



# Experimental modeling of selective photodestruction of skin angiodyplasia by laser radiation with a wavelength of 525 nm

Natalia Gorbatova<sup>1</sup> · Dinar Safin<sup>1</sup> · Anatoly Sirotkin<sup>2</sup> · Gennady Kuzmin<sup>2</sup> · Alexander Tertychny<sup>3</sup> · Sergei Zolotov<sup>1</sup> · Maria Remennicova<sup>4</sup> · Denis Seleznev<sup>4</sup> · Oleg Tikhonevich<sup>2</sup>

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## Abstract

Until now, the problem of effective treatment of skin angiodyplasia remains relevant. To solve it and improve the results of the treatment of this vascular pathology of the skin, photodestruction by laser radiation is considered, which provides a selective effect on the skin with minimal damage to the surrounding tissues. For selective photodestruction in the treatment of angiodyplasia of the skin, one can consider laser radiation with a wavelength of  $520 \pm 5$  nm in the “green” spectral range, located close to the absorption peaks of hemoglobin and oxyhemoglobin chromophores. An experimental study in vivo on the combs of live white chickens was carried out to clarify the features of damage and the regeneration process in the zone of exposure to this radiation. We used an experimental sample of a solid-state laser apparatus based on semiconductor diodes, generating laser radiation with a wavelength of  $520 \pm 5$  nm. The results of an experimental study in vivo confirmed the selectivity of the effect of “green” laser radiation of  $520 \pm 5$  nm on subepithelial vascular structures with minimal damage to the epithelium, including the area of its growth. In irradiated areas, one could see whitening and smoothing of the surface due to closure of vessel lumens in the subepithelial zone and formation of collagenosis layer there, as well as epithelialization of wound surface in physiological term without any formation of cicatricial deformation of the skin. The prospect of using “green” laser radiation of  $520 \pm 5$  nm for the purposes of selective photodestruction of angiodyplasia of the skin, which should ensure the achievement of a good clinical and aesthetic result of treatment, has been effective for selective destruction of angiodyplasia.

**Keywords** Laser radiation of the green spectral range · Selective photodestruction · Angiodyplasia of the skin · Morphological study

## Introduction

Angiodyplasia of the skin is abnormally dilated blood vessels, including capillaries, located under the basal growth zone of the epidermis. In most cases, 60–80%, they are

localized in the face, neck, and upper body, less often on the extremities. Angiodyplasia can have various forms of manifestations: diffuse, linear, stellate, and others, and also differ in the type of blood filling (arterial, mixed, venous). This vascular pathology can be of congenital and acquired origin. In newborns, capillary angiodyplasia of the skin occurs in 0.3–0.5% of cases, and in older children, including acquired forms, on average more than 2.6% [1–6]. Due to the fact that this vascular pathology can reduce the quality of life of a child and his entire family, timely and effective treatment is a significant social and medical problem [4, 6].

To date, all existing methods of treatment are ineffective, have a number of disadvantages, and do not provide the necessary clinical and aesthetic results of treatment [1–8]. The general therapeutic effect often leads to the development of negative consequences of a somatic nature on the part of the cardiac and pulmonary systems, neurological disorders, and

✉ Oleg Tikhonevich  
tichon@kapella.gpi.ru

<sup>1</sup> Clinical and Research Institute of Emergency Pediatric Surgery and Trauma, Moscow, Russian Federation

<sup>2</sup> Prokhorov General Physics Institute of the Russian Academy of Sciences, Moscow, Russian Federation

<sup>3</sup> Sechenov University, Moscow, Russian Federation

<sup>4</sup> PJSC “Perm Scientific and Production Instrument Making Company” Laboratory of Agrobiophotonics, Perm Federal Research Center of the Ural Branch of the Russian Academy of Sciences, Perm, Russian Federation

others [4, 6, 9]. Local methods of treatment often require multiple manipulations or sessions and can cause irreversible damage to the skin, up to cicatricial deformity [1, 4, 9–11].

Currently, photodestruction by laser radiation is considered the most effective and promising method of treating skin angiodyplasia. However, with the proposed methods with non-selective laser radiation, uncontrolled thermal damage to all tissue structures of the skin with the subsequent development of cicatricial deformation of the skin, hyperpigmentation, and other undesirable consequences in the affected area is not excluded [1, 2, 4, 9–16].

In this regard, the problem of treating this pathology remains relevant, which determines the need to create a new method of photodestruction based on the principle of selectivity of action on pathological subepithelial vascular structures of the skin with minimal damage to other epithelial tissues.

