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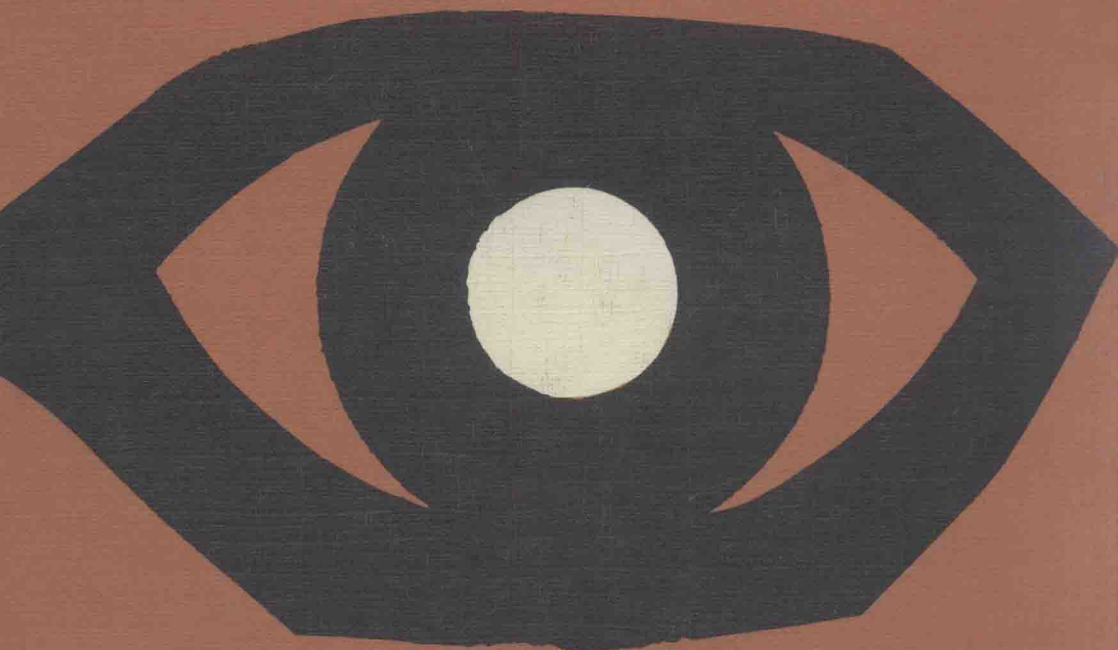
Laser Treatment and Photocoagulation of the Eye

Proceedings of the International Symposium

Munich, 1982

Edited by R. Birngruber and V.-P. Gabel



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FOREWORD

The International Symposium of Laser Treatment and Photocoagulation of the Eye took place in the University of Munich Eye Clinic in September 1982. It was the aim of this symposium to give an accurate picture of how far insights have come in the classical use of lasers in ophthalmology as well as of new laser methods, even when the latter are still in the experimental stage.

The echo of interest from this meeting has prompted us as its organizers to make the symposium speeches, in print, available to a larger audience. For this purpose the speeches were divided into five sessions, each taking as its topic an issue of importance which is presently the object of lively discussion. A few contributions to the symposium had to be omitted because of their partially commercial character.

It is not our purpose to introduce a new basic work on laser treatment of the eye; rather our desire is to make a contribution to the further development and perfection of ophthalmological laser uses and related techniques by depicting the current state of research in this area. As a result, it is understandable that some of the following articles should pass over some topics lightly, others, on occasion, do not hesitate to champion controversial points of view; consequently, even major questions had often to be left open.

The individual authors have laid special emphasis on aligning their contributions sufficiently with actual practice so that both scientists in this field and practising ophthalmologists may read them to their advantage.

Inserting the discussions which took place during the symposium at the end of each session, we hope to emphasize the relevance of the individual speeches. We have tried to reproduce the lively atmosphere in which these discussions took place as much as possible by retaining the mode of direct address. It proved unavoidable, however, to omit some parts of the discussions, for example, when simple questions of clarification were involved or when no clear relationship between question and answer could be established. Discussion comments which we had not received in writing were pieced together by us with tape recordings.

The authors' list at the end of the book contains the names and addresses not only of the main speakers but also of the participants to the discussion, with a view to stimulating contact and further discussion.

Finally we wish to thank the publishers, especially Mr. W. R. Peters, for their friendly cooperation and unfailing support during the publication of this book.

