machine was used to compare the bending resistance of polylactic acid piles, glass fiber piles and composite resin short piles after repairing the residual roots. The bending resistance after residual roots provides a reference for clinical application. The innovations of this article include exploring the bending resistance of polylactic acid post membranes to repair residual roots through the anti-bending force experiment; through case analysis, to evaluate the effect of polylactic acid post membranes to repair residual roots of infant deciduous teeth. The functional restoration of the residual crown provides a new method. It provides new ideas and directions for the treatment of residual root canal piles, and provides a solid foundation for subsequent research. It provides reference technical experience for future experiments, draws similarities and differences in research directions through comparative advantage analysis, and provides a theoretical basis for the medical field.

MATERIALS AND METHOD

Data Sources

In this experiment, the collar surgery of the top three hospitals in the author's location was selected, and 24 lower premolars extracted due to orthodontic reduction were selected as research samples. When selecting samples, in order to better control the variable research, the root length and the shape is basically the same, no wedge-shaped defects, no cracks, no caries, no internal absorption. Then clean all the soft tissues on the surface of the samples and group them into numbers. All samples were divided into PLA pile group (group A), glass fiber pile group (group B), composite resin short pile group (group C) by random grouping method, each group of 8. Subsequently, the root length of the tooth was accurately measured, and the caliper of the neck was measured using a vernier caliper and the diameter of the neck cheek and tongue. Each index of each tooth was measured three times and averaged. Then use the statistical software SPSS13.0 to analyze the variance of the measured data and compare the differences between the indicators of the three measurement groups. If there is uneven variance, you can continue to use the Welsh test. If the variance is uniform, use single-factor analysis of variance. The results showed that there was no statistically significant difference between the indicators in each group (P>0.05).

Table1.
Comparison of Root Length, Proximal and Middle Diameter of Neck, and Buccal and Tongue Diameter of Neck in Each Group

Group	Pile Type	Root Length	Neck Mesial and Distal	Neck, Buccal and Lingual Diameter
Group A	PLA Pile	15.94±2.02	5.31±0.30	7.39±0.29
Group B	Glass Fiber Pile	15.08±0.94	5.33±0.27	7.68±0.50
Group C	Composite Resin Short Pile	15.15±1.28	5.21±0.35	7.50±0.43

Experiment Procedure

First, deeply clean the teeth of the three groups of samples to ensure the normal operation of the experiment. Cut off the crown at 2 mm from the crown of the highest point of the enamel bone boundary, adjust the K file to expand the root canal to #30, and use the ProTaper machine Root canal filling with Nichin instruments, combined with two-way lateral pressure heating technology, seal the root canal mouth with zinc oxide clove oil paste, carefully check the root apex for leakage, and take X-ray film to confirm that the root filling is good. In the gastrointestinal environment, the samples were placed in normal saline for 1 week [15].

In the PLA pile group, the metal screw pile with a diameter of 1.78 mm is directly drilled to a depth of 10 mm, and the pile road is preliminarily formed with a metal bone screw, and then the PLA can absorb the internal fixation nail with a special assisting device for tapping. Make the pile path diameter 2mm, length 10mm. In the glass fiber pile group, use the special preparation drill matched with the glass fiber pile to drill to the 10mm deep pile road. In the composite resin short pile group, the P root drill was used to drill a short resin pile with a diameter of 1.5 mm and a length of 4 mm. In order to ensure that the apex is closed, the envoys will retain 4 mm of root fillings in the apex [16]. Finally, the three groups were thoroughly rinsed with 10g/L sodium hypochlorite solution, and the cotton was dried by twisting and set aside.