This can only provide the correct choice of laser radiation with a wavelength that is predominantly absorbed by chromophores by hemoglobin and oxyhemoglobin in the vascular structures of biological tissue, their further hardening, and regression with a minimal traumatic component of healthy skin structures, including the growth zone [4, 9, 11–16].

In the spectral range, laser radiation with a wavelength of  $520 \pm 5$  nm is located near the absorption peaks for hemoglobin and oxyhemoglobin [13]. In this regard, it can be considered the most promising for influencing subepithelial vascular structures, including capillary angiodyplasia, with different blood patterns.

An earlier experimental study *in vitro* on model biological objects (cooled samples of the skin and liver of minipigs (*Sus salvanus*) of the Svetlogorsk population) confirmed the selectivity of absorption of “green” laser radiation with a wavelength of  $520 \pm 5$  nm by liver tissues containing a much larger amount of hemoglobin compared to the skin [17, 18]. The results of this *in vitro* study determined the possibility of using “green” laser radiation with a wavelength of  $520 \pm 5$  nm for the purposes of selective photothermolysis of vascular structures, including subepithelial angiodyplasia, which was confirmed in this work.

## Biomedical experimental study *in vivo*

An experimental study *in vivo* on the combs of live white chickens was carried out to clarify the nature of selective photothermolysis and to study the regenerative wound process in the zone of exposure to “green” laser radiation with a wavelength of  $520 \pm 5$  nm. The results of the study determined the prospect of using this radiation for the selective

photodestruction of subepithelial pathological vascular structures, in particular, angiodyplasia of the skin.

## Experimental equipment, materials, and methods

### Equipment and modes of laser radiation

We used an experimental sample of a solid-state laser apparatus based on semiconductor diodes operating at a radiation wavelength of  $520 \pm 5$  nm in the green spectral range, near the absorption peak of hemoglobin and oxyhemoglobin (Table 1).

The experimental sample was developed for the purposes of medicine at the Prokhorov General Physics Institute of the Russian Academy of Sciences [19, 20]. The prototype manufactured at the Perm Federal Research Center of the Ural Branch of the Russian Academy of Sciences (Fig. 1).

In the experiment, we used “green” laser radiation with constant parameters: wavelength  $520 \pm 5$  nm, average power 3 W, pulse repetition rate 10 Hz, laser spot diameter 0.8 mm. In the study, the following parameters of laser radiation were changed: pulse duration 2 ms, 5 ms, and 10 ms, exposure 5 s and 10 s. The study was carried out in four modes with different combinations of these parameters. The parameters of the modes used in the experimental study are presented in Table 2.

In this work, the surface of the object was affected in two ways, pointwise with a fixed spot and with the movement of the spot by manual scanning. In this case, the corresponding identical parameters of laser radiation were used.

### Object of experimental research

The object was the red combs of biological models of live white Cross Hisex White chickens. The reason for choosing them as the closest model of subepithelial vascular formations was the presence of a large number of dilated

**Table 1** Technical and operational characteristics of the device

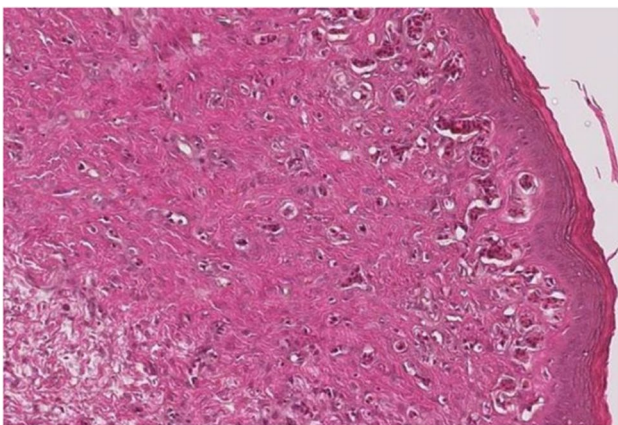
Parameter	Value
Wavelength, nm	$520 \pm 5$
Average power, W	3
Pulse duration	From 50 to 50 ms
Pulse repetition rate	From 10 kHz to 10 Hz
Control with software	Touch screen, pedal
Power supply	220 V/50 Hz
Light delivery	Flexible light guide 400, 600 $\mu$ m, length 2 m



