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COMPUTER MODELING AS THE MAIN STAGE OF ENDODONTIC ROOT NEEDLE REFINEMENT

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Abstract. The issue of high-quality root canal treatment in deciduous and permanent teeth is currently highly relevant. There is a huge variety of tools, devices, and medicines that can be used for working with the root canals. It is often the case that in the dental market medical products of various quality characteristics are being offered for a certain manipulation, leaving consumers face to face with a tough choice of what to buy to obtain good results. According to the English-language literature review, evaluation of the technical characteristics of endodontic needles and the results of their use in practice showed a rather large number of negative aspects, which outlines the need to find the ways of endodontic needle refinement. ***Aim.*** This study aims to determine the optimal technical characteristics of endodontic root needles and to develop a new design of the endodontic needle to be applied for the uniform irrigation of the root canal delta with a minimum probability of damaging periapical tissues. ***Material and methods.*** *Solid Works* software package was selected as the primary working tool because it allows to build a 3D model of biological and technical models and offers the possibility to choose the material from the existing library or to create one's own material. For the accuracy and clarity of the calculations, a biological model of the tooth and two needle models (a prototype and a modernized design) were built. ***Results and discussion.*** The result of the study is a new model of the endodontic root needle, which assures uniform irrigation of the entire surface of the root canal with minimal probability of damage to periodontal tissues. The technical solution was achieved by imparting to the design all the advantages of the analogues whilst eliminating their disadvantages. ***Conclusion***. The technical solution proposed in our work is the new model of the endodontic needle, which enables uniform irrigation along the entire perimeter of the root canal surface and minimizes the likelihood of damaging periapical tissues even when the needle is inserted into the root canal at a maximum depth.
Key words: root canal, periapical tissues, endodontic needle, drug treatment.
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КОМПЬЮТЕРНОЕ МОДЕЛИРОВАНИЕ – ОСНОВНОЙ ЭТАП УСОВЕРШЕНСТВОВАНИЯ ЭНДОДОНТИЧЕСКИХ КОРНЕВЫХ ИГЛ

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Реферат. До сегодняшнего дня остается актуальным вопрос качественной обработки корневых каналов в молочных и постоянных зубах. Для работы в корневых каналах предлагается огромный выбор различных инструментов, аппаратов, медикаментов. Часто на стоматологическом рынке для проведения одной и той же манипуляции предлагаются различные по качественным характеристикам изделия медицинского назначения, и потребители стоят перед выбором, что приобрести для получения хорошего результата. Оценка технических характеристик эндодонтических игл и результатов их использования в практике при анализе англоязычной литературы показала достаточно большое количество отрицательных сторон, что определяет необходимость поиска пути усовершенствования эндодонтической иглы. ***Цель исследования*** – определить оптимальные технические характеристики эндодонтических корневых игл и разработать новую конструкцию эндодонтической иглы, обеспечивающей равномерное орошение дельты корневого канала с минимальной вероятностью повреждения периапикальных тканей. ***Материал и методы.*** Программный пакет *Solid Works* был выбран в качестве основного рабочего инструмента, поскольку он позволяет построить трехмерную модель биологических и технических моделей и дает возможность выбрать материал из существующей библиотеки или создать собственный материал. Для точности и наглядности расчетов были построены биологическая модель зуба и две модели иглы (прототип и модернизированная конструкция). ***Результаты и их обсуждение.*** Результатом исследования стала новая модель эндодонтической корневой иглы, обеспечивающей равномерное орошение всей поверхности корневого канала с минимальной вероятностью повреждения тканей пародонта. Техническое решение достигнуто за счет передачи конструкции всех достоинств аналогов при устранении их недостатков. ***Выводы.*** Техническим результатом нашей работы стала новая модель эндодонтической иглы, которая обеспечивает равномерное орошение по всему периметру поверхности корневого канала с минимизацией вероятности повреждения периапикальных тканей даже при максимальной глубине введения иглы в корневой канал.
Ключевые слова: корневой канал, периапикальные ткани, эндодонтическая игла, медикаментозная обработка.
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Introduction. The questions of how to treat, with what to treat, and how to re-treat root canals have not lost their relevance to this day, despite the creation of modern equipment, new materials, and existence of written protocols for root canal treatment [1].

The main reason for this is the complex anatomy of the root canals, the morphological and histological features of the tissues which form this organ – all this creates a number of difficulties inthe endodontic treatment. The effectiveness of the treatment of pulpitis and periodontitis is directly dependent on the sequence of actions during the root canal treatment.