Munich, March 1983

Reginald Birngruber
Veit-Peter Gabel

CONTENTS

SESSION I

RETINAL PHOTOCOAGULATION USING DIFFERENT LIGHT SOURCES

INTRODUCTION

V.-P. GABEL

Various light sources have been employed for the production of thermal effects on the retina since Meyer-Schwickerath's introduction of light coagulation. Following attempts with sunlight, the first clinically practical instrument was constructed with a xenon arc lamp and put into operation worldwide.

The first laser coagulators, equipped with ruby lasers ($\lambda = 694$ nm), came into use only a few years thereafter. Retinal coagulation was quite feasible with these machines; in the treatment of vascular diseases, such as retinopathia diabetica, however, a laser light was still to be desired whose wavelength lay in the absorption range of blood, so as to enable selective closure of blood vessels.

In spite of the correspondence between the wavelengths of argon lasers and hemoglobin absorption, it was soon evident that selective – that is, direct – vascular coagulation with these instruments was nearly impossible, inasmuch as they had been conceived and designed for retinal coagulation. Likewise, it became clear, however, that the argon laser provides a suitable light source with respect to melanin absorption in the pigment epithelium and the choroid. We know from various studies, for instance, that the shorter the wavelength the higher the melanin absorption, and, on the other hand, we know that the transmission of the ocular media begins around 400 nm and peaks at about 500 nm. With respect to melanin absorption, the argon laser is therefore especially well suited, since it emits at wavelengths of 488 and 514 nm. The overall problem area of light absorption in the various layers of the fundus of the eye is treated extensively in Articles 1.1 and 1.2 of this chapter.

Argon lasers came on the market from the very beginning equipped with costly but very precise accessories for their use (contact glass and slit lamp); they established themselves quickly for this reason, and argon laser coagulation was soon being used for all sorts of alterations in the retinal area. The indications which had become familiar through the use of xenon arc lamp coagulators were hereby nearly all adopted and further broadened to cover:

- coagulations in which scar tissue is used to establish a firm bond between the retina and its base, that is, for 'retinopexy' of lattice degenerations or retinal breaks;
- coagulations whose primary aim is to destroy tissue, as, for example,

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in the treatment of intraocular tumors or in panretinal coagulation for diabetic retinopathy and retinal vein occlusions;

- coagulations whose aim is to bring about an indirect vascular occlusion through cicatrisation of the surrounding tissue, as, for example, in Eales' disease and Coats' disease or in the case of subretinal neovascularisation;
- coagulations for closing leaks by stimulating the proliferation of pigment epithelial cells, as, for example, in the case of central serous retinopathy.

Attracted by the possibility of coagulating alterations selectively even in the vicinity of the macula, researchers focused their attention toward the end of the 70s more and more on the macular pigment. As measurements with fresh retinal specimens showed, xanthophyll exhibits a significant absorption in the blue wavelength of the argon laser ($\lambda = 488$ nm); and experiments with monkeys demonstrated that this high absorption can lead to therapeutically undesirable intraretinal lesions in Henle's fiber layer.

These facts led to promotion of the use of krypton lasers, which emit at a wavelength of 647 nm and whose light is therefore not absorbed by xanthophyll. Histological examinations and theoretical considerations based on heat conduction models showed that the lesions of krypton lasers penetrate somewhat deeper into the choroid than those of argon lasers. In spite of numerous attempts by various researchers, however, there is as yet no clinching clinical proof that the krypton laser is superior to the argon laser. Articles 1.3, 1.4 and 1.5 of this chapter take up this problem area.

Another way of avoiding intraretinal absorption by the macular xanthophyll is to use only the green wavelength ($\lambda = 514$ nm) of the argon laser. Some study groups, however, have taken a different approach and investigated whether even deeper lesions in the choroid might not be better for therapeutic purposes – those, for example, of xenon arc lamp coagulators or neodymium lasers ($\lambda = 1060$ nm) (see Articles 1.6–1.9). Articles 1.10–1.12 take up individual clinical aspects of these problem complexes.

