Comparison of Diode Lasers in soft- tissue surgery using

cw- and superpulsed mode: an in vivo study.



by



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# **Acknoledgement**

# Abstract

**Purpose :**

Dental soft tissue surgery by diode lasers in cw- mode often causes carbonization of the tissues with following necrosis and a delay of wound healing.

In vitro studies have already shown, that superpulsed diode laser surgery has much less disadvantages for the tissues in histological approach.

Purpose of this study is to investigate in vivo, if superpulsed mode of operation can realize an improvement for surgeon and patient in soft tissue surgery.

**Materials and methods :**

26 patients were treated by diode lasers in different modes of operation for soft tissue surgery. 12 patients were treated by superpulsed Elexxion Claros diode laser :

810 nm; 10- 50 W $P_{peak}$ ; 10- 20 $\mu$s pulse duration; 12000- 20.000 Hz; 400 $\mu$m fiber and 14 patients were treated by Vision MDL-10 diode laser : 980 nm; 2,5 W; cw- mode and also 400 $\mu$m fiber.

Clinical treatment was documented by photos and questionnaires for patients and surgeons. Questions concerned: carbonization, coagulation, cutting speed, pain, swelling, bleeding, need for drugs, functional reduction and fibrine layer on wounds- during treatment, directly after treatment, after 1 day, after 3 days and after 1 week.

**Results :**

The clinical observations and the questionnaires showed in most cases significant differences between cw- mode and superpulsed diode laser treatment in surgery.

There was less carbonization in the superpulsed group.

The cutting speed was higher and the cut itself more defined and deeper by using superpulsed mode.

Superpulsed laser treatment had a shorter healing time than cw- mode treatment; the fibrine layer was build faster and also the removal of it was faster.

There was often no swelling after superpulsed diode laser treatment; and if a swelling occured it was smaller and quicker gone as in cw- mode treatment.

The duration of pain was shorter and the amount of pain smaller in the superpulsed group, therefore the patients in the superpulsed group needed less analgetic drugs.

There was less functional reduction in time and amount for the superpulsed group.

Only coagulation ability was better in the cw- mode group.


**Conclusion :**

Clinical studies have shown that superpulsed diode laser surgery is superior to continuous wave done treatment. Carbonization and thermal damage of the tissues can be reduced to a minimum, therefore healing is faster as in cw- mode surgery. Generation of a soft tissue cut is faster and more precise. Patients have less pain; in amount and time period. The need of drugs is reduced. There are less functional restrictions and there is less swelling. The advantages of superpulsed mode of operation  for soft tissue diode laser surgery are evident. Continuous wave mode should no longer be implemented in diode laser surgery.

# 1. Introduction

## 1.1 Diode lasers

Diode lasers are semiconductors, mainly with *GaAs* compounds and mixed crystals. The composition of the mixed crystals, the kind of *GaAs* compound and the temperature determine the wavelength. In diode lasers the laser beam is generated directly at the p-n junction out of electrical energy; no arc- or flashlamps are needed for pumping, therefore the efficiency is about 35- 50 % (76,141).
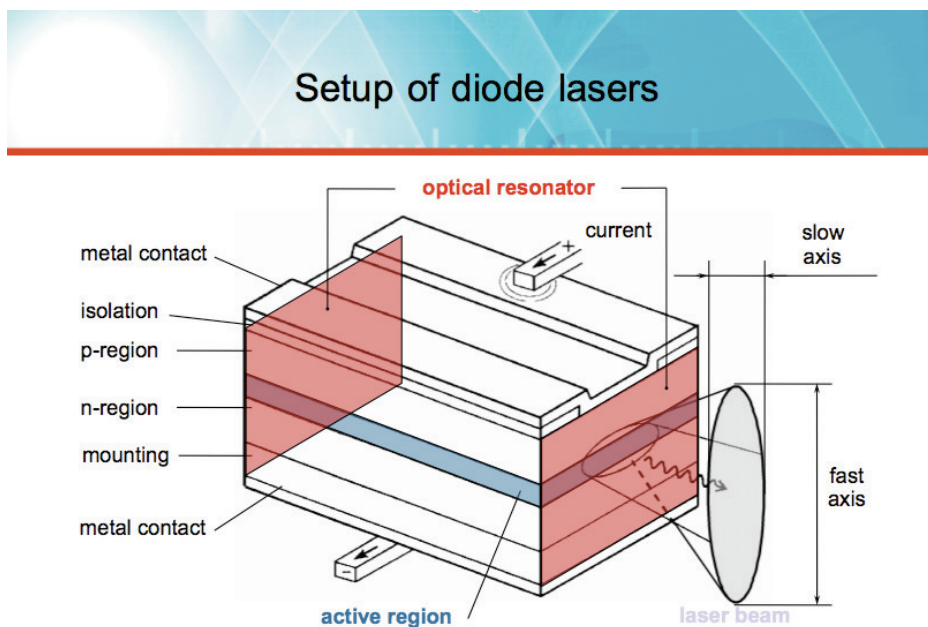


( Meister J,Franzen R: Diode Lasers, Aachen Institute for Laser Dentistry, M4, ED2006 )

There are no real resonators in common sense, the dimensions are particularly small ( 0,1 dm$^3$/ kw ). Because of the slit- diffraction at the p-n junction of the semiconductor the beam profile is elliptical and highly divergent. It has to be collimated before use. The output power from a diode is only in the mW region, so several diodes have to be arranged in arrays, bars and stacks to achieve an output power in the W range.
The focussed intensity can reach $10^4$- $10^6$ W/ cm$^2$.

Diode lasers for dentistry operate in the near infrared region. The most commonly used wavelengths are 810, 940 and 980 nm (141), because these wavelengths are very well absorbed by pigmented tissues, haemoglobine and melanin, which makes the diodes suitable for soft tissue surgery, endodontics, periodontics and LLLT (57,72,141).