The first step is to carefully remove all infected tissue from the root canal lumen under the antiseptic bath, avoiding,if possible, pushing the contents behind the apex. The second step is to mechanically remove the infected tissue from the walls of the root canal using endodontic instruments, upon the removal of which part of the chip remains on the root canal walls and lumen. The next stage is the drug treatment, with which the root canal delta is cleaned of chips, microorganisms, and the smeared layer [1–4].

For a long time, the most common way of delivering an antiseptic to the root canal during drug treatment was to use a narrow gauze swab on a rigid base – the root needles. Gauze swabs were administered repeatedly and the choice of antiseptic depended on the diagnosis. Nowadays, another method for the delivery of antiseptics has gained popularity:delivery via the endodontic root needles. It allows introducing a significant amount of antiseptic into the root canal in a short period of time. The range of needles available on the market is diverse, each needle has its own parameters, they differ in length, diameter, appearance, and the material of which they are made. Knowledge of the methodology and acorrectly justified choice of the instrument for the treatment of complicated caries affect the treatment's outcome [1, 5].

The relevance of research. The literature review showed that there are two groups of endodontic needles for manual irrigation: open-ended and closed-ended needles. In the first group – the tip of the needle ends with a hole, in the second group – it is blindly closed, with the needle opening on the sides. Open-ended endodontic needles can end with a flat, beveled, or notched apical end, while closed-ended endodontic needles can be side-vented, double side-vented and multi-vented [5, 6]. *Figure 1* shows the different needles designs and their models used in the study by Boutsioukis (2010) evaluating irrigant flow in the root canal [6].

Open-ended needles, unlike closed-ended ones, better wash the apical part of the root canal, but their use leads to a rather high risk of injection of the solution into the periapical tissues due to a strong increase in pressure, whereas the blind needles have inversely proportional properties. A beveled needle is the most dangerous of its type because of the risk of injury and jamming [7]. Later on, it was proposed to improve multi-vented needles by creating a protrusion of 0,03 mm height or a 0,04 mm deep dimple on their blind tip to control the flow [8]. There are different opinions on the effectiveness of the needles used: Boutsioukis et al. in their studies on irrigation did not find any differences in

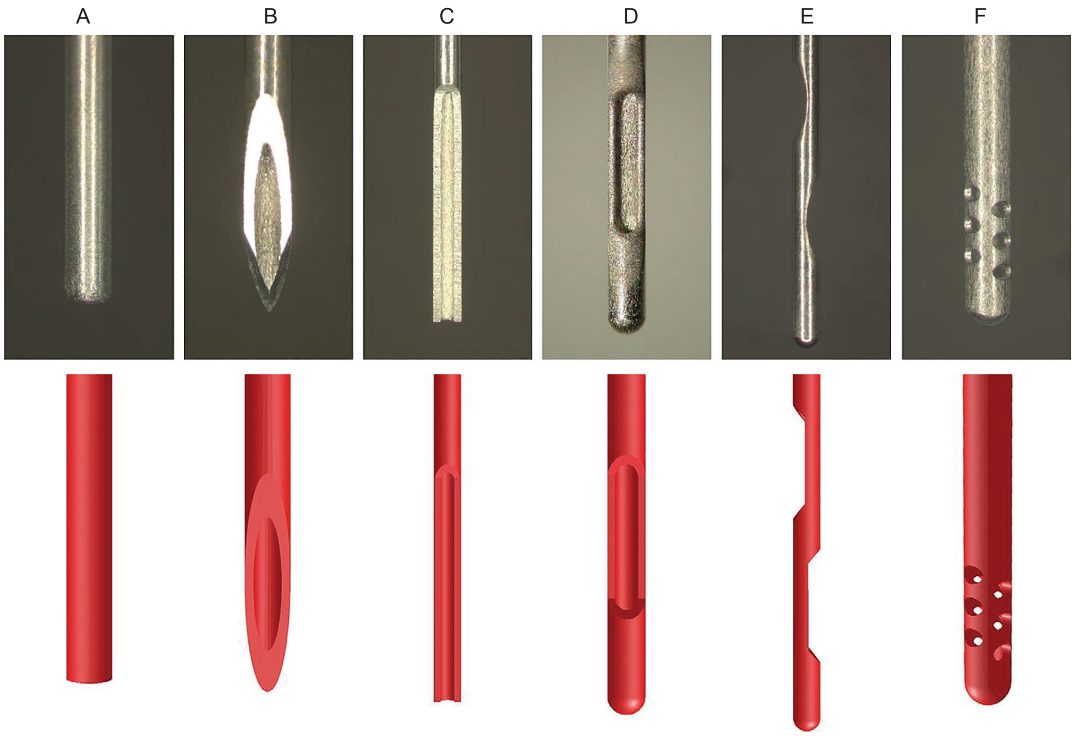

Figure 1. Different needle designs for root canal irrigation: A – flat; B – beveled; C – notched; D – side-vented; E – double side-vented; F – multi-vented

the effectiveness of side-vented and double side-vented needles [9].

