Original Research

https://doi.org/10.36377/ET-0106

Morphological evaluation of the fibrin framework in the treatment of dental pulp hyperemia: experimental study

Ksenia D. Kirsh ✉, Ekaterina S. Zaporozhskaya-Abramova, Anatoly A. Adamchik, Victoria A. Ivashchenko, Valerii V. Tairov, Umukusum A. Dotdaeva, Vladislav M. Starchenko

Kuban State Medical University, Krasnodar, Russian Federation

✉ kdkirsh@mail.ru

Abstract

INTRODUCTION. The complexity of the prognosis in the early and late stages of the conservative method of pulpitis treatment has limited its wide application. The article is aimed at studying and analyzing the potential of regenerative dentistry, which consists in restoring the function and structure of the dental pulp using innovative technologies. It is considered how biomaterials, fibrin framework (PRF) can be used to achieve this goal based on an experimental study and morphological assessment of the effect of these materials on the dental pulp. Platelet-rich fibrin (PRF) is a concentrate of platelets, which in recent years has become increasingly popular for regenerative procedures. An analysis of the materials used with appropriate conclusions is carried out.

AIM. To conduct a comparative morphological assessment of the use of modern bioactive materials and fibrin (PRF) as a scaffold in the treatment of pulp hyperemia.

MATERIALS AND METHODS**.** The experimental part of the study was performed on 8 white laboratory rats of 64 molars of teeth, Wistar lineage, of both sexes, with a body weight of 350–600 g, quarantined for at least 10–14 days, and kept in standard vivarium conditions of the Federal State Budgetary Educational Institution of Higher Medical Education of the Ministry of Health of the Russian Federation. The animals were divided into 4 groups – 2 individuals and 16 teeth in each group. Group 1 animals used fibrin (PRF) + "Trioxident" "Vladmiva", Group 2 collagen membrane Geistlich Bio-Gide® + "Biodentine", Group 3 fibrin (PRF) + "Biodentine" "Septodont", Group 4 "Dycal" "Dentsply". The experiment was conducted under anesthesia (protocol of the Ethics Committee of the Federal State Budgetary Educational Institution of Higher Education of the Ministry of Health of the Russian Federation No. 125 dated 09/12/2023). On the chewing surfaces of the 1st and 2nd molars, diamond carbide spherical borons were used to open the tooth cavity with partial pulp exposure. The formed cavity was treated with 0.05% chlorhexidine solution and dried. The test materials were then applied to the autopsy area. Experimental animals were removed from the experiment on days 3, 14, and 30. The resulting biological material was fixed in a 10% neutral formalin solution, decalcified, then poured into a histological medium and stained with hematoxylin and eosin according to Van Gieson. The sections were obtained on an Accu-Cut SRM 200 rotary microtome.

RESULTS. In the course of an experimental study in group 1 using fibrin (PRF) + Trioxidant in the area of contact with the therapeutic material, activation of reactive and compensatory processes in the tooth pulp tissue was detected while maintaining its viability for 30 days, which indicated the most pronounced regenerative potential among all the studied groups. As a result of a morphological assessment of micro-preparations of pulp with direct coating with "Dycal" material, group 4 showed that on the 30th day the pathological process developed in the pulp is irreversible, because morphological changes were most pronounced: inflammatory infiltration with the presence of lymphocytes and neutrophils in the infiltrate, sclerotic changes, as well as granulation tissue and necrosis focus in the area of contact with the therapeutic material were noted.

CONCLUSIONS. The results of an experimental study conducted to compare histological changes in the pulp state with the use of various groups of materials in the near and long-term follow-up periods showed that the combined use of bioactive materials and fibrin (PRF) for direct coating of pulp increases the effectiveness of dental treatment with diagnoses of pulp hyperemia, and is also a promising direction in regenerative dentistry, due to the high the potential to influence the stimulation of reparative processes in the tooth pulp.

Keywords: dental pulp, fibrin skeleton, pulp hyperemia, regenerative dentistry

Article info: received – 30.04.2025; revised – 13.06.2025; accepted – 18.06.2025

Conflict of interest: The authors report no conflict of interest.

Acknowledgements: There are no funding and individual acknowledgments to declare.

For citation: Kirsh K.D., Zaporozhskaya-Abramova E.S., Adamchik A.A., Ivashchenko V.A., Tairov V.V., Dotdaeva U.A., Starchenko V.M. Morphological evaluation of the fibrin framework in the treatment of dental pulp hyperemia: experimental study. *Endodontics Today.* 2025;23(3):357–365. https://doi.org/10.36377/ET-0106

Морфологическая оценка фибринового каркаса при лечении гиперемии пульпы зуба: экспериментальное исследование

К.Д. Кирш ✉, Е.С. Запорожская-Абрамова, А.А. Адамчик, В.А. Иващенко, В.В. Таиров, У.А. Дотдаева, В.М. Статченко

Кубанский государственный медицинский университет, г. Краснодар, Российская Федерация

✉ kdkirsh@mail.ru

Резюме

ВВЕДЕНИЕ. Сложность прогноза в ранние и отдаленные сроки консервативного метода лечения пульпита ограничил его широкое применение. Статья направлена на изучение и анализ потенциала регенеративной стоматологии, который заключается в восстановлении функции и структуры пульпы зуба с помощью инновационных технологий. Рассмотрено, как биоматериалы, фибриновый каркас (PRF) могут быть использованы для достижения этой цели на основании экспериментального исследования и морфологической оценки влияния данных материалов на пульпу зуба. Богатый тромбоцитами фибрин (PRF) представляет собой концентрат тромбоцитов, который в последние годы становится все более популярным для регенеративных процедур. Проведен анализ используемых материалов с соответствующими выводами.

ЦЕЛЬ**.** Провести сравнительную морфологическую оценку применения современных биоактивных материалов и фибрина (PRF) в качестве каркаса при лечении гиперемии пульпы.