1.1. THE WAVELENGTH DEPENDENCE OF LIGHT ABSORPTION IN THE FUNDUS OF THE EYE, PARTICULARLY REGARDING ARGON-, KRYPTON- AND NEODYMIUM-LASER EMISSION

B. LACHENMAYR, R. BIRNGRUBER AND V.-P. GABEL

ABSTRACT

The pigments responsible for the selective absorption of laser radiation in the retina, pigment epithelium and choroid are: xanthophyll, melanin and hemoglobin. Whereas xanthophyll is only present in the foveal region of the retina, melanin occurs both in the pigment epithelium and the choroid; hemoglobin is present in the blood vessels of the choroid, especially in the melanin-free choriocapillaris.

The absolute absorption of incident laser radiation in the retina, pigment epithelium and choroid is calculated for the wavelengths of argon, krypton and neodymium lasers at two different positions of the ocular fundus, fovea and mid-periphery, taking into account both regional variations of pigment distribution over the ocular fundus and individual variations of pigment absorption.

It is obvious that in the periphery the absorption of argon-laser radiation occurs mainly in the pigment epithelium, whereas krypton-laser radiation is more absorbed by the choroid than by the pigment epithelium.

In the fovea the absorption by xanthophyll is very pronounced in the case of argon-laser radiation; at the wavelengths of krypton- and neodymium-laser radiation, however, xanthophyll does not show any absorption.

Considering these physical results, it is to be expected that in photocoagulation of the fundus both krypton- and, even more, neodymium-laser radiation should be capable of producing lesions which are located deeper in the choroid than is the case for the argon-laser radiation.

INTRODUCTION

Photocoagulation of the ocular fundus by means of laser radiation, especially argon-laser radiation, already plays a rather important part in the prevention and therapy of diseases of the fundus. The technical availability of more laser sources with a sufficiently high output power on the one hand, and the clinical wish of producing lesions, damaging selectively either more the inner layers of the fundus – retina and pigment epithelium – or more the outer layers – choriocapillaris and choroid – on the other hand require some

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fundamental considerations of the absorption characteristics of the different layers of the ocular fundus, particularly regarding argon-, krypton- and neodymium-laser emission wavelengths.

CALCULATIONS

The pigments responsible for the absorption of radiation in the layers of the ocular fundus – retina, pigment epithelium and choroid – are: *xanthophyll*, *melanin* and *hemoglobin.* Fig. 1 shows a schematic section through the human ocular fundus, regarding both the situation in the fovea and the mid-periphery (i.e. about 30–40 degrees). Whereas xanthophyll is only present in the foveal region of the retina, melanin occurs both in the pigment epithelium and the choroid; hemoglobin is present in the blood vessels of the choroid, especially in the melanin-free choriocapillaris. The absorption by *water* plays an additional part in the case of the neodymium-laser wavelength in the infrared.

The pigment distribution of the above schematic section of the fundus, especially of the choroid, is, of course, only a simplified approximation of the real situation in order to provide a manageable basis for the following physical calculations of the absorption characteristics of the fundus. In reality the melanin of the choroid is distributed rather inhomogeneously in the form of clusters of melanophores of different sizes over the entire choroid, excluding the choriocapillaris which, in fact, is melanin-free.

The following calculations of absorption of laser radiation in the different layers of the fundus were confined to two positions: the *mid-periphery* (i.e. 30–40 degrees) and the *fovea.* Individual and regional variations of melanin and xanthophyll absorption were taken into consideration as far as data were available in the literature: Gabel et al. (1976) investigated the absorption of melanin in the pigment epithelium and choroid, Gabel and Birngruber (1979) studied the absorption of xanthophyll in the retina. In order to simplify the calculations, the absorption of hemoglobin in the choriocapillaris and the remaining choroid was considered to be both individually and regionally constant, using a mean value of the absorption coefficient of oxygenated and desoxygenated hemoglobin (Welsch et al. (1977)).

The laser wavelengths taken into consideration are the following:

1. the green 514.5 and 488 nm lines of the argon laser; in the case of the mid-periphery, the calculations were conducted by using a mean value of 500 nm, and, in the case of the fovea, the two lines were considered separately because of the distinct wavelength dependence of xanthophyll absorption.
2. the red 647 nm line of the krypton laser;
3. the infrared 1064 nm line of the neodymium laser.