Finally, after extracting the teeth of each sample, absorb the residual water stains on the surface, fix it with a self-setting resin in a 15mmx15mmx20mm cylindrical metal mold, and embed 2mm below the enamel bone cement in the self-setting resin to simulate Alveolar horizontal environment. The electronic universal material testing machine was put into use, and the bending strength of each test piece was tested separately, and various data of the bending strength were recorded according to different variables [17]. Place each test piece in the cylindrical groove of the metal base so that the loading point is at 1/3 of the tongue side of the resin crown, set the sample angle and loading direction to 45 degrees, and test the specimen at a loading speed of 1.0 mm/min Load until the tooth fractures or the restoration comes off. Record all the data in the experiment and observe its fracture mode.

Table2.
The Bending Resistance of Three Groups of Teeth

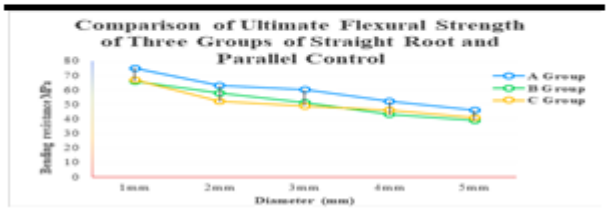
Group	N	$\bar{x}$	SD	F Value	P Value
Group A	S	1022.44	359.70		
Group B	S	1168.33	193.47	5.981	0.009
Group C	S	1767.36	677.17		

Experimental Results

It can be seen from Table 2 that the bending resistance of the teeth in group A is 1022.44±359.70N, group B is 1168.33±193.47N, and group C is 1767.36±677.17N. After the homogeneity test of Levene's variance, F=1.904, P=0.174, according to the test level of a=0.05, it shows that the three groups of samples have uniform variances in tooth bending resistance, so single factor analysis of variance [18] was used. The results showed that there was a statistically significant difference in flexural strength between the three groups (P=0.009). The LSD test was used for the pairwise comparison between the averages of the samples in each group. The results showed that there was no statistically significant difference in the flexural strength between Group A and Group B (P=0.530), and the flexural strength of Group A and Group B was lower than that of Group C. (P=0.004, 0.016). It is well known that deciduous tooth root is the only hard tissue in the human body that can be physiologically absorbed and disappeared clinically. Because a complete human anterior tooth is difficult to obtain, a single root canal premolar with a lower collar is used to simulate the residual root of the anterior teeth. Crown restoration, to explore the bending resistance of PLA post membrane resin repair [19]. At the same time, this study measured the root length of the teeth of each group of samples, the proximal and middle diameters of the neck, and the diameter of the neck cheek and tongue before the experiment. The results of statistical analysis showed no statistical difference, which balanced the bias in the selection of sample teeth and increased the credibility of the experimental results. There are certain individual differences in tooth anatomy, so it will affect the accuracy of the experimental results. In order to avoid the experimental deviation caused by the selection of the experimental sample teeth, it is recommended to choose the anterior teeth or artificial teeth with standard anatomy for further experiments afterwards [20]. Some studies have pointed out that whether to use the pile system and the type of pile system when restoring tooth roots is an important factor that affects the flexural performance of teeth. Therefore, in this study, the crowns of the sample teeth were uniformly restored to the single canine shape, and the method was simple and easy [21]. In addition, the sample teeth were fixed directly in the self-setting plastic during the preparation of the experimental specimen, which may indirectly change the inherent fracture performance of the tooth root, which can be improved by simulating the periodontal membrane.

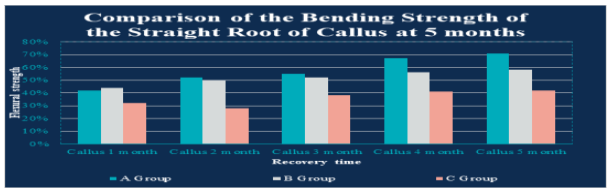
RESULT

Figure 1.
Comparison of Ultimate Bending Strength of Three Groups of Straight Roots and Parallel Controls



