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Возможности 3D–моделирования на доклиническом этапе исследования корневой иглы

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АННОТАЦИЯ

Введение. До сегодняшнего дня остается актуальным вопрос качественной обработки корневых каналов (КК) в молочных и постоянных зубах. Сложные анатомические формы КК, наличие дельтовидных ответвлений затрудняют работу. Сочетание механической и медикаментозной обработки КК позволяет добиться стерильности полости зуба, что очень важно, особенно при развитии хронических периодонтитов. Однако, добиваясь стерильности при медикаментозной обработке, врачи сталкиваются с новой проблемой — как избежать повреждения тканей периодонта антисептиком при раскрытом апикальном отверстии. Технические характеристики эндодонтических игл, предлагаемых для использования на этом этапе, не позволяют решить эту проблему с высокой степенью эффективности. Большое количество отрицательных сторон, определяют необходимость поиска путей усовершенствования конструкции эндодонтической иглы.

Цель. Определить оптимальные технические характеристики эндодонтических корневых игл и разработать новую конструкцию эндодонтической иглы, обеспечивающей равномерное орошение дельты КК с минимальной вероятностью повреждения периапикальных тканей.

Материалы и методы. Анализ показателей, влияющих на качество очищения КК при проектировании эндодонтической иглы с необходимыми техническими характеристиками проводился в программе Solid Works 16. Компьютерное моделирование биологической модели зуба с новой иглой проводилось в программе Solid Works Flow Simulation.

Результаты. Предложено усовершенствовать эндодонтическую корневую иглу методом компьютерного моделирования. Технический результат достигнут за счет придания конструкции всех положительных сторон аналогов, устраняя недостатки. Конструкция эндодонтической иглы содержит отверстия: 1 отверстие на кончике иглы и 168 отверстий, расположенных в шахматном порядке на боковой поверхности иглы. Все отверстия имеют одинаковый диаметр, равный 0,1 мм, что позволяет выровнять давление и снизить скорость центрального потока до скорости периферийных потоков, что обеспечивает равномерное орошение и минимизацию вероятности повреждения альвеолярного отростка.

Заключение. Новая модель эндодонтической иглы, имеющая 1 отверстие на кончике иглы и 168 отверстий, расположенных в шахматном порядке на боковой поверхности, обеспечивает равномерное орошение поверхности корневого канала по всему периметру с минимальной вероятностью повреждения периапикальных тканей даже при максимальной глубине введения иглы в КК.

Ключевые слова: *корневой канал; периапикальные ткани; эндодонтическая игла; медикаментозная обработка*

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Potentials of 3D-Modeling in the Preclinical Stage of Root Needle Research

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ABSTRACT

INTRODUCTION: At present, the issue of high–quality processing of the root canal (RC) of the deciduous and permanent teeth remains important. However, the procedure is hindered by the complex anatomical shape of the RC and a presence of deltoid branches. A combination of the mechanical and drug treatment of the RC allows achieving the sterility of the tooth cavity, which is very important in the development of chronic periodontitis. However, to achieve sterility during drug treatment, dentists face a new problem of how to avoid damage to periodontal tissues using an antiseptic agent with the apical foramen opened. The technical characteristics of endodontic needles available for use at this stage failed to effectively solve this problem. Thus, the multitude of issues substantiates the need to improve the design of endodontic needles.

AIM: To determine the optimal technical characteristics of endodontic root needles and to develop a new design of an endodontic needle that allows uniform irrigation of the RC delta with minimal probability of damaging the periapical tissues.

MATERIALS AND METHODS: In designing an endodontic needle with the required technical characteristics, parameters that influence the quality of cleaning the RC were analyzed in SolidWorks 16 program. Computer modeling of the biological tooth model was implemented in SolidWorks Flow Simulation program.

RESULTS: Computer modeling was used to improve the endodontic root needle. Technical results were achieved by incorporating in the design all the positive aspects of analogs and eliminating the disadvantages. The designed endodontic needle contained 1 hole on the tip and 168 holes arranged in a checker–wise manner on the lateral surface. All holes have the same diameter of 0.1 mm, which evens out the pressure, reduces the central flow rate to the rate of peripheral flows, ensures uniform irrigation, and minimizes the likelihood of damage to the alveolar process.

CONCLUSION: A new model of an endodontic needle with one hole on the tip and 168 holes arranged in a checker–wise manner on the lateral surface ensures uniform irrigation of the RC surface and the entire perimeter with minimal likelihood of damaging periapical tissues even with the maximal depth of insertion of the needle into the RC.

Keywords: *root canal; periapical tissues; endodontic needle; drug treatment*

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ECO•VECTOR

LIST OF ABBREVIATIONS

RC — root canal
ENDN — endodontic needles

INTRODUCTION

How to treat a root canal (RC), with what to treat it, and how to retreat it? These questions have not lost their significance to this day despite the development of novel equipment and materials and protocols for the treatment of the RC [1]. The main reason is the complex anatomy of RC and the histological peculiarities of tissues forming this organ. The effectiveness of the treatment of pulpitis and periodontitis directly depends on the sequence of actions when treating RC. In the first stage, the infected tissues are carefully removed from the RC lumen under an antiseptic bath, avoiding the pushing of the contents beyond the apex. The second stage is the mechanical removal of the infected tissue from the walls of RC using endodontic instruments. Here, a part of the material remains on the walls and in the lumen of RC. The next stage is cleaning the RC delta from chips, microorganisms, and smear layer [2–4].