МАТЕРИАЛЫ И МЕТОДЫ**.** Экспериментальная часть исследования выполнена на 8 белых лабораторных крысах 64 моляров зубов, линии Вистар, обоего пола, с массой тела от 350–600 г., прошедших карантин не менее 10–14 дней, находящихся в стандартных условиях вивария ФГБОУ ВО КубГМУ Минздрава России. Животных разделили на четыре группы – по 2 особи и 16 зубов в каждой группе. У животных 1-й группы применялись – фибрин (PRF) + «Триоксидент» «Владмива», 2-й группы – коллагеновая мембрана Geistlich Bio-Gide® + «Biodentine», 3-й группы – фибрин (PRF) + «Biodentine» «Septodont», 4-й группы – «Dycal» «Dentsply». Эксперимент проводился под наркозом (протокол этического комитета ФГБОУ ВО КубГМУ Минздрава России №125 от 12.09.2023 г.). На жевательных поверхностях 1 и 2 моляров алмазным твердосплавными шаровидным борами производили вскрытие полости зуба с частичным обнажением пульпы. Сформированную полость обрабатывали 0,05% раствором хлоргексидина, высушивали. Затем на область вскрытия наносили исследуемые материалы. Экспериментальных животных выводили из эксперимента на 3, 14 и 30-е сутки. Полученный биологический материал фиксировали в 10% нейтральном растворе формалина, подвергали декальцинированию, затем заливали в гистологическую среду и окрашивали гематоксилином и эозином по Ван-Гизону. Срезы получали на ротационном микротоме Accu-Cut SRM 200.

РЕЗУЛЬТАТЫ. В ходе экспериментального исследования в 1-й группе при использовании фибрин (PRF) + «Триоксидент» в зоне контакта с лечебным материалом была обнаружена активизация реактивных и компенсаторных процессов в ткани пульпы зуба с сохранением ее жизнеспособности на 30 сутки, что свидетельствовало о наиболее выраженном регенеративном потенциале среди всех исследуемых групп. В результате морфологической оценки микропрепаратов пульпы при прямом покрытии материалом «Dycal» 4-й группе, показал, что на 30 сутки развившийся в пульпе патологический процесс носит необратимый характер, так как морфологические изменения были наиболее выражены: отмечалась воспалительная инфильтрация с наличием в инфильтрате лимфоцитов и нейтрофилов, склеротические изменения, а так же определялась грануляционная ткань и очаг некроза, в зоне контакта с лечебным материалом.

ВЫВОДЫ. Результаты проведенного экспериментального исследования с целью сравнительного анализа гистологических изменений состояния пульпы в зоне применения различных групп материалов в ближайшие и отдаленные сроки наблюдения показали, что сочетанное применение биоактивных материалов и фибрина (PRF) для прямого покрытия пульпы повышают эффективность лечения зубов с диагнозам гиперемия пульпы, а так же являются перспективным направлением в регенеративной стоматологии, в связи с высоким потенциалом влияния на стимуляцию репаративных процессов в пульпе зуба.

Ключевые слова: пульпа зуба, фибриновый каркас, гиперемия пульпы, регенеративная стоматология

Информация о статье: поступила – 30.04.2025; исправлена – 13.06.2025; принята – 18.06.2025

Конфликт интересов: авторы сообщают об отсутствии конфликта интересов.

Благодарности: финансирование и индивидуальные благодарности для декларирования отсутствуют.

Для цитирования: Кирш К.Д., Запорожская-Абрамова Е.С., Адамчик А.А., Иващенко В.А., Таиров В.В., Дотдаева У.А., Статченко В.М. Морфологическая оценка фибринового каркаса при лечении гиперемии пульпы зуба: экспериментальное исследование. *Эндодонтия Today.* 2025;23(3):357–365. https://doi.org/10.36377/ET-0106

INTRODUCTION

Despite the introduction and widespread use of modern preventive and therapeutic strategies aimed at the prevention and management of pulp hyperemia, this dental condition remains one of the most prevalent pathologies worldwide [1]. The primary treatment approach for early (reversible) forms of pulpitis typically involves endodontic procedures accompanied by complete pulp removal. However, such interventions often have an adverse impact on the physiological properties of the tooth, including disruption of its protective, trophic, and reparative functions, which ultimately compromises the tooth's viability, increases the risk of complications in periapical tissues, and may result in tooth loss [1; 2]. For this reason, biological approaches to pulpitis management – based on the regenerative capacity of the dental pulp – are increasingly regarded as promising alternatives [3]. Currently, the main conservative method for treating pulp hyperemia involves the use of "therapeutic" liners and bioactive materials [4; 5].

The advancement of regenerative dentistry and the development of modern bioactive materials have necessitated the exploration of novel treatment modalities for pulp inflammation. In most published studies, regenerative procedures involve the application of autologous platelet-rich fibrin (PRF), which can be readily prepared in dental settings with minimal ex vivo manipulation. PRF is rich in growth factors – including transforming growth factor-beta (TGF-β), tumor necrosis factor (TNF), insulin-like growth factors, and angiogenic growth factors–that stimulate collagen synthesis, angiogenesis, and cellular differentiation. Moreover, PRF does not undergo rapid degradation and forms a stable three-dimensional fibrin matrix [6–9]. Its 3D architecture retains bioactive molecules that support stem cell proliferation and differentiation, thus enhancing wound healing. Consequently, the clinical application of PRF is increasingly viewed as a promising direction in regenerative dentistry [10; 11].

Another material used in regenerative dentistry is the collagen membrane *Geistlich Bio-Gide®*. This resorbable bilayer membrane is designed for guided bone regeneration and is composed of highly purified type I and III collagen. Among its advantages are active hemostasis and chemotaxis of fibroblasts. Its unique structure ensures excellent biocompatibility and minimizes the risk of inflammatory responses. Furthermore, its ability to be combined with various therapeutic fillers makes its use particularly attractive and promising in dental practice.