**Fig. 1** Medical laser device used for selective photodestruction

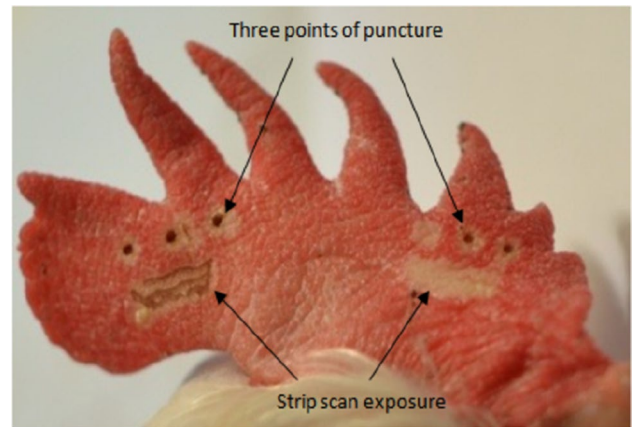
**Table 2** Parameters of modes used in the experiment

Mode no	Power	Pulse duration	Exposure
1	3 W	2 ms	5 s
2	3 W	2 ms	10 s
3	3 W	5 ms	5 s
4	3 W	10 ms	10 s



**Fig. 2** Micrograph of a histological specimen of unchanged comb tissue

capillaries in the subcutaneous vascular network and the absence of melanin pigment in the tissues. On the micrograph of the histo-preparation of the combs, dilated capillaries in the subepithelial zone are determined (Fig. 2).



**Fig. 3** The procedure for the formation of zones of laser exposure

The micrograph of unchanged comb tissue shows well-defined cells of stratified squamous epithelium; in the underlying stroma, there are a large number of congested capillaries with an expanded lumen, staining with hematoxylin and eosin, magnification  $\times 200$ .

### Experimental research methodology

The experiment involved 42 individuals of chickens with red combs, aged 7 to 8 months, each of which was marked with a ring on its paw.

The experiment with biological models was performed using general anesthesia by intramuscular administration of Zoletil, diluted in accordance with the instructions at the rate of 0.01 ml per 100 mg of live bird weight.

On the combs of the models, zones of exposure to “green” laser radiation with a wavelength of  $520 \pm 5$  nm were formed, with the indicated mode parameters. Spot and scanned zones were applied only on one side of the ridge, using two modes of radiation parameters for each ridge, namely 1 and 2 for one ridge and on the other 3 and 4 modes. First, for each mode, 3 point zones were formed on the ridge, located for the mode with a lower intensity closer to the beak, for the second with more aggressiveness closer to the back of the head. Then, under them, at a distance of 1–2 mm, a strip of 1.0–2.0 mm wide, up to 10.0 mm long was applied by scanning at a speed of about 1 cm per second, using the corresponding point energy mode. For each pair of methods of exposure used, 3 biological models were used, that is, three chicken combs. A schematic procedure for the formation of zones of laser action on the combs of biological models is shown in Fig. 3.

The sampling of the experimental material was carried out immediately after exposure—zero period, then on the 4th day, 7th, 12th, 21st, and 30th days, as well as after 3 months. The combs were harvested under general

anesthesia with Zoletil by surgical excision with stitching on the surgical wound.

In the experiment, the determined changes in the zones of influence on live combs and after their cutting off on macro-preparations were studied, from which samples were prepared for subsequent histological examination. During the entire observation, the state of the tissues and the peculiarities of the course of the regenerative wound process, as well as the selectivity to hemoglobin-containing vascular structures in the affected zones, were investigated.

### Methodology for performing histological examination

Tissue samples with laser exposure zones for histological examination were fixed in 10% neutral formalin. Further processing was carried out automatically in an Excelsior apparatus for histological wiring (TermoScientific, Great Britain) and embedded in paraffin using an EC350 apparatus (Microm, Germany). From paraffin blocks, sections with a thickness of 2–3  $\mu\text{m}$  were obtained using an HM355S microtome with an STS section transfer system (Termo Scientific, Great Britain). The resulting histological preparations were dewaxed in successive changes of xylene and alcohol solutions, and then stained with hematoxylin and eosin. The finished stained histological preparations were placed under a cover glass and examined under a CX41 microscope (Olympus, Japan).

A PanoramicMidi scanning microscope (3DHISTECH Hungary) was used to obtain high-precision images of histological preparations. Software processing of the images of histological preparations made it possible to assess their morphometric parameters with the measurement of areas of damaged tissues in the zones of laser exposure.

### Research results

Examples of the results of a morphological macroscopic study of the zones of exposure to laser radiation with a wavelength of  $520 \pm 5$  nm at various times after exposure to laser radiation with parameters of modes 1 to 4 on chicken combs samples are shown in Fig. 4(a–j).