The history of diode lasers started 1962 with the first *GaAs* diode laser, 840 nm, pulsed in fluid *He* or $N_2$. It was developed by IBM, General Electric and Lincoln Laboratories.(155). The first red diode laser was introduced.

1966 the first fiber to guide the laser beam was created.

In 1970 the Bell Laboratories produced the first cw- mode diode laser (155).

In 1995, on the IDS, the first diode laser for dentistry was shown. It was an 810 nm diode laser with cw mode. (133). Peak power was 6 W.

1999 diode lasers with 10- 15 W followed.

2000 a short pulsed diode laser with 810 nm, 20 W, 50 $\mu$s pulse and an average power of 2,0- 6,7 W was introduced, which showed a faster cutting and only 50 % of the necrosis zone of an cw- mode diode laser. (156).

2002 the peak power reached 30 W with a pulse duration of 9 $\mu$s, a frequency of 20000 Hz and a limited average power of 10 W. Today frequencies up to 30000 Hz and peak powers of 50 W are possible. To gain a sufficient result the peak power has to be more than 8 W in this case. (141).


During the first years of diode laser treatment in dentistry only cw mode was possible. Several studies at that time showed that cw mode and 1 W was enough to reach a bactericidal effect on and in roots and root canals, so as on implant surfaces. (13- 16,51,88,106,118,120,156). Application of 3- 4 W in cw mode led very fast to carbonization of the soft tissue; the carbonization caused higher absorption followed  by a heavy thermal damage and necrosis of the tissue. (71,146,149,150,156).

To approach better results in soft tissue treatment without much carbonization it was necessary to interrupt the cw mode. That was done by chopping the cw mode. Pulses down to several 100 $\mu$s were realized. (141,97,145). The peak power of the pulses was in fact not higher than the peak power of the cw mode pulse, but the applied dose was decreased and the carbonization and thermal damage was reduced.

Operation modes of a diode laser
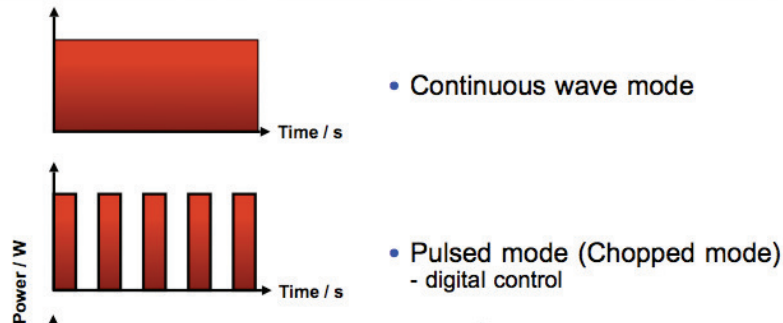
( Meister J,Franzen R: Diode Lasers, Aachen Institute for Laser Dentistry, M4, ED 2006 )

A further progress were pulse durations of 9 $\mu$s, a frequency of 20000 Hz and a peak power of 50 W, which could only be generated by DPL (digital pulse technique).

Using these parameters could generate a fast, sharply edged cut nearly without thermal damage of the surrounding tissue and only minimal carbonization at the cutting edges. (17,24,26,34,35,109,153,154,156).

To make a statement about the laser - tissue interactions something about the general mechanisms of laser irradiation has to be said.

If a laser beam hits the tissue surface 4 different effects can be noticed. (67,68)

1. Reflection

2. Transmission

3. Scattering

4. Absorption

Very important for a surgical effect on the tissue is the absorption of laser light. The kind of tissue and the wavelength are essential for absorption. There are some more factors been involved in laser- tissue interactions, so as the frequency, the dose applied, the pulse duration, power density and very important: the mode of operation ( cw, pulsed, superpulsed ) which is a main question of the in vivo studies done here.

Dependend on the just mentioned factors there are different effects to be watched in the tissue. (52,67,68,151,152)

Photodynamical effects

Photochemical effects

Thermal effects

(34,64,67,68,71,146,147,148,149,150,151,152)


T= 40- 60 °C:  oedema, functional imbalance of metabolism
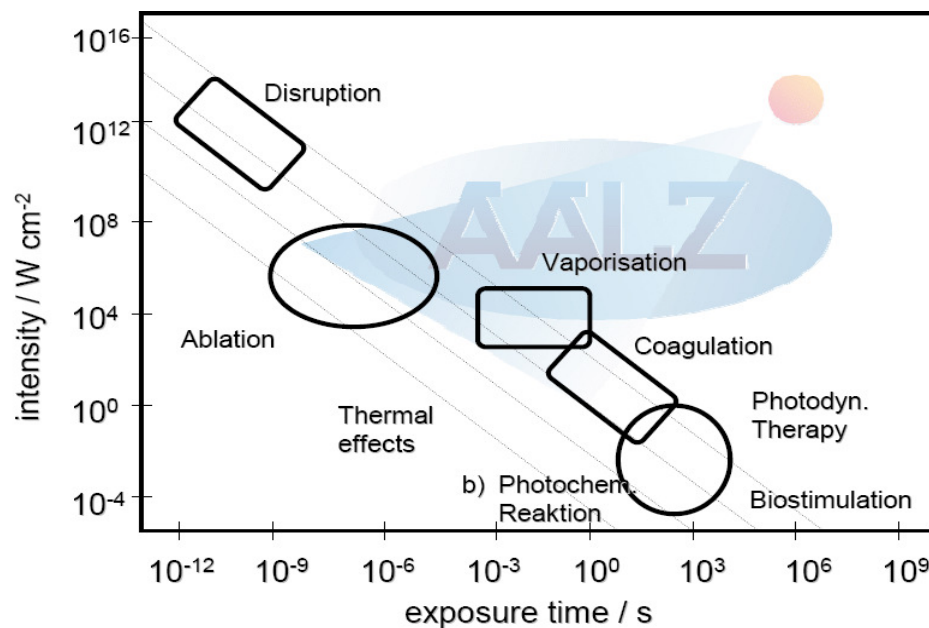
                ( up to 50°C reversibel )

T= 60- 100°C:  denaturation of the proteins, coagulation, contraction

                because of dehydration

T > 100°C :  disruption, evaporation of water, ablation

T > 150°C :  vaporisation, ablation

T > 300°C :  carbonisation



( Franzen R, Meister J: Dosimetry. Aachen Institute for Laser Dentistry, M3, ED 2006 )

## 1.2 Diode lasers in dentistry

As mentioned above diode lasers were used in dentistry since1995.