A comparative analysis of the literature on materials and methods for treating pulp hyperemia – aimed at preserving pulp vitality – highlights the need for developing precise diagnostic criteria to better understand the morphological changes in the pulp. It also underscores the importance of continued research into novel treatment modalities and their rational implementation in clinical practice.

AIM

To conduct a comparative morphological evaluation of the application of modern bioactive materials and platelet-rich fibrin (PRF) as a scaffold in the treatment of pulp hyperemia.

MATERIALS AND METHODS

The experimental part of the study was conducted on 8 Wistar-line white laboratory rats (both sexes), weighing between 350–600 g. All animals underwent a quarantine period of no less than 10–14 days and were housed under standard vivarium conditions at the Federal State Budgetary Educational Institution of Higher Education "Kuban State Medical University" of the Ministry of Health of Russia. A total of 64 molars were examined. The animals were randomly divided into four groups, each comprising 2 rats and 16 molars.

Group 1: Platelet-rich fibrin (PRF) + "TrioxyDent" (VladMiVa).

Group 2: Collagen membrane *Geistlich Bio-Gide®* + "Biodentine".

Group 3: Platelet-rich fibrin (PRF) + "Biodentine" (Septodont).

Group 4: «Dycal» (Dentsply).

All surgical procedures were performed under general anesthesia using "Zoletil" at a dose of 20 mg/kg, a veterinary-approved anesthetic. After induction, the animals were fixed on a custom surgical table. Upon completion of the experiment, euthanasia was performed in accordance with Directive 2010/63/EU of the European Parliament and of the Council on the protection of animals used for scientific purposes. Tissue sampling for histological analysis was carried out following intravenous or intracardiac administration of sodium pentobarbital (Nembutal) at a dose of 200 mg/kg using an 18% (200 mg/mL) solution.

The experiment was conducted under acute surgical conditions and was approved by the Ethics Committee of Kuban State Medical University (protocol No. 125 dated September 12, 2023).

Due to the naturally rapid coagulation of rat blood, all materials were prepared in advance, and the centrifuge was pre-configured. The centrifuge used (CM-6M, ELMI, Latvia; rotor 6M, 12 × 15 mL) was set at 2300 rpm (400 g) for 8 minutes, in accordance with the established protocol. To maintain balance, three Vacutainer tubes filled with sterile saline were used as counterweights during PRF preparation. Blood for PRF was collected via cardiac puncture, a method chosen to obtain a sufficient volume for fibrin production. Before application, the *Geistlich Bio-Gide®* collagen membranes were pre-soaked in sterile saline.

On the occlusal surfaces of the first and second molars, cavities were prepared using high-speed diamond-tungsten carbide burs (200,000 rpm) under physiological saline cooling to expose the coronal pulp surface. The cavities were disinfected with 0.05% chlorhexidine solution and gently dried with sterile cotton pellets. The following materials were then applied:

– PRF + «TrioxyDent» (VladMiVa);

– *Geistlich Bio-Gide®* membrane + "Biodentine";

– PRF + «Biodentine» (Septodont);
– «Dycal» (Dentsply).

All cavities were subsequently sealed with temporary filling material.

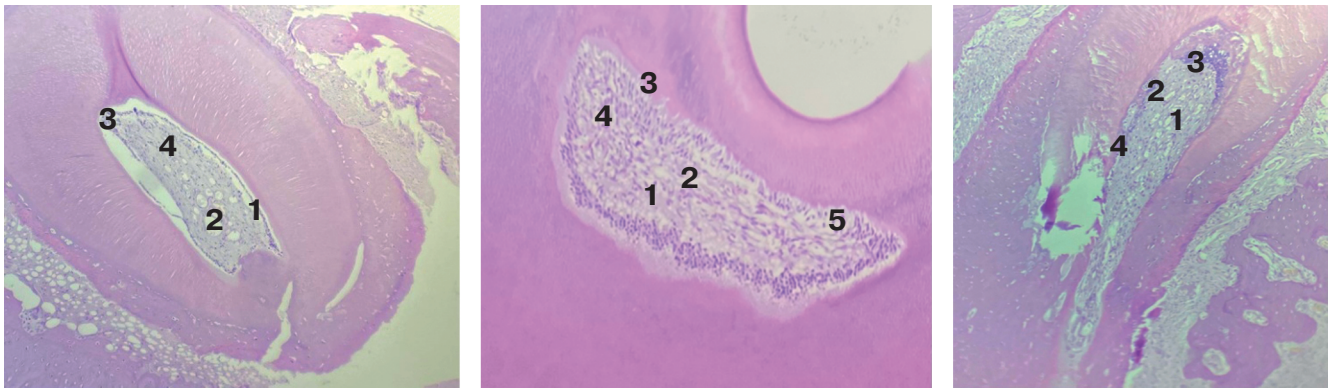
The animals were euthanized at 3-, 14- and 30-days post-procedure. Harvested tissues were fixed in 10% neutral buffered formalin, then decalcified in a 10% Trilon B solution for three days. Specimens were embedded in Histomix paraffin using a TISSUE-tek TEC5 embedding station. Serial sections (5–15 μm thick) were prepared using a rotary microtome (Accu-Cut SRM 200). The histological slides were stained with hematoxylin and eosin, and van Gieson's stain, and examined under a Nikon Eclipse 80i microscope.

RESUTLS AND DISCUSSION

Histological examination of specimens from Group 1 (PRF + TrioxyDent, VladMiVa) on Day 3 revealed the presence of a delicate loose fibrous matrix in the area of material contact. Moderate interstitial edema and dilated blood vessels were observed, accompanied by mild disorganization of the odontoblastic layer and a minimal lymphocytic inflammatory infiltrate. These findings indicate a low-grade pulpal inflammatory response at Day 3 in the group treated with PRF + TrioxyDent (Fig. 1, *A*).