Based on the morphological macroscopic examination of the zones of exposure to laser radiation with a wavelength of  $520 \pm 5$  nm, characteristic features were determined.

Immediately after the application of the zones of laser action, for all the parameters of the radiation regimes used, changes of a similar nature were noted, the severity of which somewhat increased with an increase in energy activity. With point application, the formation of shallow defects—craters—was observed and a relatively rapid recovery by 12 days in the form of whitish dots of areas of damaged skin.

During scanning, the surface of the skin immediately acquired a whitish color and became smoother in comparison with the surrounding skin, which persisted throughout the observation period, including 30 and 90 control days.

Thus, in all cases, regardless of the regime used and the method of applying laser radiation, by day 12, restoration of the skin surface with a whitish color in the affected areas was noted, and at all indicated periods, perifocal inflammatory changes in the tissues of the combs were not noted.

Examples of micrographs of histological preparations with laser scanning zones with the most energetically aggressive parameters of 4 modes are shown in Fig. 5(a–h).

Based on the analysis of the results of histological examination, characteristic changes and features of the tissue regeneration process after exposure to laser radiation with a wavelength of  $520 \pm 5$  nm with the most energetically aggressive parameters of 4 modes were noted. In all cases, minimal damage was noted to the basal cellular structures of the epithelial growth zone, which, while maintaining their viability, provide the possibility of central epithelialization from day 7 to complete restoration of the differentiation of epithelial cell structures by day 21.

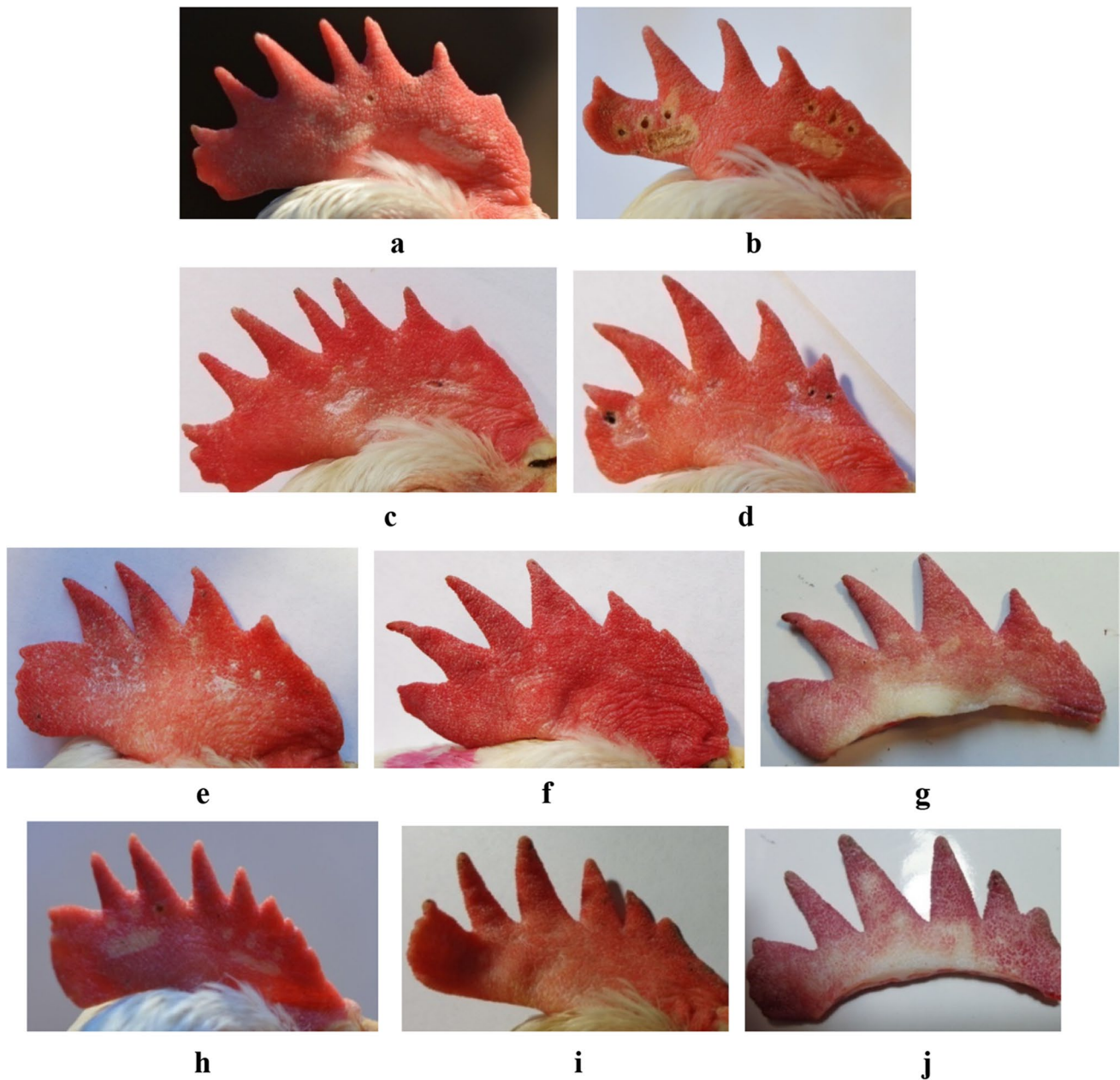
In the subepithelial zone, by the 21st day, the formation of a section of compactly located large collagen fibers is determined, the organization of which significantly increases by the 30th and 90th days, and in the subepithelial zone, the effect of closure of full-blooded capillaries with a wide lumen is preserved. At all designated periods and with all energy parameters of exposure, the epithelium is minimally damaged, while the depth of the zone of thermal damage to subepithelial tissue structures is from 350 to 390  $\mu\text{m}$  with a relatively clear border with the underlying, unchanged tissues.