Mostly with a wavelength of 810 nm. Later the wavelength 980 nm follows and recently a wavelength of 940 nm is in progress.

In comparison to other lasers the diodes are more economical, the construction is more simple, laser light is generated directly from electrical energy, service periods are rare ( maintainance only in intervals of 10000 hours ) and the efficiancy is high. The laser beam is guided through a quarz- fiber, which makes it easier to reach problematic zones in the oral cave. Unfortunately diode lasers are only applicable in soft tissue procedures, endodontics, periodontics and LLLT, but not practicable for the ablation of hard tissues.

In soft- tissue treatment the diode lasers have similar effects than the Nd:YAG laser, which is not so far away regarding to the wavelength ( 1064 nm ).

Diode lasers are established in endodontical treatment because of the good bactericidal effect ( 2,13-15,26,28,29,57,72,98 ).

Diodes are implemented in periodontal treatments and periimplantitis to remove granulated tissue and to sterilize the surface of root and implant (2,11,13,16,18-23,40,50,57,60,72,80,82,85,104,105,134-136,139,140,144).

Also in little surgery diodes are used because of several advantages:
- efficient cutting
- good haemostasis
- nearly without bleeding and therefore good visibility of the op site
- mostly no sutures needed
- no or only small post op oedema
- bactericidal effect
- pain reduction post and intra op treatment
- no secondary bleeding
- precision of cut
- calculated depth of cut
- reduced application of drugs (antibiotics, analgetics..)
- only minimal destruction of adjacent tissues
- uncomplicated handling

- high patient acceptance
- low level of scar forming
- use on patients with haemorrhagic diathesis without or only with little substitution
- good handling due to fiber optics
- reduction of needed instruments ( change of parameters- different effects )
- treatment duration shorter ( no suture, not often change of instrument..)
- biostimulation of the surrounding tissue

  (1,3-10,12,17,25-27,30-39,42-49,57-69,72,74,77,81,86-89,91-97,106,
  109-114,116,119-132,138,141,142,145-154,156)

In the beginning soft tissue surgery by diodes was limited because of the low peak powers and the cw- mode as only mode of operation. The doses which were applied to the soft tissue led very fast to carbonization, thermal damage and necrosis of the tissue if the power exceeds 3-4 W in cw- mode. To achieve a better result the dose had to be reduced.

This can be done by decreasing the power, but then there will be no sufficient cutting ability. Another way is to shorten the treatment time, or to split the continuous wave into pulses; and change the frequency of the pulses.

By using mechanical shutters the cw- mode of the diode was changed into a chopped mode, the dose was reduced, but the peak powers of the pulses equaled the peak powers of the cw- mode. Carbonization was reduced for a certain degree but no efficient cutting could be done. The peak power of the pulses was not sufficiently high enough. So the management of the pulses was changed from mechanical to digital. (DPL). Now very short pulses with high peak powers could be generated to avoid carbonization and thermal damage as good as possible. Several studies in the recently past years have shown, that short pulses with high peak powers could generate a much better result than lower powers with longer pulse duration. (17,24,26,34,35,109,153,154)

Already Bach et al. (109 ) could show 2008 in vitro, that different modes of operation; cw- pulsed- superpulsed; led to different effects.

Result of the study was the suggestion that cw- mode diodes should no longer be used in soft tissue surgery because of the high amount of thermal damage and necrosis of the

adjacent tissue. The superpulsed diode had much less carbonization and thermal damage as side effect. Interestingly 980 nm and 810 nm diodes have been used in that study-- but histologically there was no difference between the 810 nm and 980 nm diode; only the mode of operation was responsible for the grade of cell damage.

Case reports of Maiorano et al. ( 153 ) from 2006 could show in vivo that superpulsed diode lasers caused only minimal involvement of the adjacent tissue during surgery, that there was a clean cut without thermal side effects, but still coagulation. Result was an excellent postoperative condition with minimal swelling and pain.

Until now there are unfortunately no clinical or in vivo studies to show the different results of diode laser soft tissue surgery with different modes of operation. Theoretically the difference in treatment results with cw- mode and pulsed is comprehencible; in vitro it is shown already ( 109 ) but in vivo it is still unproven. It would be very nice to have no more carbonization during surgical treatment, because carbonization causes a higher grade of absorption and due to that a higher thermal damage of the tissue, which will lead to more discomfort of the patient and a delayed wound healing.

Therefore it is a major task of this thesis to answer the question if highly pulsed diode lasers are more suitable for soft tissue surgery than cw- mode diode lasers and how the achievable results differ.

Of course a number of noticed parameters in the following study, so as patient`s pain, influence on oral hygiene, reduced masticatory or lingually function etc. are subjective criteria, but at least it can show a tendency for the right direction to go.

# 2. Materials and methods

Within a period of 5 months 26 dental surgery treatments have been done by diode laser. Predominantly simple laser cuts, but also removal of hyperplasia and fibromas, exposure of teeth and implants, abscess incision and gingivo- and vestibuloplasty.