As shown in Figure 1(The data in the figure is collected by the author), these are the straight roots of the three groups of different materials selected in the experiment. After varying degrees of bending force, it shows that the bending strength and the diameter are inversely related to the power function. However, due to the addition of different materials inside, so that with the change of diameter, the flexural strength it bears also has different changes. In the polylactic acid pile group, when the flexural strength is 1 mm, the flexural strength reaches 75 Mpa, and gradually decreases to 63 Mpa, 60 Mpa, 52 Mpa. When the maximum diameter of the test experiment is 5 mm, the bearing strength is 46 Mpa. In general, polylactic acid effectively improves the flexural strength after stress. In comparison, in the other two experimental control groups, the glass fiber pile group decreased from the initial 66 Mpa to 58 Mpa, 51 Mpa, 43 Mpa,

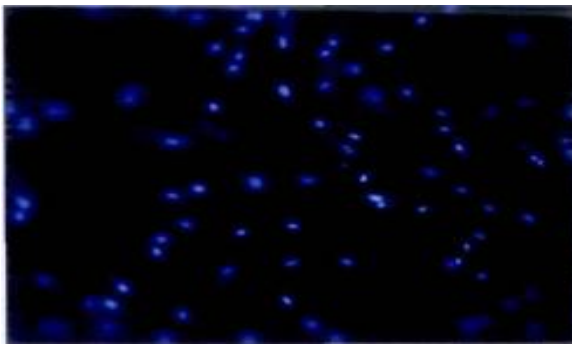
Figure2.
Comparison of Straight Root Flexural Strength after 5 Months of Callus



39 Mpa with the diameter change. Between 1mm and 2mm, the rate of descent is very fast. The compressive capacity of the composite resin short piles changed more rapidly. The flexural strength at 1 mm was 67 Mpa, and at 2 mm, it became 52 Mpa, after which the downward trend slowed down to 49 Mpa, 46 Mpa, 41 Mpa. From this point of view, the polylactic acid post membrane has better bending resistance after repairing residual roots.

As shown in Figure 2 (Data from the website of National Bureau of Statistics), the analysis of the changes in the 5 months of injury is mainly performed here by comparing the data of 3 different experimental groups. In the polylactic acid pile group, as the recovery time increases, the recovery of flexural strength also continues to increase. After a month of injury, you can recover to 42%, and the recovery rate is gradually

Figure3.
DIPI Staining Diagram



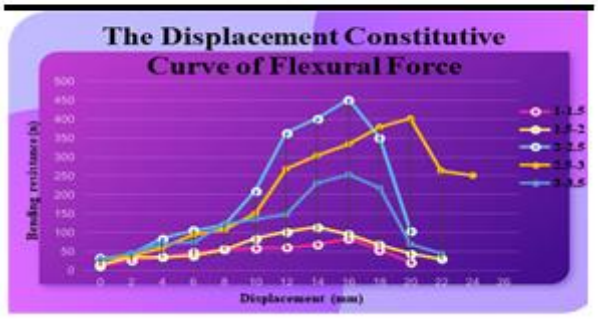
increasing, reaching 52% in 2 months, 55% in 3 months, and 57 in 4 months %, and 5 months can reach 71%. From the overall trend, this is higher than the other two groups. The recovery level of the glass fiber pile group is gentle, and has been at a medium level, from 44% in the first month, which is the fastest recovery of the bending resistance after one month, and then it is always around 50%, and 58% after five months, 13% lower than the polylactic acid group. The overall fluctuation of the composite resin short pile group is relatively large, but the overall recovery resistance is not high, respectively 32%, 28%, 38%, 41%, 42%. There is still a decline in the recovery period of injury after two months, which may also be caused by various environmental inadaptation.