The severity of thermal destructive changes in the tissues of chicken comb samples at the same radiation power, 3 W, increases with an increase in energy activity, pulse duration, and exposure to pulsed exposure, while the nature of thermal damage to tissue structures of the combs continues to remain the same.

### The discussion of the results

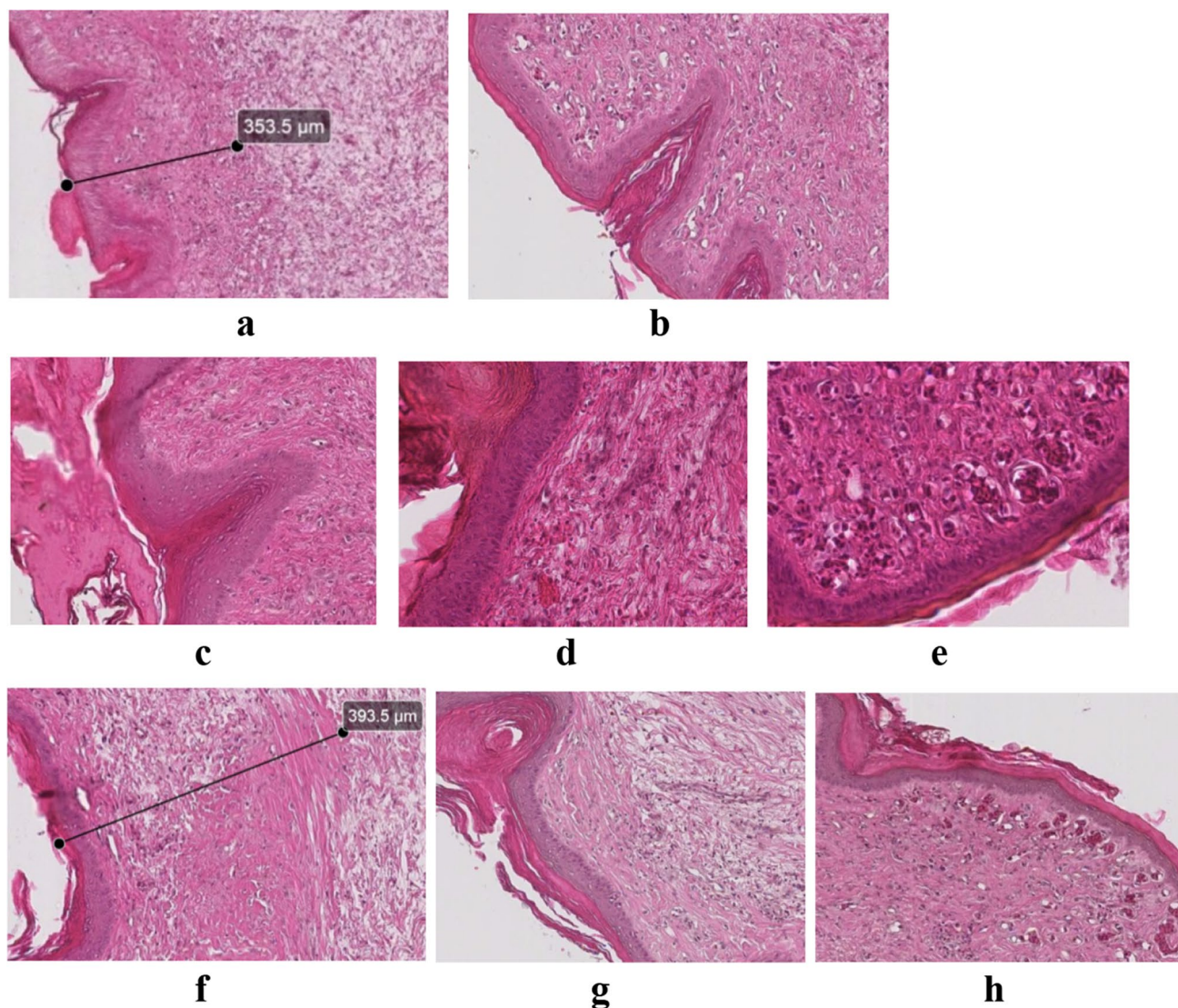
The peculiarity of the effect of laser radiation with a wavelength of  $520 \pm 5$  nm lies in the predominant damage to the subepithelial vascular structures of the combs with minimal reversible damage to the epithelium, including the zone of its growth. This ensures persistent whitening and leveling of the skin surface in the affected areas, due to the closure of the full-blooded vessels with a wide lumen in the subepithelial zone, in the future the formation of a parallel organized surface of the collagenosis layer there, as well as the preservation of the epithelial