**14 patients** have been treated by *Vision MDL-10* diode laser :

• Vision Lasertechnik GmbH, Lügensteinweg 27, 30890 Göxe, Germany

- cw- mode or 20 Hz mode

- max. 2,5 W

- 200 $\mu$m and 400 $\mu$m fiber

- 980 nm

All procedures have been done with: **cw mode; 2,5 W; 400 $\mu$m fiber**

| Treatment | $P_{peak}$ | Mode |
|---|---|---|
| Single cut (4x) | 2,5 W | cw |
| Incision abscess (1x) | 2,5 W | cw |
| Hyperplasia (1x) | 2,5 W | cw |
| Exposure implant (3x) | 2,5 W | cw |
| Exposure tooth (1x) | 2,5 W | cw |
| Fibroma (2x) | 2,5 W | cw |
| Gingivoplasty (1x) | 2,5 W | cw |
| Vestibuloplasty (1x) | 2,5 W | cw |

**12 patients** were treated by *Elexxion Claros* diode laser :



- Elexxion AG, Schützenstraße 84, 78315 Radolfzell, Germany
- 810 nm
- 10 mW- 50 W  $P_{peak}$
- 2,5 $\mu$s- cw pulse duration
- 200 $\mu$m, 300 $\mu$m, 400 $\mu$m and 600 $\mu$m fiber
- digitally superpulsed ( 8- 20.000 Hz )

| Treatment | $P_{peak}$ | Frequency | Pulse duration | $P_{avg}$ |
|---|---|---|---|---|
| Single cut (3x) | 50,0 W | 20.000 Hz | 11 $\mu$s | 11,0 W |
| Incision abscess (2x) | 10,0 W | 20.000 Hz | 20 $\mu$s | 4,0 W |
| Hyperplasia (1x) | 50,0 W | 12.000 Hz | 10 $\mu$s | 6,0 W |
| Frenectomy (1x) | 15,0 W | 20.000 Hz | 16 $\mu$s | 4,8 W |
| Exposure implants (2x) | 15,0 W | 15.000 Hz | 10 $\mu$s | 2,25 W |
| Exposure tooth (1x) | 25,0 W | 15.000 Hz | 10 $\mu$s | 3,75 W |
| Fibroma (2x) | 50,0 W | 12.000 Hz | 10 $\mu$s | 6,0 W |

All treatments have been done with the 400 $\mu$m fiber for better comparison.

Both lasers have been used with fibers in contact to tissue.

The fibers had been under permanent control for tidiness, because contaminated fibers decrease the applied energy, the cutting speed drops down, the treatment time prolongs and more thermal energy is given to the tissue (145).

After sufficient anesthesia, for abscess incision only superficial, in all other cases infiltration anesthesia, the treatment was done in consideration of the laser safety directions given for laser treatment of class 4 lasers.

Before, during and directly after laser treatment photos were taken and the patients had to fill in a questionnaire. Another questionnaire had to be done by the surgeon. 1 day, 3 days, 1 week, 2 weeks and sometimes 3 month later there was a recall to control the op sites clinically and to take some more photos. The patients had to fill in their questionnaires until 1 week after surgery. Asked subjects were intra- and postoperative pain, need of analgetic drugs, difficulties in oral hygiene or mastication. The surgeons questionnaire asked about cutting speed of the laser, bleeding intra- and post op, swelling, carbonization, coagulation and fibrine layer covering. Time schedule was the same as for the patients.

# Questionnaire

*for patient*

**Name:**                                              **Subject :  Laser treatment**

**<u>Pain :</u>**

**During laser treatment :**

| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|

**No pain**                                        **Unbearable pain**

**Directly after laser treatment :**

| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|

**No pain**                                         **Unbearable pain**

**1 day after laser treatment :**

| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|

**No pain**                                         **Unbearable pain**

**3 days after laser treatment :**

| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|

**No pain**                                         **Unbearable pain**

**1 week after laser treatment :**

| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|

**No pain**                                                         **Unbearable pain**

**Analgesic drugs needed :**

only 1 day            3 days            the first week            more than a week

**Reduced  masticatory or lingually function :**

only 1 day            3 days            the first week            more than a week

**Difficulties in oral hygiene :**

only 1 day            3 days            the first week            more than a week

# Questionnaire

*for surgeon*

**Name:**                                    **Subject :  Laser treatment**

## During laser treatment

**Speed of cutting**

| 0 | 1 | 2 | 3 |
|---|---|---|---|
| **very slow** | **slow** | **fast** | **very fast** |

**Carbonization**

| 0 | 1 | 2 | 3 |
|---|---|---|---|
| **no carbonization** | **little carbonization** | **carbonization** | **heavy carbonization** |

**Coagulation**

| 0 | 1 | 2 | 3 |
|---|---|---|---|
| **no coagulation** | **little coagulation** | **good coagulation** | **very good coagulation** |

## Directly post OP

**Bleeding**

| 0 | 1 | 2 | 3 |
|---|---|---|---|
| **No bleeding** | **little bit** | **bleeding** | **heavy bleeding** |

## 1 day post OP

**Bleeding**

| 0 | 1 | 2 | 3 |

**No bleeding**        **little bit**        **bleeding**        **heavy bleeding**

**Turgor, swelling**

| 0 | 1 | 2 | 3 |

**No swelling**        **little swelling**        **swelling**        **large swelling**

**Fibrine layer :**

| 0 | 1 | 2 | 3 |

**No layer**        **small region**        **mostly covered**        **completely  covered**

## 3 days post OP

**Bleeding :**

| 0 | 1 | 2 | 3 |

**No bleeding**        **little bit**        **bleeding**        **heavy bleeding**

**Turgor, swelling :**

| 0 | 1 | 2 | 3 |
|---|---|---|---|
| No swelling | little swelling | swelling | large swelling |

**Fibrine layer :**

| 0 | 1 | 2 | 3 |
|---|---|---|---|
| no layer | small region | mostly covered | completely covered |

**<u>1 week post OP</u>**

| 0 | 0 | 0 |
|---|---|---|
| bleeding | swelling | fibrine layer |

As already mentioned in the introduction the purpose and aim of this in vivo study is to show, that superpulsed diode lasers are more suitable for oral surgery than cw- mode diode lasers, because it is expected that there is nearly no carbonization and thermal damage of the adjacent soft tissue because of the very short pulse durations, the high peak power and high frequency.