Khan et al., studying comparatively the operation of needles in the root canals, reported that side-vented needles were more effective than ordinary ones [7, 10, 11]. High-quality drug treatment of the root canal depends on many factors, with a lot of attention paid by the researchers to the depth of insertion of the endodontic needle. Emel Uzunoglu-Özyürek, like most researchers, considered 2 levels of insertion: 1 mm less than the working length and 3 mm [7, 12]. An analysis of their results shows that open-ended needles can be inserted by 3 mm less than the working length, while closed-ended ones – by 1 mm less than the working length to increase the efficiency of treating the apical third.

Of equal importance is the determination of the adequate pressure for the creation of the optimal flow rate during irrigation of the root canal walls and for the active replacement of the antiseptic solution volume with a new volume, without damaging the periapical tissues [13]. Excessively high pressure can lead to the damage of periodontal tissues not only by the «air bubble», formed near the apical foramen due to the surface tension of the solution, but also by the subsequent removal of the irrigant itself. The root canal irrigation is based on Pascal's law, according to which the pressure equals the force divided by the surface area; the value is not scalar. According to Boutsioukis research, many factors influence the force exerted by doctors for creating optimal pressure, including: the gender of the doctor, work experience, type of canal, material from which the syringe is made, diameter of the needle, needle type. Therefore, one cannot speak of any exact universal value of pressure created in the cylinder of the syringe. Most often, it is considered to be in the range of 400–550 kPa. As a result, the irrigant flow rate is also different [5]. A solution flow rate of >0,1 m/s was taken as desired for the optimal tissue irrigation and solution exchange in the canal. The rate of the flow coming out of the holes in the needles decreases 5–10 times, which affects the depth of the solution exchange from the tip of the needle. The flow itself can mechanically clean the walls of the root canals of a large area under the pressure from the perforations of the needles or simply from the filling of the canal with the irrigant. Studies have shown a higher degree of cleaning from a direct hit of the flow onto the canal walls under pressure than from a simple filling [13, 14].

In addition to the speed, the direction of flow created by using endodontic needles of various groups also affects the depth of exchange. For open-ended needles, the flow is directed towards the apex of the root, and for closed-ended ones – towards the side of the walls. The lateral flow direction allows a well mechanical cleaning of the walls, while the apical direction provides for a better exchange of the solution at a depth [10, 12]. In terms of the depth of exchange, flat, beveled, and notched endodontic needles showed the best performance, delivering a «new» solution to a depth of 2,5 mm from the tip of the needle, while side-vented and double side-vented needles showed a worse result – up to 1,5 mm, and multi-vented needle – up to 1 mm. Based on these data, it becomes clear that open-ended needles deliver the irrigant well to the depth, but increase the risk of damage to periapical tissues. Therefore, in order to prevent damage, it is better to use a multi-vented needle [10, 12].

In their study, Boutsioukis noted that the pressure created by the flow of open-ended needles in the apical third of the canal of size 30 and 2% taper was on average about 400 kPa, while of closed-ended needles – about 120 kPa. These values confirm the danger of using open type needles [5, 6, 14].

O'Connel noted that manual irrigation leads to satisfactory irrigation of the upper and middle parts of the root canal, but not enough of the apical third. This is due to the surface tension of the solution, which allows for the formation of an «air bubble» [6, 14].

The detailed analysis of different types of irrigation needles reveals their significant disadvantages, which seriously affect the irrigation exchange in various parts of root canals. Even if all requirements on injection depth and piston pressure are observed it is not possible to control the rate of antiseptic flow in the root canal and, therefore, to guarantee an effective and safe method of solutions' delivery.

Research Goal. This study aims to determine the optimal technical characteristics of endodontic root needles and to develop a new design of the endodontic needle which will provide for the uniform irrigation of the root canal delta with a minimum probability of damaging periapical tissues.

Data and Methods. *Solid Works* software package was selected as the main working tool because it allows to build a 3D model of biological and technical models and offers the possibility to choose the material from the existing library or to create one's own material.

For the accuracy and clarity of the calculations, a biological model of the tooth and two needle models (a prototype and a modernized design) were built. The analysis of the effectiveness of irrigation of the root delta of the tooth and the likelihood of damage to the periapical tissues was carried out in the *Solid Works Flow Simulation* software supplement package.