**Fig. 4** **a** 0 term, mode 1–2. The zones of exposure when using modes 1 and 2 with lower energy in spot application and in scanning mode are represented by whitish areas of even skin. **b** 0 term, mode 3–4. Point impact zones with higher energy at 3 and 4 modes have the form of small brownish craters no more than 1.5 mm in diameter, with a narrow yellowish rim up to 1.0 mm. In the case of scanning at mode 3, areas of white-yellow color are determined; at mode 4, there are light brown crusts in places, and the surface of the areas is even. **c** 12 days, mode 1–2. All affected areas have a whitish, flat surface of the skin; there are no signs of inflammation in the surrounding tissues. **d** 12 days, mode 3–4. The areas of influence are white with a flat slightly reduced surface; there are no inflammatory manifestations in the surrounding tissues (single deep defects are the result of damage by another individual). **e** 30 days, mode 1–2. In all areas of exposure, a relatively flat, whitish surface remains; deformation of the skin

and inflammatory manifestations are not detected. **f, g** 30 days, mode 3–4. Comb and comb macro preparation. **f** All areas of exposure retain a whitish color with a flat surface; there is no deformation of the skin and no inflammatory changes. **g** These changes are preserved and are better defined on a macro-preparation of a comb; the entire surface of which becomes even. **h** 90 days, mode 1–2. In the affected areas, a persistent effect of white color and surface leveling is noted; there is no deformation of the skin and no inflammatory manifestations. **i, j** 90 days, mode 3–4. Comb and scomb macro-preparation. **i** In all areas of exposure, the effect of white color remains and the surface of the skin is relatively flat with a slight retraction; there are no deforming changes and inflammatory manifestations. **j** On the macro-preparation of the comb in the affected zones, white areas with a flat surface are clearly defined



growth zone and epithelialization of the wound surface in physiological terms, without the formation of cicatricial deformity of the skin.

This effect of exposure is based on the selective absorption of the used “green” laser radiation with a wavelength of  $520 \pm 5$  nm, mainly by blood chromophores (hemoglobin, oxyhemoglobin) of subepithelial vessels, then their desolation and collagenization, as well as minimal absorption by other chromophores of skin tissues and preservation of its growth zone.

Thus, the results of the experimental study confirmed the selectivity of the action of laser radiation of the green spectrum with a wavelength of  $520 \pm 5$  nm on the subepithelial vascular structures, which is one of the necessary conditions for precision photodestruction of angiodyplasia of the skin and some of its other vascular pathologies.

## Conclusion

It has been experimentally substantiated that “green” laser radiation with a wavelength of  $520 \pm 5$  nm ensures the selectivity of photodestruction of subepithelial vascular structures, with minimal reversible damage to the skin and without the formation of deforming scars. In the experiment, it was determined that for an effective effect on subepithelial vascular structures, it is sufficient to use a laser radiation power of 3 W, with a pulse duration range from 2 to 10 ms, with an exposure duration from 5 to 10 s, respectively, with a scanning speed of about 1.0 cm per second.