Until now there are not enough data from in vivo studies available to support the supposed results, but in vitro studies already came to a similar resume.

( 24,34,35,109,132,153 )

The diode lasers used in this study are not of the same wavelength; on the one hand there is an 810 nm diode ( Elexxion Claros ) on the other hand a 980 nm diode ( Vision MDL- 10 ).

According to the wavelength it must be said that normally there is a stronger thermal effect using the 980 nm diode (72) but as shown in a recent in vitro study (109) from 2008, the mode of operation is much more responsible for the clinical results on soft tissue as the diode`s wavelength.

# 3. Results

## 3.1 Clinical results

To show the visual results of a soft tissue surgery treatment by diode laser in cw and superpulsed mode 2 similar cases were taken as example for all clinical cases. Treatment procedure was the same in both cases and the local sites were comparable.
In both procedures a fibroma was removed out of the inner lip.
Once on the right and once on the left side of the lower jaw.
For better comparison it would have been perfect if both treatments had been done on the same patient, but there was no such case during the investigation period.

### 3.1.a  1st case : as example for Vision MDL- 10; cw

Removal of fibroma by Vision MDL 10 diode laser:

980 nm;  cw mode;  2,5 W;  400 $\mu$m fiber;  contact mode

Female patient, 60 years old, hypertonia. No other general deseases.
18, 15, 25, 28, 36, 48 missing. Bridge 14- 16.
Fair oral care. General horizontal loss of bone. No periodontal problems.

Patient was often sucking on the fibroma.
Fibroma was situated at regio 43, inner lip. Diameter about 8 mm.

After little infiltration anesthesia with Ultracain DS® the fibroma was removed under permanent tension with the 400 $\mu$m fiber in contact.
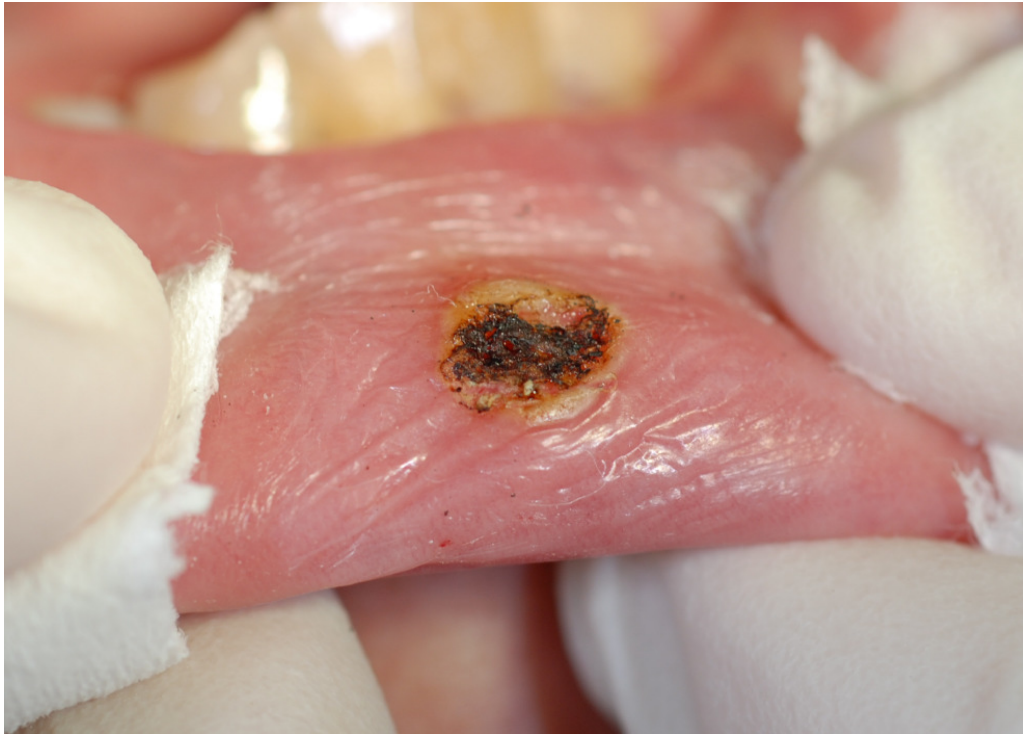
Before treatment.



During treatment  ( 980 nm; cw;  2,5 W;  400 $\mu$m fiber )

Because of the good absorption of the 980 nm wavelength in melanin and haemoglobine there was a sufficient cutting ability and no bleeding.



Directly after treatment.

The treatment procedure took a little longer because the cutting speed of the 980 nm diode in cw mode with only 2,5 W peak power was slow.
No bleeding because of the very good coagulation of the 980 nm diode,
but strong carbonization of the soft tissue was seen.
No sutures needed.
There was no pain or discomfort for the patient during the surgical procedure.
1 day after surgical treatment no secondary bleeding, but a little swelling and a fibrine layer that covered the wound was seen. The patient had no pain but the mastication, the lingual function and the oral hygiene was influenced.

1 day after surgical treatment.





3 days after surgical treatment

No bleeding, a little swelling and a fibrine covered wound was seen.

The patient had no longer functional limitations. No pain.

1 week after treatment

No bleeding and no more fibrine layer was seen.





3 months later. No rezidiv. Total recovery. No scar.

### 3.1.b  2nd case :  as example for Elexxion Claros; superpulsed

Removal of fibroma by Elexxion Claros diode laser.


810 nm; 50 W $P_{peak,}$ ; 12000 Hz; 10 $\mu$s pulse duration; 6 W $P_{avg}$ ;

400 $\mu$m fiber;  contact mode

Female patient, 72 years old, diabetic disorder. No other general deseases.