Results and Discussion. The result of the study is a new model of the endodontic root needle, which provides uniform irrigation of the entire surface of the root canal, with minimal probability of damage to periodontal tissues [15].

The technical solution was achieved by imparting to the design all the advantages of the analogues, whilst eliminating their disadvantages. The design of the endodontic needle contains holes: 1 hole on the tip of the needle and 168 holes staggered on the side surface of the needle. All holes have the same diameter of 0,1 mm, which helps equalize the pressure and reduce the speed of the central stream to the speed of the peripheral flows. This ensures uniform irrigation and minimizes the likelihood of damage to the alveolar bone.

The 3D model of the newly developed endodontic needle model is illustrated on *Figure 2*. The main function of the endodontic root needle is to deliver an antiseptic to the root canal in a certain volume and to process it well without damaging the periodontal tissue. Considering all the possible parameters during the antiseptic treatment – the rate of insertion, the depth of insertion of the endodontic needle into the root canal, the volume of the antiseptic, the shape and volume of the root canal, – we analyzed the results of modeling of the biological tooth model with a new needle. The obtained results are shown on *Figure 2* and in *Table.*

The calculations were carried out at the insertion of the needle at 1/3, 2/3 and 3/3 of the depth of the root canal, with a pressure on the liquid of 50 Pa. To compare the results, identical calculations were carried out with the well-known model with the introduction of a needle 1/3 of the length of the root canal.

Figure 3 presents the results of the analysis of the effectiveness of root canal irrigation using various needle models and their positions.

In *Figure 3*, the displayed models show the following: a) a study of dentin irrigation using a known needle model; b) an enlarged image of the apex in the study of dentin irrigation; c) a study of irrigation of dentin using the newly developed needle immersed by 1/3; d) an enlarged image of the apex in the study of dentin irrigation; e) a study of irrigation of dentin using the newly developed needle immersed by 2/3; f) an enlarged image of the apex in the study of dentin irrigation; g) research of dentin irrigation using the newly developed needle immersed by 3/3; h) an enlarged image of the apex in the study of dentin irrigation.

The generalized results of the study are given in *Table.*

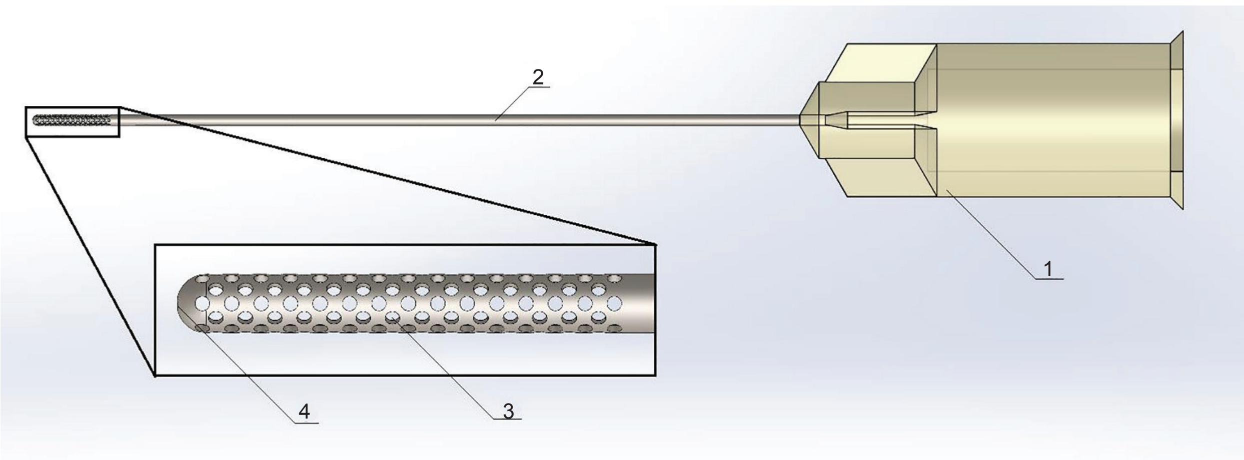

Figure 2. Modernized endodontic needle: 1 – cannula; 2 – the body of the needle; 3 – side holes; 4 – hole on the tip