Histological analysis of Group 1 specimens (PRF + TrioxyDent) on Day 14 revealed that, in the area of contact with the applied material, the pulp tissue was composed of loose fibrous connective tissue. There was evidence of granulation tissue formation, a mild inflammatory infiltrate, and initial formation of a dentin bridge. Additionally, irregular alignment of odontoblasts was observed, suggesting only minor inflammatory changes. These findings indicate the early onset of regenerative processes, as demonstrated by granulation tissue development and dentin bridge formation (Fig. 1, *B*).

On Day 30, histological examination of Group 1 revealed a well-defined presence of granulation tissue, pronounced reparative dentinogenesis with formation of dentin bridges and focal areas of dentinogenesis, and a clearly organized layer of odontoblasts aligned along the walls of the root canal (Fig. 1, *C*). These features signify marked regenerative processes. By Day 30, an activation of reactive and reparative processes was noted in the dental pulp tissue, alongside preservation of pulp vitality under the influence of PRF + TrioxyDent. These regenerative signs were characterized by increased metabolic activity and enhanced cellular responses within the pulp tissue, including noticeable activation of pulp defense mechanisms aimed at resolving inflammation and restoring functional integrity. Evidence of this includes an active fibroblastic response and replacement of inflammatory foci with granulation tissue, serving as a scaffold for subsequent substitution by mature connective tissue.



A **B** **C**

Fig. 1. Root pulp of a rat tooth treated with platelet-rich fibrin (PRF) + TrioxyDent (hematoxylin and eosin staining, ×100 magnification): *A* – on the 3rd day from the start of the experiment: *1* – edema, *2* – dilated vessels, *3* – weak disorganization of the odontoblast layer, *4* – a delicate loose fibrous matrix and a minimally pronounced inflammatory infiltrate; *B* – on the 14th day after the start of the experiment: *1* – loose fibrous connective tissue, *2* – granulation tissue, *3* – formation of a dentinal bridge, *4* – mild inflammatory infiltrate, *5* – disorganization of the odontoblast layer; *C* – on the 30th day from the start of the experiment: *1* – granulation tissue, *2* – formation of dentinal bridges, *3* – formation of foci of dentinogenesis, *4* – the presence of a layer of odontoblasts along the walls of the root canal

Рис. 1. Корневая пульпа зуба крысы в условиях применения препарата фибрин (PRF) + «Триоксидент» (окраска гематоксилин-эозином, ув. 100х): *A* – на 3-и сутки от начала эксперимента: *1* – отек, *2* – расширенные сосуды, *3* – слабая дезорганизация слоя одонтобластов, *4* – «нежный» рыхлого волокнистый матрикс и минимально выраженный воспалительный инфильтрат; *B* – на 14-е сутки от начала эксперимента: *1* – рыхлая волокнистая соединительная ткань, *2* – грануляционная ткань, *3* – формирование дентинного мостика, *4* – слабовыраженный воспалительный инфильтрат, *5* – дезорганизация слоя одонтобластов; *C* – на 30-е сутки от начала эксперимента: *1* – грануляционная ткань, *2* – образование дентинных мостиков, *3* – образование очагов дентиногенеза, *4* – наличие слоя одонтобластов вдоль стенок корневого канала

Histological analysis of Group 2 specimens (Geistlich Bio-Gide® membrane + Biodentine) on Day 3 revealed, in the contact area, a large number of blood vessels with stasis within the pulp chamber, disorganization, and partial loss of the odontoblastic layer. Additionally, a dense fibrous matrix was noted, along with a moderately expressed lymphocytic inflammatory infiltrate (Fig. 2, *A*).

In Group 2 (Geistlich Bio-Gide® membrane + Biodentine), histological analysis on Day 14 revealed irregular alignment of odontoblasts, the presence of loose fibrous matrix, and a large number of fibroblast-like cells. A minimal lymphocytic inflammatory infiltrate was observed, which may be interpreted as moderately expressed inflammatory changes (Fig. 2, *B*).

By Day 30, the morphological features of the pulp tissue in Group 2 were characterized by residual signs of inflammation, pronounced reparative dentinogenesis, the presence of granulation tissue, sclerotic changes, and the formation of dentin bridges and focal areas of dentinogenesis (Fig. 2, *C*).

Histological examination of Group 3 specimens (PRF + Biodentine) on Day 3 showed a high number of blood vessels with stasis in the pulp chamber, moderate disorganization of the odontoblastic layer, a dense fibrous matrix, and a moderately expressed inflammatory infiltrate (Fig. 3, *A*).

Histological analysis of specimens from Group 3 (PRF + Biodentine) on Day 14 revealed the absence of odontoblasts in the pulp chamber, the presence of a necrotic focus, and a pronounced polymorphonuclear inflammatory infiltrate with neutrophilic leukocytes in the infiltrate (Fig. 3, *B*).

On Day 30, the morphological features of the pulp tissue in Group 3 were characterized by more prominent signs of pulp inflammation and moderately expressed reparative dentinogenesis. A mild lymphocytic infiltrate was observed, along with the presence of granulation tissue and formation of a dentin bridge (Fig. 3, *C*).

Histological evaluation of Group 4 specimens (control group, Dycal) on Day 3 demonstrated pulpal tissue edema, dilated blood vessels with stasis, moderate disorganization of the odontoblastic layer, presence of loose fibrous matrix, and a mild lymphocytic inflammatory infiltrate (Fig. 4, *A*).

Examination of specimens from Group 4 (control group, Dycal) on Day 14 revealed the absence of odontoblasts in the pulp tissue, presence of necrotic foci, sclerotic changes, granulation tissue, and a pronounced polymorphonuclear inflammatory infiltrate with neutrophilic leukocytes (Fig. 4, *B*).

On Day 30, the morphological pattern of the pulp tissue in Group 4 was characterized by more pronounced signs of pulp inflammation, sclerotic alterations, and moderately expressed reparative dentinogenesis. A dense inflammatory infiltrate containing both lymphocytes and neutrophils was observed. In the area of contact with the applied material, granulation tissue, necrotic foci, sclerotic changes, and formation of dentin bridges were also present (Fig. 4, *C*).