18- 28, 38- 35, 32-48 missing.

Total upper denture. Lower partial denture with clasps at 33, 34.

General horizontal and vertikal loss of bone. Fair oral care.

Fibroma was situated at regio 35, inner lip, lower jaw. Diameter about 11 mm.

After sufficient anesthesia with Ultracain DS® the fibroma was removed under good

tension with the 400 $\mu$m fiber in contact.



Before treatment ( little bleeding spot from injection of anesthesia )

During treatment

( 810 nm; 50 W $P_{peak}$; 12000 Hz; 10 $\mu$s pulse; 6 W $P_{avg}$; 400 $\mu$m fiber )



No bleeding because of good coagulation of 810 nm wavelength (good absorption in haemoglobine and melanin).

Extremly fast cutting speed because of high power, short pulses and high frequency.

The patient felt no discomfort or pain during the surgical treatment time.

Directly after treatment no bleeding of the wound, no sutures needed.

Good coagulation and only a little carbonization zone was seen.

Directly after treatment



1 day after treatment

3 days after treatment

No bleeding, no swelling. Wound is completely covered by fibrine layer.
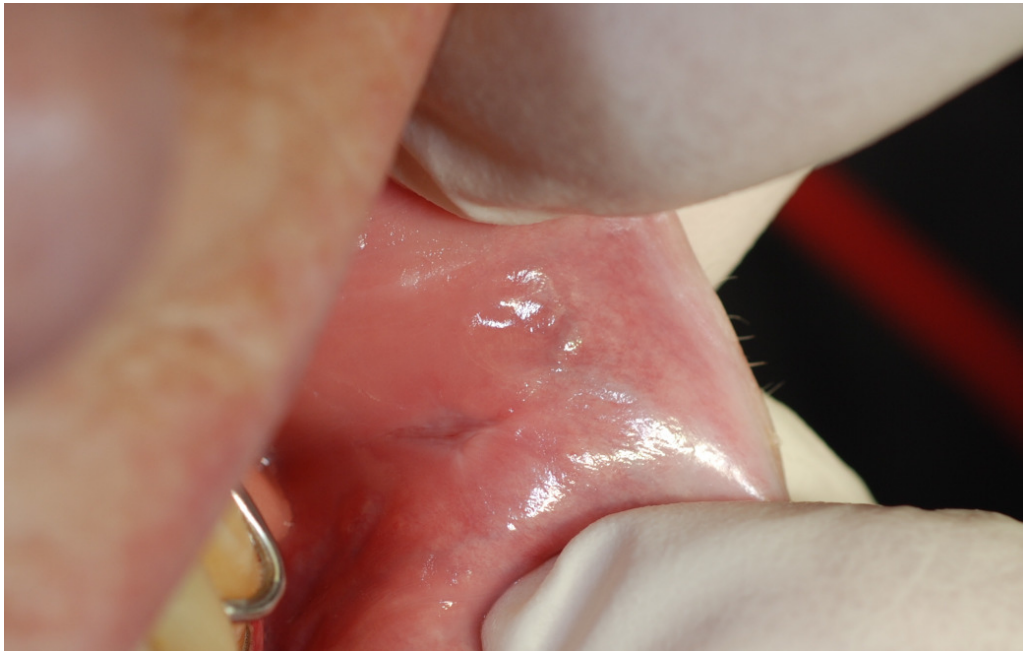Patient had no discomfort or pain.





1 week after treatment

No bleeding, no swelling, partial fibrine layer. Patient without any discomfort.

## 2 weeks after treatment

Nearly full recovery. Only a little impression of the soft tissue remained.

No rezidiv, no scar. Healing much quicker than with cw diode laser.

# 4. Results of questionnaires

In total there were 52 questionnaires to analyse.

26 from the patients and 26 from the surgeons.

## 4.1 Patient`s questionnaire :

### 4.1.a  VISION MDL- 10 treatment  ➡  14 patients; cw

**During laser treatment**

All patients felt no **pain** during laser treatment ( 100 % )

**Directly after laser treatment**

All patients without any **pain** ( 100 % )

**1 day after laser treatment**

| Number of patients | Pain: scale 0- 9 | Percentage of total number of patients |
|---|---|---|
| 3 | 0 ( no pain ) | 21,43% |
| 3 | 1 | 21,43% |
| 5 | 2 | 35,71% |
| 2 | 3 | 14,29% |
| 1 | 7  ( strong pain ) | 7,14% |

**3 days after laser treatment**

| Number of patients | Pain: scale 0- 9 | Percentage of total number of patients |
|---|---|---|
| 10 | 0  ( no pain ) | 71,43% |
| 3 | 1 | 21,43% |
| 1 | 7  ( strong pain ) | 7,14% |

**1 week after laser treatment**

| Number of patients | Pain: scale 0- 9 | Percentage of total number of patients |
|---|---|---|
| 13 | 0 | 92,86% |
| 1 | 5 | 7,14% |

**Analgesic drugs** needed

| Number of patients | Analgesic drugs needed | Percentage of total number of patients |
|---|---|---|
| 8 | No | 57,14% |
| 5 | Yes, 1 day | 35,71% |
| 0 | Yes, 3 days | 0% |
| 1 | Yes, 1 week | 7,14% |

**Reduced masticatory or lingually function**

| Number of patients | Time of reduction | Percentage of total number of patients |
|---|---|---|
| 0 | No reduction | 0% |
| 4 | 1 day | 28,57% |
| 8 | 3 days | 57,14% |
| 1 | 1 week | 7,14% |
| 1 | more than a week | 7,14% |

**Difficulties in oral hygiene**

| Number of patients | Time of handicap | Percentage of total number of patients |
|---|---|---|
| 0 | No | 0% |
| 5 | 1 day | 35,71% |
| 8 | 3 days | 57,14% |
| 0 | 1 week | 0% |
| 1 | more than a week | 7,14% |