In the case of the *mid-periphery* the absorption characteristics of the fundus were calculated at 500, 647 and 1064 nm; considering the regional variations of melanin absorption in the pigment epithelium and choroid over the fundus, the mid-periphery represents an approximate mean value

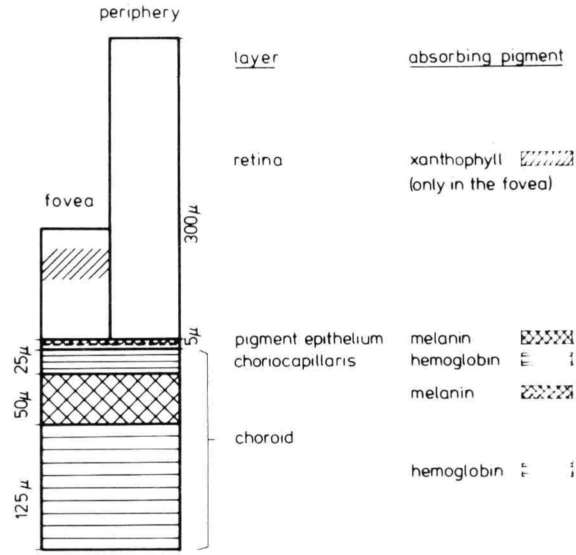
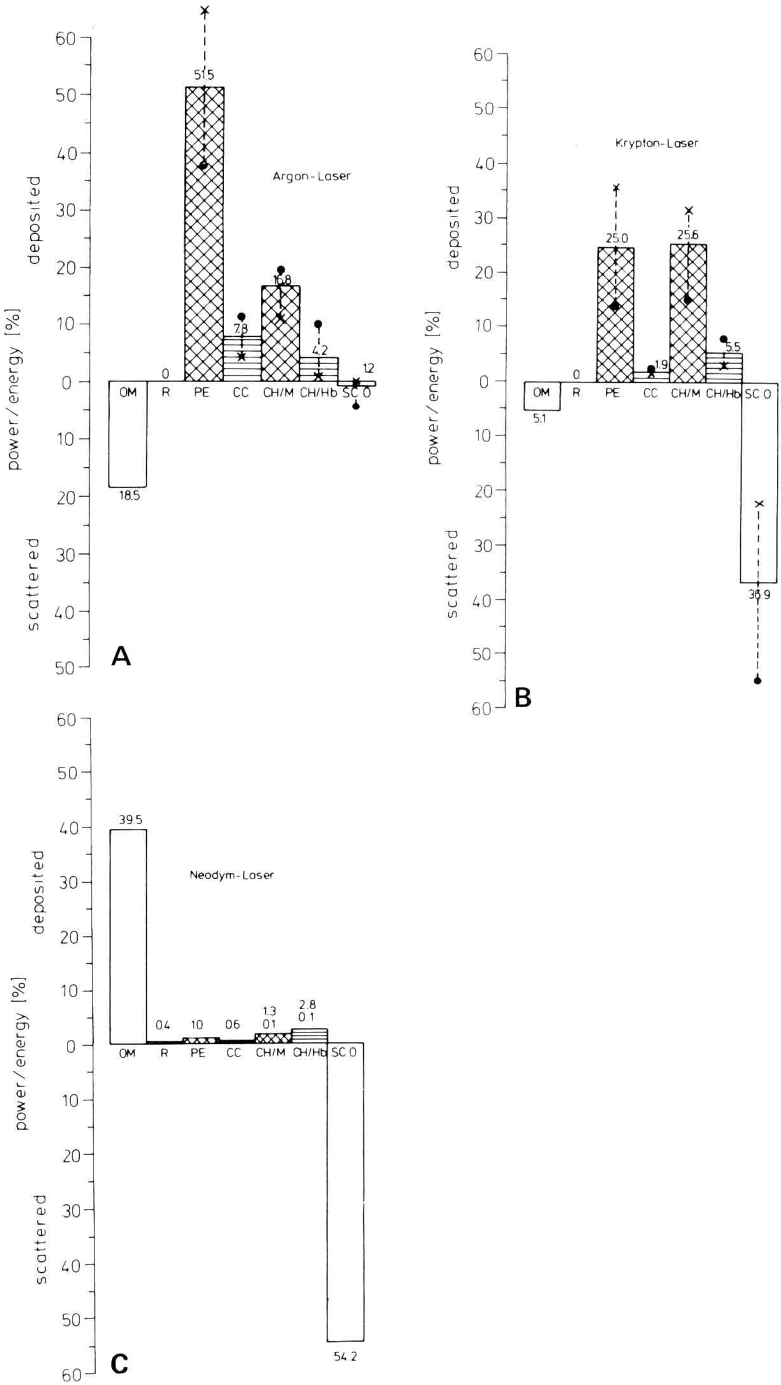


Fig. 1. The absorbing layers of the human ocular fundus, concerning the situation in both the fovea and the mid-periphery.

and, thus, was selected for the following calculations as representative of the entire fundus. The diagram of Fig. 2 show the calculated absorption values.