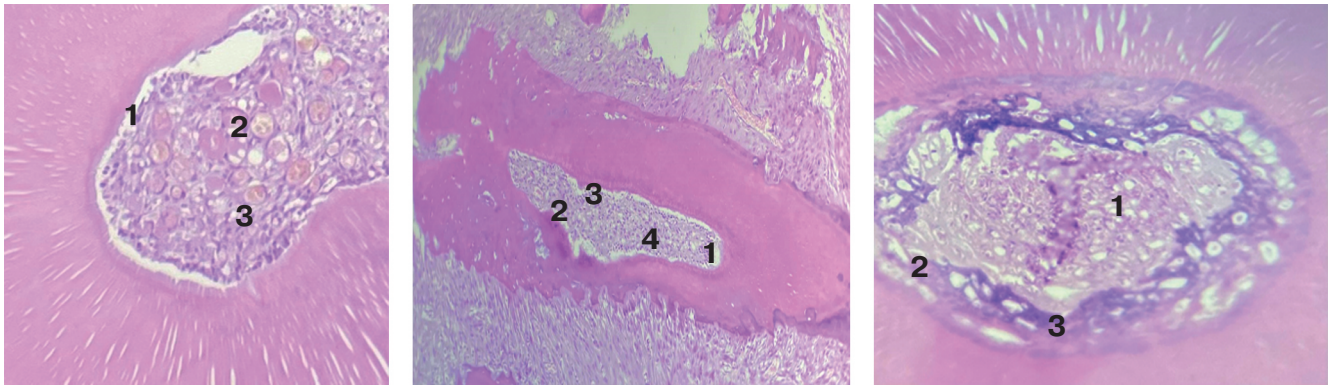


Fig. 2. Root pulp of a rat tooth under conditions of application of the drug Membrane Geistlich Bio-Gide® + "Biodentine", experiment (hematoxylin-eosin staining): *A* – on the 3rd day after the start of the experiment (in V. 400x): *1* – disorganization and loss of the odontoblast layer, *2* – numerous dilated vessels with rhinestones, *3* – dense fibrous matrix, *4* – moderate inflammatory infiltrate; *B* – on the 14th day from the start of the experiment (for c. 100 x): *1* – disorganization of odontoblasts, *2* – dense fibrous matrix, *3* – a large number of fibroblast-like cells, *4* – minimal lymphocytic inflammatory infiltrate; *C* – on the 30th day from the start of the experiment (in V. 400x): *1* – granulation tissue, *2* – dentinal bridge, *3* – foci of dentinogenesis

Рис. 2. Корневая пульпа зуба крысы в условиях применения препарата Мембрана Geistlich Bio-Gide® + «Biodentine», эксперимента (окраска гематоксилин-эозином): *A* – на 3-и сутки от начала эксперимента (ув. 400х): *1* – дезорганизация и потеря слоя одонтобластов, *2* – многочисленные расширенные сосуды со стазами, *3* – плотный волокнистый матрикс, *4* – умеренно выраженный воспалительный инфильтрат; *B* – на 14-е сутки от начала эксперимента (ув. 100х): *1* – дезорганизация одонтобластов, *2* – плотный волокнистый матрикс, *3* – большое количество фибробласто-подобных клеток, *4* – минимальный лимфоцитарный воспалительный инфильтрат; *C* – на 30-е сутки от начала эксперимента (ув. 400х): *1* – грануляционная ткань, *2* – дентинный мостик, *3* – очаги дентиногенеза

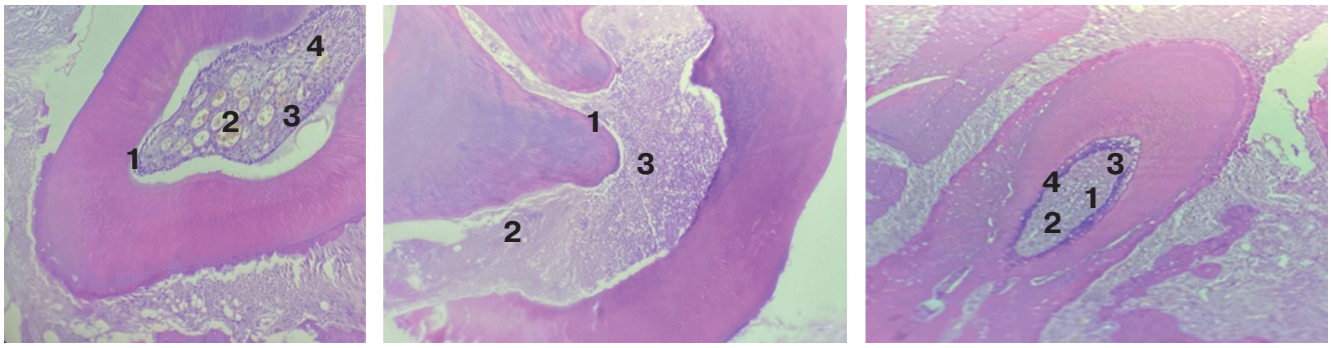


Fig. 3. Root pulp of a rat tooth under the conditions of using the drug fibrin (PRF) + "Biodentine" (hematoxylin-eosin staining, uv. 100 x): *A* – on the 3rd day after the start of the experiment: *1* – disorganization of the odontoblast layer, *2* – numerous dilated vessels with rhinestones, *3* – dense fibrous matrix, *4* – moderate inflammatory infiltrate; *B* – on the 14th day after the start of the experiment: *1* – absence of odontoblasts, *2* – foci of necrosis, *3* – pronounced polymorphic cellular inflammatory infiltrate with the presence of neutrophilic leukocytes in the infiltrate; *C* – on the 30th day from the start of the experiment: *1* – mild lymphocytic inflammatory infiltration, *2* – granulation tissue, *3* – necrosis site, *4* – the presence of dentine bridges