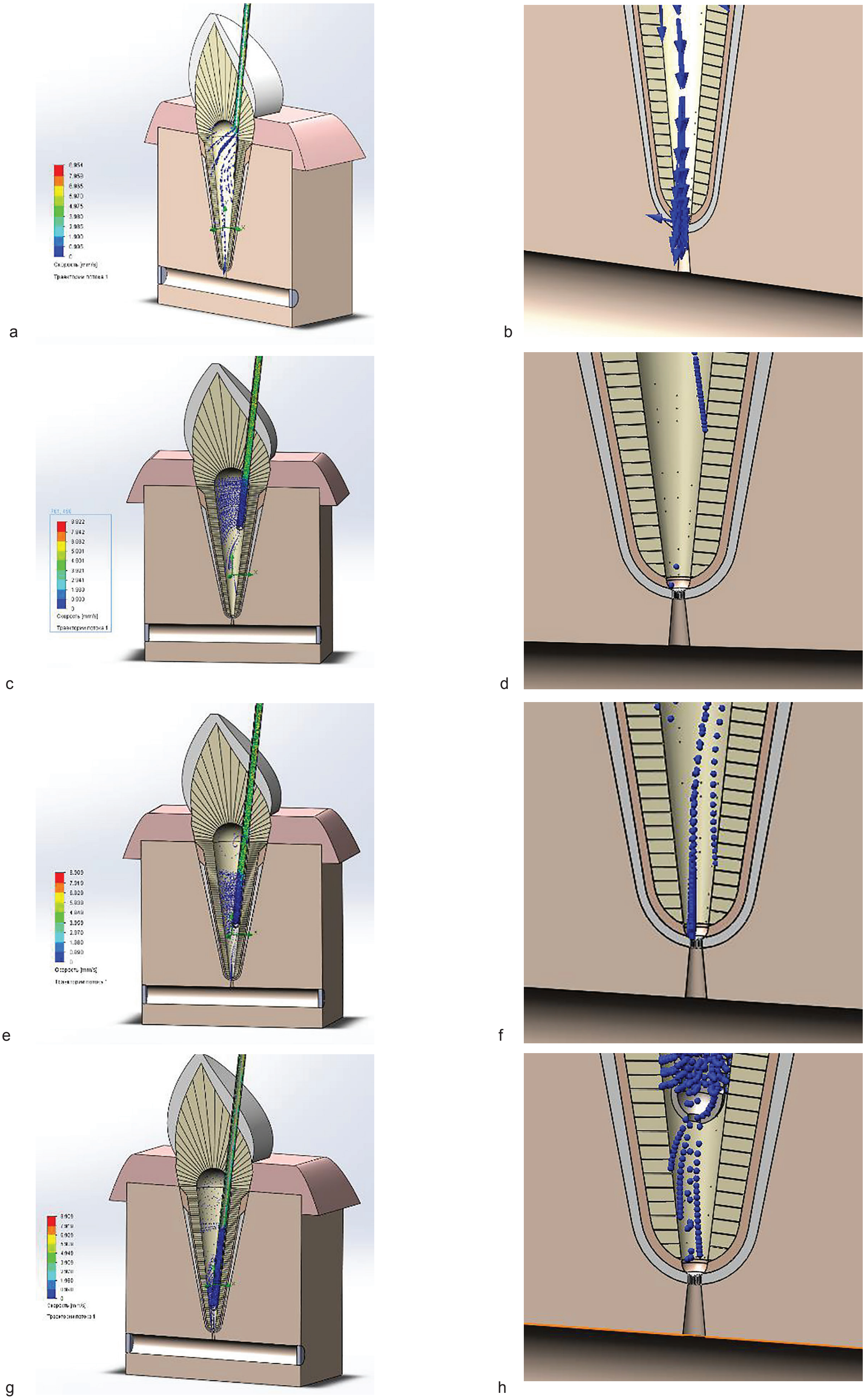

Figure 3. Comparison of the hydrodynamic characteristics of a known and a modernized needle design

The results of the analysis of effectiveness of the well-known and the modernized needle models

Parameter	Well-known model	Modernized model	Unit of analysis
Linear flow rate in the needle	7–8	6–7	mm/s
Linear flow rate in the root canal	5–6	3–4	mm/s
Irrigation angle of the irrigant (including all needle openings)	45–60	360	degrees
Condition of periapical tissues	Damaged	Not damaged	–

Analysis of the data in Table demonstrates the benefits of the newly developed design of endodontic needle.

Conclusion. The technical solution as a result of our work is a new model of the endodontic needle, which provides uniform irrigation along the entire perimeter of the surface of the root canal while minimizing the likelihood of damage to periapical tissues even with a maximum depth of insertion of the needle into the root canal.

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Declaration of financial or other relationships. *All authors participated in the conception and design of the study and in the writing of the manuscript. The final version of the manuscript was approved by all the authors. The authors did not receive a fee for the study.*

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