In accordance with the above schematic section, the ocular fundus was divided into the following layers: retina (R), pigment epithelium (PE), choriocapillaris (CC), choroid–melanin absorption (CH/M) and choroid–hemoglobin absorption (CH/Hb). The incident radiation first has to pass through the ocular media, indicated by OM, leading to an attenuation either by scattering or by absorption. The ocular transmission data are taken from Gerraets and Berry (1968). That part of the incident radiation, which is neither dissipated in the ocular media nor absorbed in the fundus, reaches the sclera and orbita respectively (Sc, O). If the dissipation of radiation both in the ocular media and the sclera and orbita is mainly due to absorption, the corresponding columns were plotted upwards; if the dissipation is mainly due to scattering, the corresponding columns were plotted downwards. The columns in the diagram indicate average absorption values, the absorption of melanin being indicated by crossed hatching and the absorption of hemoglobin by horizontal hatching. The absorption values of the diagrams are to be understood in terms of that percentage of the incident radiation which actually is absorbed or dissipated in the corresponding layer, i.e. if we assume that 100% of the energy is falling onto the surface of the cornea, then, in the case of the argon laser, for example, 18.5% is dissipated in the ocular media, nothing is absorbed in the retina, 51.5% is absorbed in the pigment epithelium, 7.8% is absorbed in the choriocapillaris, 16.8% is absorbed by melanin in the choroid, 4.2% is absorbed by hemoglobin in the choroid and 1.2% reaches the sclera and orbita. The bars in the case of the


Argon-Laser
Krypton-Laser
Neodym-Laser
power/energy [%]
deposited
scattered
OM
R
PE
CC
CH/M
CH/Hb
SC O
51.5
7.8
16.8
4.2
1.2
18.5
25.0
1.9
25.6
5.5
5.1
36.9
39.5
0.4
1.0
0.6
1.3
0.1
2.8
0.1
54.2
A
B
C

argon and krypton lasers indicate the individual variations of absorption, the maximum and minimum absorption values being calculated by assuming maximum and minimum absorption in *all* layers simultaneously: the crosses indicate the maximum absorption in all layers and the dots indicate the minimum amount of absorption. Because of a lack of data in the literature in the case of the neodymium laser in the infrared wavelengths, we can only present mean values which, in the case of melanin absorption in the choroid, are based on estimated absorption values.

RESULTS

We may draw the following conclusions:

1. At the wavelengths of the *argon laser* (about 500 nm; see Fig. 2A), the main part of the incident radiation is absorbed in the pigment epithelium (51.5%), whereas only a relatively small part is deposited in the choroid: the hemoglobin in the choriocapillaris absorbs 7.8%, the melanin in the choroid 16.8% and the hemoglobin in the remaining choroid 4.2%. The rest is dissipated in the ocular media (18.5%) and practically nothing reaches the sclera and orbita (1.2%). The absorption of argon-laser radiation thus mainly takes place in the *inner* layers of the fundus.

2. In the case of the *krypton laser* (647 nm; see Fig. 2B), the situation is quite different: the melanin in the pigment epithelium and the choroid absorbs nearly the same amount of the incident radiation (25.0 and 25.6% respectively). In addition 1.9 and 5.5% are absorbed by hemoglobin in the choriocapillaris and the remaining choroid respectively, so that totally 33% is deposited in the choroid. An enormous part of the incident radiation is transmitted to the sclera (36.9%); only 5.1% is dissipated in the ocular media. The absorption of krypton-laser radiation thus equally takes place both in the *inner* and the *outer* layers of the fundus.