Рис. 3. Корневая пульпа зуба крысы в условиях применения препарата фибрин (PRF) + «Biodentine», (окраска гематоксилин-эозином, ув. 100х): *A* – на 3-и сутки от начала эксперимента: *1* – дезорганизация слоя одонтобластов, *2* – многочисленные расширенные сосуды со стазами, *3* – плотный волокнистый матрикс, *4* – умеренно выраженный воспалительный инфильтрат; *B* – на 14-и сутки от начала эксперимента: *1* – отсутствие одонтобластов, *2* – очаги некроза, *3* – выраженный полиморфный клеточный воспалительный инфильтрат с наличием в инфильтрате нейтрофильных лейкоцитов; *C* – на 30-е сутки от начала эксперимента: *1* – слабовыраженная лимфоцитарная воспалительная инфильтрация, *2* – грануляционная ткань, *3* – очаг некроза, *4* – наличие дентинных мостиков

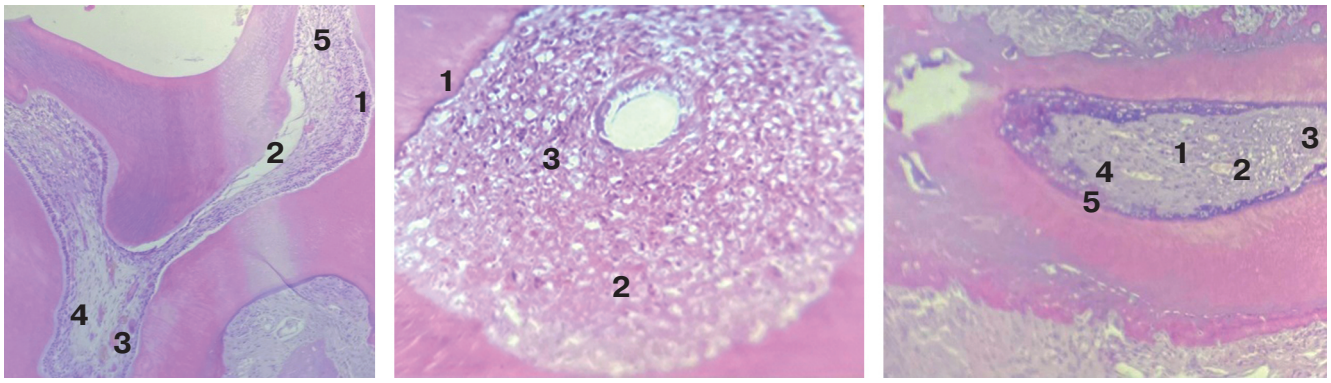


Fig. 4. Crown and root pulp of a rat tooth under the conditions of using the drug "Dycal" (hematoxylin-eosin staining): *A* – on the 3rd day from the start of the experiment, (for B. 100 x): *1* – disorganization of the odontoblast layer, *2* – edema of the pulp, *3* – dilated vessels with stasis, *4* – loose fibrous matrix, *5* – weakly expressed lymphocytic inflammatory infiltrate; *B* – on the 14th day from the start of the experiment, (in B. 400x): *1* – absence of odontoblasts, *2* – foci of necrosis, *3* – pronounced polymorphic cellular inflammatory infiltrate with the presence of neutrophil leukocytes in the infiltrate; *C* – on the 30th day from the start of the experiment (in V. 400x): *1* – Inflammatory infiltration with the presence of lymphocytes and neutrophils in the infiltrate, *2* – granulation tissue, *3* – necrosis site, *4* – sclerotic changes, *5* – the presence of dentine bridges

Рис. 4. Коронковая и корневая пульпа зуба крысы в условиях применения препарата «Dycal», (окраска гематоксилин-эозином): *A* – на 3-и сутки от начала эксперимента, (ув. 100х): *1* – дезорганизация слоя одонтобластов, *2* – отек пульпы, *3* – расширенные сосуды со стазами, *4* – рыхлый волокнистый матрикс, *5* – слабовыраженный лимфоцитарный воспалительный инфильтрат; *B* – на 14-е сутки от начала эксперимента, (ув. 400х): *1* – отсутствие одонтобластов, *2* – очаги некроза, *3* – выраженный полиморфный клеточный воспалительный инфильтрат с наличием в инфильтрате нейтрофильных лейкоцитов; *C* – на 30-е сутки от начала эксперимента, (ув. 400х): *1* – воспалительная инфильтрация с наличием в инфильтрате лимфоцитов и нейтрофилов, *2* – грануляционная ткань, *3* – очаг некроза, 4 – склеротические изменения, *5* – наличие дентинных мостиков

CONCLUSION

It is evident that the search vector for the "ideal" material and application technique for improving the effectiveness of treatment for pulp hyperemia is directly dependent on advances in understanding the morphological features of dental pulp and their clinical application. Based on the findings of the present experimental study aimed at a comparative histological evaluation of pulp tissue response to different material groups and the use of platelet-rich fibrin (PRF) as a scaffold, the following conclusions can be drawn:

The combination of modern bioactive materials for direct pulp capping significantly enhances the effectiveness of treatment in cases diagnosed with pulp hyperemia. One of the most promising directions in stimulating reparative processes in the dental pulp is the combined use of bioactive materials with PRF. The experimental morphological evaluation of pulpal responses demonstrated that the combination of PRF with the bioactive materials "TrioxyDent" and "Biodentine" resulted in the lowest inflammatory response and the highest biocompatibility with pulp tissue, while also promoting reparative activity at the site of direct pulp contact.

Among the two bioactive materials tested in combination with PRF, "TrioxyDent" produced the most favorable outcomes, possibly due to its unique formulation – specifically, the inclusion of calcium-copper hydroxide as an active bacteriostatic additive, which may enhance its biological properties.

In Group 2, where Geistlich Bio-Gide® membrane was used in combination with Biodentine, the histological pattern showed residual signs of inflammation and active reparative dentinogenesis. However, these changes were less consistent and more variable compared to those observed in Groups 1 and 3, where PRF was used as a scaffold. It can be assumed that a different combination or modified application protocol might be needed for more effective use of the Geistlich membrane.