As shown in Figure 3(Pictures from www.Wikipedia.com), after the API staining, the HGFS cell nucleus showed a typical blue light, which showed that polylactic acid can absorb the adhesion and growth of fibroblasts on the surface of the root canal graft. After the experiment, it can be found that polylactic acid has a good effect of restoring the residual roots. First, the fracture gap recovers quickly, and the resistance to folding has also improved. Secondly, through the observation of the electron microscope and the naked eye, it can be seen that the implanted polylactic acid absorbable makeup film has good contact with the surrounding tissues, without very obvious damage and thought, and reacts well with other tissues. There is a lot of inflammatory granulation tissue hyperplasia around the clever membrane, which is basically the same as the test result.

The polylactic acid absorbable post membrane

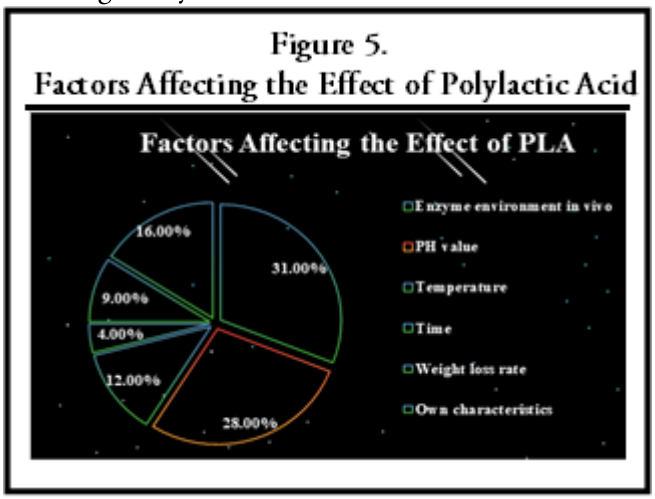
provides a retention system that can be simultaneously absorbed by the polylactic acid absorbable plant, and at the same time, it also improves a new method for residual root repair. As shown in Figure 4(Pictures from *www.baidu.com*), five root systems with different diameters were selected for constitutive testing. The diameters are 1-1.5mm, 1.5-2mm, 2-2.5mm, 2.5-3mm, 3-3.5mm. The flexural strength displayed also has a certain relationship with it. The overall trend of the five curves is that with the change of displacement, the flexural force increases first and then decreases, and the rate of increase and decrease are also different. In general, it has experienced a change from fast to slow and from increasing to decreasing. Specifically, when the displacement is in the range of 10-12mm, the growth rate of the five curves begins to change significantly, and the root system around 3mm changes more obviously. As the displacement increases, the straight root bending resistance increases slowly. This shows that when the root system bears a small force, its own buffer displacement during the breaking and deformation process is large, and the buffer capacity is strong.

Figure4.
Straight Flexural Displacement Constitutive Curve



As shown in Figure 5(The picture comes from the experiment of HowNet), polylactic acid can absorb root canal piles to repair residual roots due to many factors. In action, the polymer compound is hydrolyzed and decomposed by microorganisms. Among them, 31% of the factors are caused by the enzymatic environment in the body, which will not only affect the reaction rate, but also the reaction time. 28% of the factors are related to the pH value of the experimental environment. When the polylactic acid copolymer degrades, The PH value inside the material rapidly decreases, forming a locally acidic environment inside the material, which promotes the autocatalytic degradation of the internal material. The effects of temperature and time accounted for 4% and 12%, respectively. The weightlessness rate can reach 9%, and the change of the weightlessness rate of the polylactic acid can absorb the degradation of the root canal pile at different times shows that it has obvious degradation phenomenon in about six months. Finally, its own characteristics accounted for 16%. In addition, it is also affected by the hydrophobicity, chemical structure, molecular weight and stereoregularity of the material.