Selective photodestruction by laser radiation with a wavelength of  $520 \pm 5$  nm, combining the precision of action on hemoglobin-containing subepithelial vascular structures with a minimal traumatic component of the epithelium, is promising for the treatment of various angiodyplasia of the skin, including capillary, and its use should ensure



**Fig. 5 a, b** Micrograph of a histological specimen of a comb, 0 term, and its fragment with an area of unchanged comb tissue. **a** In the affected area, the preservation of horny masses on the surface and soft coagulation of stratified squamous epithelium, in the form of erasing the boundaries of cells with the absence of nuclei, while maintaining the basement membrane, is noted. In the underlying stroma, the closure of the lumens of the capillaries, the fusion, and homogenization of collagen fibers are noted. The depth of the determined changes is about 350 microns. Staining with hematoxylin and eosin. Magnification  $\times 100$ . **b** Unchanged comb tissue with well-defined cells of stratified squamous epithelium and a large number of full-blooded capillaries with an expanded lumen in the underlying stroma. Staining with hematoxylin and eosin. Magnification  $\times 100$ . **c** Micrograph of a histological specimen of a comb, day 7. A small depression on the surface is made with necrotic masses from the stratum corneum. The basal cellular structures of the epithelium are preserved; differentiated cellular structures of the epithelium are determined above them. In the subepithelial sections, collapsed capillary lumens remain; there is a slight edema of the stroma. Staining with hematoxylin and eosin. Magnification  $\times 100$ . **d, e** Micrograph of a histological specimen of a comb, 21 days and its fragment with an area of unchanged comb tissue. **d** The epithelium with pronounced hyperkeratosis, its basal and cellular structures are differentiated. In the subepithelial sections, the collapsed lumens of the capillaries are preserved, and there is also a zone with a compact arrangement of large collagen fibers, followed by a zone of loose connective tissue with edema and thin collagen fibers. Staining with hematoxylin and eosin. Magnification  $\times 200$ . **e** For comparison, unaltered comb tissue with stratified squamous epithelium and a large number of full-blooded capillaries with a wide lumen in the subepithelial zone. Staining with hematoxylin and eosin. Magnification  $\times 200$ . **e, f** Micrograph of a comb preparation, 30 days. Slight hyperkeratosis of the epithelium, distinct cellular differentiation of the epithelium, including the basal layer. In the subepithelial regions, the lumens of the capillaries collapsed. Under the epithelium, there is a zone with a compact arrangement of large collagen fibers, and behind it is an area of loose connective tissue with slight edema and then a layer of thinner collagen fibers. Changes are noted down to a depth of 390 microns. Staining with hematoxylin and eosin. Magnification  $\times 100$ . **g, h** Micrograph of a comb preparation, day 90 and its fragment with an area of unchanged comb tissue. **g** The epithelium with typical hyperkeratosis and its cellular structures, including the basal ones, are clearly defined. In the subepithelial regions, the lumens of almost all capillaries collapsed. In the subepithelial zone, there is a relatively wide and structurally pronounced collagenization zone with a compact arrangement of large collagen fibers parallel to the epithelium. This zone is followed by an area of loose connective tissue with thin, chaotically directed collagen fibers. Staining with hematoxylin and eosin. Magnification  $\times 100$ . **h** For comparison, an area of unchanged comb tissue with a large number of full-blooded capillaries with a wide lumen in the stroma, underlying stratified squamous epithelium. Staining with hematoxylin and eosin. Magnification  $\times 100$

the achievement of the optimal possible clinical and aesthetic result, which needs to be confirmed by further clinical studies.