**4.1.b  ELEXXION CLAROS treatment ➡ 12 patients; superpulsed**

**During laser treatment**

All patients felt no **pain** during laser treatment. ( 100 % )

**Directly after laser treatment**

All patients without any **pain** ( 100 % )

**1 day after laser treatment**

| Number of patients | Pain: scale 0- 9 | Percentage of total number of patients |
|---|---|---|
| 5 | 0 ( no pain ) | 41,67% |
| 3 | 1 | 25% |
| 3 | 2 | 25% |
| 1 | 3 | 8,33% |

**3 days after laser treatment**

| Number of patients | Pain: scale 0- 9 | Percentage of total number of patients |
|---|---|---|
| 8 | 0 ( no pain ) | 66,67% |
| 4 | 1 | 33,33% |

**1 week after laser treatment**

| Number of patients | Pain: scale 0- 9 | Percentage of total number of patients |
|---|---|---|
| 12 | 0 ( no pain ) | 100% |

**Analgesic drugs** needed

| Number of patients | Analgesic drugs needed | Percentage of total number of patients |
|---|---|---|
| 8 | No | 66,67% |
| 3 | Yes, 1 day | 25% |
| 1 | Yes, 3 days | 8,33% |

**Reduced masticatory or lingually function**

| Number of patients | Time of reduction | Percentage of total number of patients |
|---|---|---|
| 2 | No reduction | 16,67% |
| 4 | 1 day | 33,33% |
| 6 | 3 days | 50% |

**Difficulties in oral hygiene**

| Number of patients | Time of handicap | Percentage of total number of patients |
|---|---|---|
| 1 | No | 8,33% |
| 5 | 1 day | 41,67% |
| 6 | 3 days | 50% |

## 4.2. Surgeon`s questionnaire

**4.2.a  VISION MDL- 10 treatment ➡ 14 patients; cw**

**During laser treatment**

**Speed of cutting** was all time low ( 100 % )

**Carbonization**

| Number of patients | Degree of carbonization | Percentage of total number of patients |
|---|---|---|
| 0 | no carbonization | 0% |
| 2 | little carbonization | 14,29% |
| 7 | carbonization | 50% |
| 5 | heavy carbonization | 35,71% |

**Coagulation**

| Number of patients | Degree of coagulation | Percentage of total number of patients |
|---|---|---|
| 0 | no coagulation | 0% |
| 0 | little coagulation | 0% |
| 8 | good coagulation | 57,14% |
| 6 | very good coagulation | 42,86% |

**Directly post op**

| Number of patients | Degree of bleeding | Percentage of total number of patients |
|---|---|---|
| 11 | no bleeding | 78,57% |
| 3 | little bleeding | 21,43% |

**1 day post op**

There was no recognizable **bleeding** ( 100 % )

**Swelling**

| Number of patients | Degree of swelling | Percentage of total number of patients |
|---|---|---|
| 4 | no swelling | 28,57% |
| 9 | little swelling | 64,29% |
| 1 | swelling | 7,14% |

**Fibrine layer**

| Number of patients | Size of fibrine layer | Percentage of total number of patients |
|---|---|---|
| 4 | no layer | 28,57% |
| 5 | small region | 35,71% |
| 5 | mostly covered | 35,71% |

**3 days post op**

There was no recognizable **bleeding** ( 100 % )

**Swelling**

| Number of patients | Degree of swelling | Percentage of total number of patients |
|---|---|---|
| 8 | no swelling | 57,14% |
| 6 | little swelling | 42,86% |

**Fibrine layer**

| Number of patients | Size of fibrine layer | Percentage of total number of patients |
|---|---|---|
| 2 | no layer | 14,29% |
| 3 | small region | 21,43% |
| 3 | mostly covered | 21,43% |
| 6 | completely covered | 42,86% |

**1 week post op**

No **bleeding** ( 100 % ) left; no **swelling** ( 100 % ) left.

6 patients of 14 still had a little **fibrine layer** ( 42,86 % ).

**4.2.b   ELEXXION CLAROS treatment ➡ 12 patients; superpulsed**

**During laser treatment**

**Speed of cutting**

| Number of patients | Speed of cutting | Percentage of total number of patients |
| --- | --- | --- |
| 0 | slow | 0% |
| 3 | fast | 25% |
| 9 | very fast | 75% |

**Carbonization**

| Number of patients | Degree of carbonization | Percentage of total number of patients |
| --- | --- | --- |
| 4 | no carbonization | 33,33% |
| 4 | little carbonization | 33,33% |
| 4 | carbonization | 33,33% |
| 0 | heavy carbonization | 0% |

**Coagulation**

| Number of patients | Degree of coagulation | Percentage of total number of patients |
| --- | --- | --- |
| 0 | no coagulation | 0% |
| 2 | little coagulation | 16,67% |
| 10 | good coagulation | 83,33% |
| 0 | very good coagulation | 0% |

**Directly post op**

**Bleeding**

| Number of patients | Degree of bleeding | Percentage of total number of patients |
|---|---|---|
| 7 | no bleeding | 58,33% |
| 5 | little bleeding | 41,67% |

**1 day post op**

There was no recognizable **bleeding** ( 100 % )

**Swelling**

| Number of patients | Degree of swelling | Percentage of total number of patients |
|---|---|---|
| 5 | no swelling | 41,67% |
| 7 | little swelling | 58,33% |
| 0 | swelling | 0% |

**Fibrine layer**

| Number of patients | Size of fibrine layer | Percentage of total number of patients |
|---|---|---|
| 2 | no layer | 16,67% |
| 6 | small region | 50% |
| 4 | mostly covered | 33,33% |

**3 days post op**

There was no recognizable **bleeding**. ( 100 % )

**Swelling**

| Number of patients | Degree of swelling | Percentage of total number of patients |
|---|---|---|
| 11 | no swelling | 91,67% |
| 1 | little swelling | 8,33% |

**Fibrine layer**

| Number of patients | Size of fibrine layer | Percentage of total number of patients |
|---|---|---|
| 0 | no layer | 0% |
| 4 | small region | 33,33% |
| 5 | mostly covered | 41,67% |
| 3 | completely covered | 25% |

**1 week post op**

No **bleeding** ( 100 % ); no **swelling** ( 100 % ) left.