Figure 5.
Factors Affecting the Effect of Polylactic Acid



DISCUSSION

The deciduous tooth root is the only hard tissue in the human body that can disappear through physiological absorption, so the polylactic acid absorbable pile is used to study the bending resistance after restoring the residual root. After experimental measurement records and data analysis, after caries or external shock, under the condition of 1/2-2/3 crown defect, the residual root and crown of the deciduous tooth, the composite resin pile and crown can be repaired together. Effect [22]. Therefore, it is concluded that the bite force (213.17, 143.97) N of children 3-5 years old and the bending resistance of the composite resin short pile crown repair group is (1767.36 1677.20) N, which has no effect on normal chewing function. However, it is worth noting that when repairing residual roots, the root canal length should not be too long. After the operation, it is necessary to

ensure that the crown has a sufficient amount of healthy tooth tissue [23].

The fiber pile is beautiful in appearance, excellent in performance, strong in bending resistance, and not easy to corrode during use, and has high biocompatibility. In the clinical practice of the restoration of permanent roots and crowns of permanent teeth, there are very impressive results [24]. The flexural strength of fiber pile and PLA absorbable root canal pile after repairing residual roots is (1168.33, 1119.50) N, (1022.44, 1357.70) N, although the flexural strength of PLA repair group is lower than that of fiber pile, but neither the statistical difference is greater than the average level of normal people (22.4-68.3) kg (about 224-683) N. This experiment may have some differences in terms of biological morphology and medical anatomy, but in essence, it will not affect the accuracy of the experimental results. In addition, according to the analysis of the experimental results, the bending strength of the self-made deciduous PLA threaded pile is (126.7 15.8) MPa, which is higher than the standard bending strength (80MPa) of the composite resin in the IS04049 standard [25]. This also shows that polylactic acid has no problem at all in the bending resistance of absorbable pipe piles to repair residual roots.