3. Because of a lack of data in the case of the *neodymium laser* a wavelength of 1064 nm (see Fig. 2C), we had to confine our calculations to an estimation of the absorption characteristics regarding only the spectral transmissivity of the different tissues; in reality the absorption of neodymium-laser radiation is increased by scattering. Our calculations show enormous

Fig. 2. The distributions of deposit and scattering of incident radiation power or energy over the different layers of the fundus and the ocular media. (A) Mid-periphery; wavelength 500 nm, representative of the 488 and 514.5 nm argon-laser lines. (B) Mid-periphery; wavelength 647 nm, krypton laser. (C) Mid-periphery; wavelength 1064 nm, neodymium laser. If the dissipation of radiation in the different layers is due mainly to absorption, the corresponding columns are plotted upwards, if the dissipation is mainly due to scattering, the corresponding columns are plotted downwards. The columns indicate average values, the absorption of melanin being indicated by crossed hatching and the absorption of hemoglobin by horizontal hatching. The percent values are to be understood in terms of that part of the incident radiation which actually is deposited or scattered in the corresponding layer, the summation over all layers amounting to 100%; OM = ocular media; R = retina; PE = pigment epithelium; CC = choriocapillaris; CH/M = choroid–melanin absorption; CH/Hb = choroid–hemoglobin absorption, SC, O = sclera and orbita.

losses both in the ocular media (39.5%) and in the sclera and orbita (54.2%). Only the remaining 6.3% is deposited in the ocular fundus with 1% being absorbed by the pigment epithelium and 4.9% by the choroid. In the choroid the absorption of hemoglobin (0.6 and 2.8%) surpasses the absorption of melanin (1.3%). In addition there is a small contribution of water absorption: 0.2% in the choroid and 0.4% in the retina. These small values are to be considered as lower limits, which in reality are increased by scattering processes. With respect to the spectral absorption characteristics, the absorption of neodymium-laser radiation thus mainly takes place in the *outer* layers of the fundus.

The above calculations are considered to be representative of the situation in the mid-periphery of melanin and hemoglobin absorption of the entire fundus; in the *fovea* there is the additional absorption by xanthophyll which is considered to be present mainly in the upper layers of the foveal retina. As xanthophyll does not show any absorption at wavelengths longer than about 550 nm, the only significant difference between the absorption characteristics of the fovea and the mid-periphery should be expected in the case of the *argon laser* at wavelengths of 488 and 514.5 nm. Because of the strong

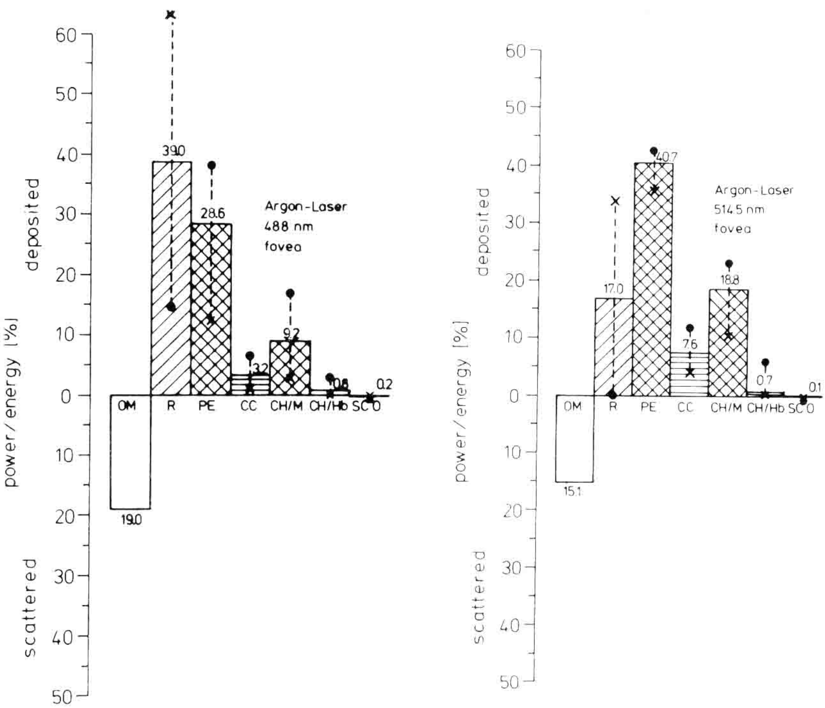


Fig. 3. The distribution of deposit and scattering of incident radiation power or energy is shown over the different layers of the fundus and the ocular media (left) Fovea; wavelength 488 nm, argon laser (right) Fovea; 514 nm, argon laser. For explanation of symbols used see Fig. 2.