## Declarations

**Ethical approval** Not required.

**Conflict of interest** The authors declare no competing interests.

## References

- Dan VN, Sapelkin SV, Sharobaro VI (2013) Taktika lechenija arteriovenoznyh angiodisplazij golovy i shei [Tactics of treatment of arteriovenous angiodysplasias of the head and neck. *Flebologija*. [Phlebology]; 7: 17–25. (in Russian)
- Nerobeev AI, Bol'shakov MN (2006) Kombinirovannoe lechenie sosudistykh mal'formacij golovy i shei [Combined treatment of vascular malformations of the head and neck]. *Annaly plasticheskoy, rekonstruktivnoy i jesteticheskoy hirurgii* [Annals of plastic, reconstructive and aesthetic surgery]; 4: 118 p. (in Russian)
- Shafraanov VV (1984) Some problems and prospects of using low temperatures in pediatric surgery. // *Bulletin of the Academy of Medical Sciences*. 1984; 9: p. 12–19. Shafraanov V.V. Nekotoryye problemy i perspektivy ispol'zovaniya nizkikh temperatur v detskoy khirurgii.// *Vestnik AMN*; 9: s. 12–19. (in Russian)
- Jushina TE, Gorbatova NE, Saruhanjan OO (2019) Problema lechenija kapilljarnoj angiodisplazii kozhi u detej [The problem of treatment of capillary angiodysplasia of the skin in children]. *Detskaja hirurgija* [Pediatric Surgery] 2(19):72–78 (in Russian)
- Adams BB, Lucky AW (2000) Acquired port-wine stains and antecedent trauma: case report and review of the literature. *Arch Dermatol* 136:897–899. <https://doi.org/10.1001/archderm.136.7.897>
- Enjolras O (2003) Vascular malformations. In: Bologna JL, Jorizot JL, Rapini RP et al (eds) *Dermatology*. Mosby, London, pp 1615–1629
- Chen H et al (2009) Patients with intralesional hemorrhage in venous malformations: diagnosis and embolosclectherapy. *J Vasc Surg* 49(2):429–433. <https://doi.org/10.1016/j.jvs.2008.08.051>
- Hren C, Garcia C, Clark RE (1996) Sclerotherapy of telangiectases using sodium tetradecyl sulfate (Sotradecol). *N C Med J* 57(1):42–46
- Tanzi EL, Lupton JR, Alster TS (2003) Lasers in dermatology: four decades of progress. *J Am Acad Dermatol* 49(1):1–31. <https://doi.org/10.1067/mjd.2003.582> (quiz 31–34)
- Piper JA, Pask HM (2007) Crystalline Raman Lasers // *IEEE. J Sel Top Quantum Electron* 13(3):692–704. <https://doi.org/10.1109/JSTQE.2007.897175>
- Alster TS, Lupton JR (2001) Lasers in dermatology. An overview of types and indications. *Am J Clin Dermatol* 2(5):291–303. <https://doi.org/10.2165/00128071-200102050-00004>
- Sirotkin AA, Vlasov VI, Zagumennyj AI et al (2014) Control of the spectral parameters of vanadate lasers. *Quantum Electron* 44(1):7. <https://doi.org/10.1070/QE2014v044n01ABEH015282>
- Shpol'skij Je V (1946) Spektroskopija v biologii [Spectroscopy in biology]. *Uspehi fizicheskikh nauk* [Advances in physical sciences]; 29 (7): 221–249. (in Russian)
- Anderson RR, Parrish JA (1981) Microvasculature can be selectively damaged using dye lasers: a basic theory and experimental evidence in human skin. *Lasers Surg Med* 1:263. <https://doi.org/10.1002/lsm.1900010310>
- Anderson RR, Parrish JA (1983) Selective photothermolysis: precise microsurgery by selective absorption of pulsed radiation. *Science* 220:524–527. <https://doi.org/10.1126/science.6836297>
- Chang CJ, Hsiao YC, Mihm MC Jr et al (2008) Pilot study examining the combined use of pulsed dye laser and topical Imiquimod versus laser alone for treatment of port wine stain birthmarks. *Lasers Surg Med* 40(9):605–610. <https://doi.org/10.1002/lsm.20716>
- Gorbatova N, Gasanova E, Zolotov S, Sirotkin A, Kuzmin G, Tertychny A, Stankova N, Remennicova M, Tikhonovich O

- (2021) Experimental confirmation of the promising selective use of “green” laser radiation for photothermolysis of hemoglobin-containing tissues. *Lasers Med Sci*. <https://doi.org/10.1007/s10103-020-03220-x>
18. Sirotkin AA et al (2018) Optimization of selective photodestruction by laser radiation of the yellow-green range of capillary angiodyplasia of the skin. 2018 International Conference Laser Optics (ICLO), St. Petersburg, Russia, pp 602–602. <https://doi.org/10.1109/LO.2018.8435420>
  19. Sirotkin AA, Kuzmin GP, Gorbatova NE, Zolotov SA (2018) Tverdotel'naja lazernaja ustanovka s diodnoj nakachkoj dlja lechenija sosudistyh obrazovanij kozhi i podkozhnoj kletchatki [Diode-pumped solid-state laser system for the treatment of vascular lesions of the skin and subcutaneous tissue]. RF patent № 2644690 of February 13. (in Russian)
  20. Tikhonovich OV, Sirotkin AA, Gorbatova NE, Kuzmin GP, Remennikova MV, Seleznev DA (2020) Development of a laser medical device for the selective removal of pathological vascular. 2020 International Conference Laser Optics (ICLO), pp 396–396. <https://doi.org/10.1109/ICLO48556.2020.9285442>

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