For a long time, the most common way to deliver an antiseptic agent into the RC was using a narrow cotton swab on a hard basis (root needles). The swabs were inserted repeatedly, and the choice of an antiseptic depended on the diagnosis. Nowadays, another method to deliver the antiseptic has come into practice: the endodontic root needles. This introduces a significant amount of antiseptic in RC within a short period of time.

The range of endodontic needles (ENDN) on the market is diverse. Needles have different lengths, diameters, and designs and are made of different materials. The method and the instrument used for treating complicated caries will determine the result of treatment [1, 5].

This study aimed to determine the optimal technical characteristics of endodontic root needles and to design a novel ENDN structure that provides uniform irrigation of the RC delta with minimal probability of damaging the periapical tissues.

MATERIALS AND METHODS

The parameters influencing the quality of cleaning the RC were analyzed to design the ENDN according to the required technical characteristics using Solid Works 16 Program. A computer modeling of the biological model of the tooth and a novel needle was created using SolidWorks Flow Simulation Program.

RESULTS

The technical result was achieved through implementing all the positive aspects of analogs and eliminating disadvantages in the design. The ENDN structure has several holes: one at the tip of the needle and 168 holes arranged in a checkerwise pattern on the lateral surface of the needle. All holes have the same diameter of 0.1 mm, which equalizes the pressure and reduces the rate of the central flow to the rate of peripheral flows. This ensures uniform irrigation and minimizes the likelihood of damage to the alveolar process.

The principal structure of the developed ENDN model for the antiseptic treatment of the RC is demonstrated in Figures 1 and 2.

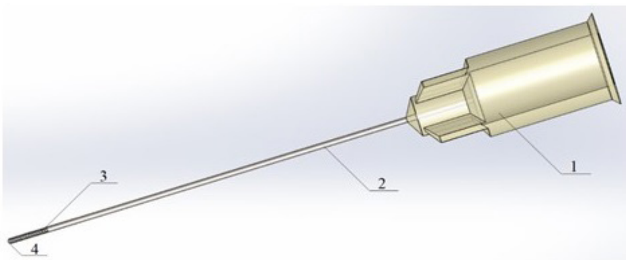

Fig. 1. Modernized endodontic needle: (1) cannula; (2) needle body; (3) side holes; (4) apical hole.

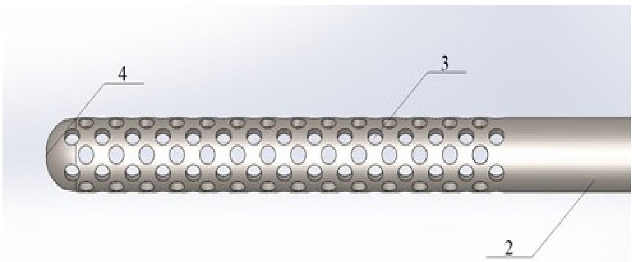

Fig. 2. 3D model of the needle with the precise location of holes: (3) side holes and (4) apical hole; front view.

The main function of ENDN is to deliver a certain volume of an antiseptic drug into RC for qualitative treatment without damaging the periodontium. Considering all possible parameters of antiseptic treatment of RC (the rate of introduction of the drug, the depth of insertion of the ENDN into RC, the amount of the drug, and the shape and volume of RC), we compared the results of a novel ENDN and the existing variants of root needles using a biological model of a tooth created in the SolidWorks Flow Simulation Program (Table 1). When an endodontic root needle is inserted to 1/3 of the length of RC, with a medium and maximum flow rate of 5 mm/s and 9 mm/s, the penetration depth of the solution beyond the apical opening of the tooth is 0 mm (high efficiency), but the irrigation density of the lower third of the RC is minimal.

Table 1. Results of comparing the effectiveness of known and modernized model of needle based on a biological model of tooth created using SolidWorks Flow Simulation Program

Parameters	Known model	Modernized model
Linear flow rate in the needle, mm/sec	7–8	6–7
Linear flow rate in the root canal, mm/sec	5–6	3–4
Irrigation angle (with all holes taken into account), °	45–60	360
Condition of periapical tissues	Damaged	Not damaged

When inserting an ENDN to 2/3 of the length of the RC with a medium and maximal flow rate of 5 and 9 mm/s, the depth of penetration of the solution beyond the apical opening of the tooth is 0 mm (high effectiveness), but the irrigation density of the lower third of the RC is medium. when inserting an ENDN into the RC 3 mm short of the physiological hole with a medium and maximal flow rate of 5 and 9 mm/s, the depth of penetration of the solution beyond the apical hole of tooth is 0 mm (high effectiveness), and the density of irrigation of the lower third of the RC is high. Table 1 shows the advantage of the developed ENDN.