Histological assessment of pulp tissue in Group 4, treated with Dycal, revealed significant irreversible changes by Day 30, indicating the progression of a chronic inflammatory process with a high likelihood of exacerbation. These findings suggest that Dycal does not provide adequate conditions for resolving inflammation and promoting pulp regeneration.

Based on these experimental data, one of the key challenges in regenerative dentistry remains the successful re-establishment of functionally active odontoblasts, which are essential for dentin regeneration. The materials evaluated in this study demonstrated limited capacity to stimulate full pulpal tissue regeneration. From a biological standpoint, the ideal biomaterial should provide an optimal microenvironment for pulp cells, promoting their adhesion, survival, and differentiation into mature cells capable of replacing the damaged extracellular matrix, thereby restoring both the structure and function of the pulp-dentin complex.

REFERENCES / СПИСОК ЛИТЕРАТУРЫ

1. Adamchik A.A., Kirsh K.D., Ivashchenko V.A., Zaporozhskaya-Abramova E.S. Review of modern materials for the treatment of pulpal hyperemia. *Endodontics Today*. 2023;21(2):124-132. (In Russ.) https://doi.org/10.36377/1683-2981-2023-21-2-124-132
   Адамчик А.А., Кирш К.Д., Иващенко В.А., Запорожская-Абрамова Е.С. Обзор современных материалов для лечения гиперемии пульпы. *Эндодонтия Today*. 2023;21(2):124–132. https://doi.org/10.36377/1683-2981-2023-21-2-124-132
2. Vafiadi M.Yu., Sirak S.V., Shchetinin E.V., Balandina A.V., Ivaschenko V.A., Adamchyk A.A., Borodulina I.I. Experimental stimulation of reparative dentinogenesis after vital amputation of the pulp of the tooth. *Medical news of the North Caucasus*. 2019;14(1-2):171–176. (In Russ.) https://doi.org/10.14300/mnnc.2019.14008
   Вафиади М.Ю., Сирак С.В., Щетинин Е.В., Баландина А.В., Иващенко В.А., Адамчик А.А., Бородулина И.И. Стимуляция репаративного дентиногенеза после витальной ампутации пульпы зуба в эксперименте. *Медицинский вестник Северного Кавказа*. 2019;14(1-2):171–176. https://doi.org/10.14300/mnnc.2019.14008
3. Ivashchenko V.A., Adamchik A.A., Arutyunov A.V., Risovanny S.I., Sidorenko A.N., Tsymbalov O.V. Morphological Changes in the Dental Pulp of Experimental Animals in the Treatment of Acute Partial Pulpitis using Modern Materials. *Kuban Scientific Medical Bulletin*. 2019;26(5):29–41. (In Russ.) https://doi.org/10.25207/1608-6228-2019-26-5-29-41
   Иващенко В.А., Адамчик А.А., Арутюнов А.В., Рисованный С.И., Сидоренко А.Н., Цымбалов О.В. Морфологические изменения в пульпе зубов экспериментальных животных при лечении острого очагового пульпита с использованием современных материалов. *Кубанский научный медицинский вестник*. 2019;26(5):29–41. https://doi.org/10.25207/1608-6228-2019-26-5-29-41
4. Nesterova M.M., Nikolaev A.I., Cepov L.M., Galanova T.A. Experience in the treatment of permanent teeth pulpitis by biological method. *Clinical Dentistry* (*Russia*). 2018;(1):16–19. (In Russ.) https://doi.org/10.37988/1811-153X_2018_1_16
   Нестерова М.М., Николаев А.И., Цепов Л.М., Галанова Т.А. Опыт лечения пульпита постоянных зубов биологическим методом. *Клиническая стоматология*. 2018;(1):16–19. https://doi.org/10.37988/1811-153X_2018_1_16
5. Arandi N.Z. Calcium hydroxide liners: a literature review. *Clin Cosmet Investig Dent*. 2017;9:67–72. https://doi.org/10.2147/CCIDE.S141381
6. Anitua E., Sánchez M., Nurden A.T., Nurden P., Orive G., Andía I. New insights into and novel applications for platelet-rich fibrin therapies. *Trends Biotechnol*. 2006;24(5):227–234. https://doi.org/10.1016/j.tibtech.2006.02.010
7. Anitua E., Andia I., Ardanza B., Nurden P., Nurden A.T. Autologous platelets as a source of proteins for healing and tissue regeneration. *Thromb Haemost*. 2004;91(1):4–15. https://doi.org/10.1160/TH03-07-0440

8. Chanchareonsook N., Junker R., Jongpaiboonkit L., Jansen J.A. Tissue-engineered mandibular bone reconstruction for continuity defects: A systematic approach to the literature. *Tissue Eng Part B Rev.* 2014;20(2):147–162. https://doi.org/10.1089/ten.teb.2013.0131
9. Martin D.E., De Almeida J.F., Henry M.A., Khaing Z.Z., Schmidt C.E., Teixeira F.B., Diogenes A. Concentration-dependent effect of sodium hypochlorite on stem cells of apical papilla survival and differentiation. *J Endod.* 2014;40(1):51–55. https://doi.org/10.1016/j.joen.2013.07.026
10. Dombrovskaya Yu.A., Enukashvily N.I., Kotova A.V., Bilyk S.S., Kovalenko A.N., Silin A.V. Fibrin scaffolds containing dental pulp stem cells for the repair of periodontal bone defects. *Translational Medicine*. 2020;7(1):59–69. (In Russ.) https://doi.org/10.18705/2311-4495-2020-7-1-59-69
Домбровская Ю.А., Енукашвили Н.И., Котова А.В., Билык С.С., Коваленко А.Н., Силин А.В. Оценка возможности создания фибриновых скаффолдов, заселенных стволовыми клетками пульпы зуба, для замещения костных дефектов челюсти. *Трансляционная медицина*. 2020;7(1):59–69. https://doi.org/10.18705/2311-4495-2020-7-1-59-69
11. Pavlovic V., Ciric M., Jovanovic V., Trandafilovic M., Stojanovic P. Platelet-rich fibrin: Basics of biological actions and protocol modifications. *Open Med*. 2021;16(1):446–454. https://doi.org/10.1515/med-2021-0259