REFERENCE

1. Wen P, Zhu D H, Feng K, et al. Fabrication of Electrospun Polylactic Acid Nanofilm Incorporating Cinnamon Essential Oil/Beta-Cyclodextrin Inclusion Complex for Antimicrobial Packaging. *Food Chemistry*2016;196(APR.1):996-1004.
2. Li N, Li Y, Liu S. Rapid Prototyping of Continuous Carbon Fiber Reinforced Polylactic Acid Composites by 3D Printing. *Journal of Materials Processing Technology*2016;238(5):218-225.
3. Ding J, Chen B, Lv T, et al. Bone Marrow Mesenchymal Stem Cell-Based Engineered Cartilage Ameliorates Polyglycolic Acid/Polylactic Acid Scaffold-Induced Inflammation Through M2 Polarization of Macrophages in a Pig Model. *Stem Cells Translational Medicine* 2016;3(1):2015-0263.
4. Elsawy M A, Kim K H, Park J W, et al. Hydrolytic degradation of polylactic acid (PLA) and its composites. *Renewable & Sustainable Energy Reviews*2017;79(11):1346-1352.
5. Torres J, Cole M, Owji A, et al. An Approach for Mechanical Property Optimization of Fused Deposition Modeling with Polylactic Acid Via Design of Experiments. *Rapid Prototyping Journal*2016;22(2):387-404.
6. Xia X, Liu W, Zhou L, et al. Modification of Fax Fiber Surface and Its Compatibilization in Polylactic Acid/Flax Composites. *Iranian polymer journal*2016; 25(1):25-35.
7. Lee R E, Guo Y, Tamber H, et al. Thermoforming of Polylactic Acid Foam Sheets: Crystallization Behaviors and Thermal Stability. *Industrial & Engineering Chemistry Research* 2016; 55(3):560-567.
8. Yin X, Wang L, Li S, et al. Preparation and Characterization of Carbon Fiber/Polylactic Acid/Thermoplastic Polyurethane (CF/PLA/TPU) Composites Prepared by A Vane Mixer. *Journal of polymer engineering*2017;37(4):355-364.
9. Aytac Z, Uyar T. Core-shell Nanofibers of Curcumin/Cyclodextrin Inclusion Complex and Polylactic Acid: Enhanced Water Solubility and Slow Release of Curcumin. *International Journal of Pharmaceutics*2017;518(1-2):177-184.
10. Couture A, Lebrun G, Laperriere L. Mechanical Properties of Polylactic Acid (PLA) Composites Reinforced with Unidirectional Flax and Flax-paper Layers.*Composite Structures*2016;154(10):286-295.
11. Li J, Song Z, Gao L, et al. Preparation of Carbon Nanotubes/Polylactic Acid Nanocomposites Using a Non-Covalent Method. *Polymer Bulletin*2016;73(8):2121-2128.
12. Hamad K, Kaseem M, Deri F, et al. Mechanical Properties and Compatibility of Polylactic Acid/Polystyrene Polymer Blend. *Materials Letters*2016;164(FEB.1):409-412.
13. Song A Y, Oh Y A, Roh S H, et al. Cold Oxygen Plasma Treatments for the Improvement of the Physicochemical and Biodegradable Properties of Polylactic Acid Films for Food Packaging. *Journal of Food Science* 2016;81(1-3):86-96.
14. Yubo T, Honglei W, Zelong L, et al. Development and Application of Wood Flour-Filled Polylactic Acid Composite Filament for 3D Printing. *Materials* 2017; 10(4):339.
15. Da Luz C M, Boyles M S P, Falagan-Lotsch P, et al. Poly-Lactic Acid Nanoparticles (PLA-NP) Promote Physiological Modifications in Lung Epithelial Cells and Are Internalized by Clathrin-Coated Pits and Lipid Rafts. *Journal of Nanobiotechnology*2017;15(1):11.
16. Caires H R, Esteves T, Quelhas P, et al. Macrophage Interactions with Polylactic Acid and Chitosan Scaffolds Lead to Improved Recruitment of Human Mesenchymal Stem/Stromal Cells: A Comprehensive Study with Different Immune Cells. *Journal of The Royal Society Interface*2016;13(122):20160570.
17. Kim S Y, Kim B S, Kim Y. Mandibular Second Molar Root Canal Morphology and Variants in A Korean Subpopulation. *International Endodontic Journal*2016; 49(2):136-144.
18. Persoon I F, Buijs M J, zok, Ahmet R, et al. The Mycobiome of Root Canal Infections is Correlated to the Bacteriome. *Clinical Oral Investigations*2017; 21(5):1871-1881.
19. Cangül Keskin, Özgür Özdemir, İsmail Uzun, et al. Effect of Intracanal Cryotherapy on Pain after Single-Visit Root Canal Treatment. *Australian Endodontic Journal*2016; 43(2):83-88.
20. Torabinejad M, White S N. Endodontic Treatment

Options after Unsuccessful Initial Root Canal Treatment. *Journal of the American Dental Association (1939)*2016;147(3):214-220.

21. Plascencia H, Cruz, álvaro, Díaz, Mariana, et al. Root Canal Filling after Revascularization/Revitalization. *Journal of Clinical Pediatric Dentistry*2016; 40(6):445-449.
22. Nagendrababu V, Gutmann J L. Factors Associated with Postobturation Pain Following Single-Visit Nonsurgical Root Canal Treatment:A Systematic Review. *Quintessence International*2016;48(3): 193-208.
23. Graudejus O, Li T, Cheng J, et al. The Effects of Bending on the Resistance of Elasticaliy Stretchable Metal Conductors, and A Comparison with Stretching. *Applied Physics Letters*2017;110(22):221906.1-221906.5.
24. Deepak M S, Shanthi V M. Section Bending Resistance of New Hybrid Double-I-Box Beams. *Advances in Structural Engineering*2018;21(11):1676-1695.
25. Samadi A F, Suzuki H, Ueda T, et al. Identification of Quantitative Trait Loci for Breaking and Bending Types Lodging Resistance in Rice, Using Recombinant Inbred Lines Derived from Koshihikari and A Strong Culm Variety, Leaf Star. *Plant Growth Regulation*2019;89(1):83-98.