DISCUSSION

The analysis of the literature showed that ENDN used for manual irrigation are classified into two groups: open and closed. In open ENDN, the tip ends with a hole, while closed ENDN are blindly closed, and the holes are located on the side surfaces. Open-type needles end with flat, beveled, or serrated apical end. Closed needles come in single-side, double-side, and multivented versions [5, 6].

Open needles, unlike closed ones, better irrigate the apical part of RC, but their use is associated with a rather high risk of the solution getting into the periapical tissues due to a strong increase in pressure, and blind needles have inverse properties. A beveled needle is the most dangerous because of the risk of injury and jamming. Besides, it has recently been proposed to improve the function of the multivented needles by creating a 0.03 mm high protrusion on their blind tip or a 0.04 mm deep dimple to control the flow. There are different opinions related to the effectiveness of the needles used: several authors found no significant differences in the effectiveness of single-side and double-side vented ENDN [6–8]. Others reported greater efficiency of single-side vented ENDN [7, 9–11].

A high-quality medical treatment of RC depends on many factors. Much attention is given to the depth of introduction of the needle. E. Uzunoglu–Özyürek et al. (2018), as most researchers, consider two levels of introduction: 1 mm and 3 mm short of the working length [12]. Analysis of their results shows that open needles can be introduced 3 mm short of the working length and the closed ones can be introduced 1 mm short of the working length to increase the efficiency of treatment of the apical third.

It is equally important to determine an adequate pressure to create an optimal flow rate when irrigating the walls of the RC and actively replace the volume of the antiseptic solution with a new volume, without damaging the periapical tissues [13, 14]. Excessively high pressure can lead to damage to periodontal tissues not only by an "air bubble" formed near the apical opening due to the surface tension of the solution, but also by the subsequent removal of the irrigant. Calculating the irrigation pressure is based on Pascal law, according to which the pressure equals the ratio of force to surface area. According to investigations by C. Boutsioukis, et al., the force applied by doctors to create the optimal pressure was determined by many factors: the gender of the doctor, the working experience, the type of canal, the material of the syringe, and the diameter of the needle and its type. Therefore, it is impossible to determine an exact universal value of the pressure created in the cylinder of the syringe. Most often, it is in the range of 400–550 kPa, and as a result, the flow rate of an irrigant is also different [5, 15]. A solution flow rate of more than 0.1 m/s was accepted as desirable for optimal tissue irrigation and replacement of the solution in the canal. The rate of flow coming out of the holes in the needles decreases 5–10 times, which affects the depth of replacement of the solution from the tip of the needle. The flow can mechanically clean the walls of a large area of RC due to the pressure from the holes or simply by filling the canal with an irrigant. The studies have shown a better degree of cleaning when the flow directly hit the canal walls under pressure compared with simple filling [6, 13, 16, 17].

Besides the flow rate, another factor that influences the depth of solution replacement is the direction of flow created in different types of ENDN. In the open needles, the flow is directed toward the apex of the root, and in closed ones, toward the walls. The lateral direction of the flow provides a good mechanical cleaning of the walls, and the apical direction provides better solution replacement at depth [6, 15]. As to the depth of solution replacement, the best parameters were demonstrated using flat, beveled, and serrated ENDN, delivering the "new" solution to the depth of 2.5 mm from the tip of the needle, while single-side vented and two-side vented needles reached a less depth up to 1.5 mm and multivented needle, up to 1 mm. Based on the previously mentioned data, it becomes clear that open needles well deliver the irrigant to the needed depth but have an increased risk of damage to periapical tissues. Therefore, to prevent damage, multivented needles should be used [6, 15].

C. Boutsioukis et al. noted in their study of ENDN that the pressure created using a flow of size 30 and taper 2% open needles in the apical third of the canal was on average about 400 kPa, while closed needles created a pressure of about 120 kPa [5,15]. These values confirm the danger of using open-type needles [5,15,16]. The manual irrigation provides sufficient treatment of the upper and middle part of RC, but insufficient for the apical third. This is because of the surface tension of the solution, which forms an air bubble.

Based on the results of the analysis of positive and negative aspects of ENDN, we proposed to computer-model ENDN while considering all parameters that influence the quality of cleaning the RC. The analysis helped design a root needle with the required technical characteristics [18–20].

CONCLUSION

A novel model of the ENDN with one apical hole and 168 holes arranged in checkerwise order on the side surface provides a uniform irrigation of the surface of the RC along the entire perimeter with a minimal probability of damaging the periapical tissues, even with the insertion of the needle to the maximal depth.

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Contribution of the authors: *A. V. Kuligin* — concept and design of the study, editing, *L. N. Kazakova* — collection and processing of the material, writing the text, editing, *O. S. Tereshchuk* — collection and processing of the material, writing the text, *V. V. Bokov* — collection and processing of the material, statistical processing. All authors made a substantial contribution to the conception of the work, acquisition, analysis, interpretation of data for the work, drafting and revising the work, final approval of the version to be published and agree to be accountable for all aspects of the work.

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