INFORMATION ABOUT THE AUTHORS

Ksenia D. Kirsh – Assistant, Chair of the Department of Therapeutic Dentistry, Kuban State Medical University, 4 Mitrofana Sedina Str., Krasnodar 350063, Russian Federation; https://orcid.org/0000-0002-6786-9347

Ekaterina S. Zaporozhskaya-Abramova – Cand. Sci. (Med.), Assistant Professor, Chair of the Department of Therapeutic Dentistry, Kuban State Medical University, 4 Mitrofana Sedina Str., Krasnodar 350063, Russian Federation; https://orcid.org/0000-0003-0675-6581

Anatoly A. Adamchik – Dr. Sci. (Med.), Professor, Chair of the Department of Therapeutic Dentistry, Kuban State Medical University, 4 Mitrofana Sedina Str., Krasnodar 350063, Russian Federation; https://orcid.org/0000-0002-2861-0260

Victoria A. Ivashchenko – Cand. Sci. (Med.), Assistant, Chair of the Department of Therapeutic Dentistry, Kuban State Medical University, 4 Mitrofana Sedina Str., Krasnodar 350063, Russian Federation; https://orcid.org/0000-0002-9946-9700

Valerii V. Tairov – Cand. Cand. Sci. (Med.), Assistant Professor, Chair of the Department of Therapeutic Dentistry, Kuban State Medical University, 4 Mitrofana Sedina Str., Krasnodar 350063, Russian Federation; https://orcid.org/0000-0003-0379-5964

Umukusum A. Dotdaeva – Assistant, Chair of the Department of Therapeutic Dentistry, Kuban State Medical University, 4 Mitrofana Sedina Str., Krasnodar 350063, Russian Federation; https://orcid.org/0009-0003-7200-4975

Vladislav M. Starchenko – Assistant, Chair of the Department of Therapeutic Dentistry, Kuban State Medical University, 4 Mitrofana Sedina Str., Krasnodar 350063, Russian Federation; https://orcid.org/0009-0007-4367-6886

ИНФОРМАЦИЯ ОБ АВТОРАХ

Кирш Ксения Дмитриевна – ассистент кафедры терапевтической стоматологии, ФГБОУ ВО «Кубанский государственный медицинский университет», 350063, Российская Федерация, г. Краснодар, ул. Митрофана Седина, 4; https://orcid.org/0000-0002-6786-9347

Запорожская-Абрамова Екатерина Сергеевна – к.м.н., доцент кафедры терапевтической стоматологии, ФГБОУ ВО «Кубанский государственный медицинский университет», 350063, Российская Федерация, г. Краснодар, ул. Митрофана Седина, 4; https://orcid.org/0000-0003-0675-6581

Адамчик Анатолий Анатольевич – д.м.н., доцент, заведующий кафедрой терапевтической стоматологии, ФГБОУ ВО «Кубанский государственный медицинский университет», 350063, Российская Федерация, г. Краснодар, ул. Митрофана Седина, 4; https://orcid.org/0000-0002-2861-0260

Иващенко Виктория Александровна – к.м.н., ассистент кафедры терапевтической стоматологии, ФГБОУ ВО «Кубанский государственный медицинский университет», 350063, Российская Федерация, г. Краснодар, ул. Митрофана Седина, 4; https://orcid.org/0000-0002-9946-9700

Таиров Валерий Владиславович – к.м.н., доцент кафедры терапевтической стоматологии, ФГБОУ ВО «Кубанский государственный медицинский университет», 350063, Российская Федерация, г. Краснодар, ул. Митрофана Седина, 4; https://orcid.org/0000-0003-0379-5964

Дотдаева Умукусум Арсеновна – ассистент кафедры терапевтической стоматологии, ФГБОУ ВО «Кубанский государственный медицинский университет», 350063, Российская Федерация, г. Краснодар, ул. Митрофана Седина, 4; https://orcid.org/0009-0003-7200-4975

Статченко Владислав Максимович – ассистент кафедры терапевтической стоматологии, ФГБОУ ВО «Кубанский государственный медицинский университет», 350063, Российская Федерация, г. Краснодар, ул. Митрофана Седина, 4; https://orcid.org/0009-0007-4367-6886

AUTHOR'S CONTRIBUTION

Ksenia D. Kirsh – conducting an experiment, analyzing the results of an experiment, writing a manuscript.
Ekaterina S. Zaporozhskaya-Abramova – the idea of the study, analyzing the results of experiments, writing a manuscript.
Anatoly A. Adamchik – designing an experiment, analyzing the results of experiments, writing a manuscript.
Victoria A. Ivashchenko – analyzing the results of experiments, writing a manuscript.
Valerii V. Tairov – conducting an experiment, analyzing the results of an experiment, writing a manuscript.
Umukusum A. Dotdaeva – literature review, analyzing the results, writing a manuscript.
Vladislav M. Starchenko – translation of the text into English, literature review.
All the authors have read and agreed with the published version of the manuscript.

ВКЛАД АВТОРОВ

К.Д. Кирш – проведение эксперимента, анализ результатов эксперимента, написание рукописи.
Е.С. Запорожская-Абрамова – задумка исследования, анализ результатов экспериментов, написание рукописи.
А.А. Адамчик – разработка дизайна эксперимента, анализ результатов экспериментов, написание рукописи.
В.А. Иващенко – анализ результатов экспериментов, написание рукописи.
В.В. Таиров – проведение эксперимента, анализ результатов эксперимента, написание рукописи.
У.А. Дотдаева – обзор литературы, анализ результатов, написание рукописи.
В.М. Статченко – перевод текста на английский язык, обзор литературы.
Все авторы прочитали и согласились с опубликованной версией рукописи.