4 of 12 patients still had a little **fibrine layer** ( 33,33 % )

# 5. Summary of results

## 5.1 Surgeon`s results

The visible clinical results could be described as followed :

During surgical treatment and directly after treatment the soft tissues at the involved area were more carbonized by the Vision MDL- 10 laser, which ran in cw- mode;

35,71 % heavy carbonization.

The superpulsed laser , Elexxion Claros, showed sometimes carbonization too, but the amount of carbonization was much smaller, the color of the carbonized zones was more brown than black and in a third of all cases there was no carbonization at all.

| Carbonization | cw- mode | superpulsed |
|---|---|---|
| no | 0% | 33,33% |
| little | 14,29% | 33,33% |
| medium | 50% | 33,33% |
| heavy | 35,71% | 0% |

Coagulation was good with both lasers, in some situations ( a patient with anticoagulant therapy - Marcumar® - INR > 2,5 ; not substituted ) the 980 nm diode in cw- mode ( Vision MDL- 10 ) had a better coagulation.

| Coagulation | cw- mode | superpulsed |
|---|---|---|
| little | 0% | 16,67% |
| good | 57,14% | 83,33% |
| very good | 42,86% | 0% |

Both lasers did not allow common bleedings post op, but in some cases there was a little oozing bleeding; more after superpulsed laser therapy than after cw- mode treatment.

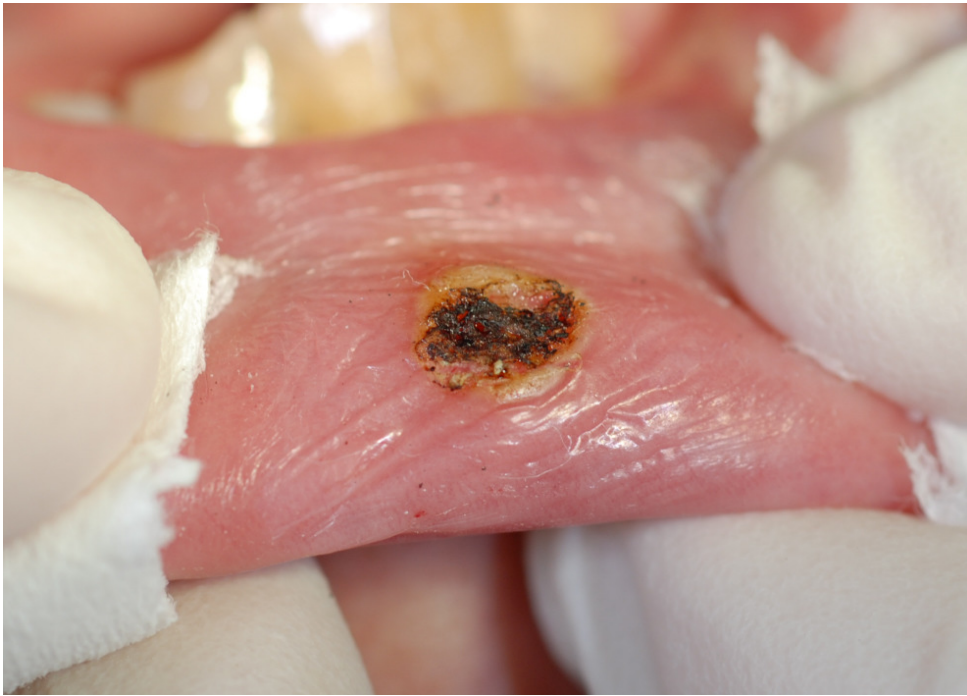| Bleeding | cw- mode | superpulsed |
|---|---|---|
| post op : no | 78,57% | 58,33% |
| post op : little | 21,43% | 41,67% |

The **speed of cutting** was very different, the superpulsed Elexxion diode laser cutted much easier and faster than the Vision diode laser.
The surgical procedure was done much faster by using the superpulsed laser.

| Speed of cutting | cw- mode | superpulsed |
|---|---|---|
| low | 100% | 0% |
| fast | 0% | 25% |
| very fast | 0% | 75% |

On pictures taken after the surgical procedure the wound areas looked much nicer when the treatment was done by superpulsed Elexxion laser.
The cutting margins had sharper edges, the cut was more straight and seemed to go deeper into the tissue with one movement.

cw mode



superpulsed

The following days there was a swelling of the treated soft tissue in different sizes noticed for both laser systems.

| Swelling 1 day post op | cw- mode | superpulsed |
|---|---|---|
| no swelling | 28,57% | 41,67% |
| little swelling | 64,29% | 58,33% |
| swelling | 7,14% | 0% |

The swelling tendency of the superpulsed diode laser was lower and there was no swelling in significant more cases.

| Swelling 3 days post op | cw- mode | superpulsed |
|---|---|---|
| no swelling | 57,14% | 91,67% |
| little swelling | 42,86% | 8,33% |

After 3 days there was only in 8,33 % a little swelling left after superpulsed diode laser treatment but in the cw- mode group 42,86 % of the patients still had a recognizable swelling. One week after laser treatment there was no swelling left in both laser groups.

Another phenomenon to be watched was the fibrine layer.

| Fibrine layer 1 day post op | cw- mode | superpulsed |
|---|---|---|
| no layer | 28,57% | 16,67% |
| small region | 35,71% | 50% |
| mostly covered | 35,71% | 33,33% |

Including 4 osteotomy cuts for cw- mode and 3 for superpulsed mode.

In total there was more fibrine layer after superpulsed treatment.

| Fibrine layer 3 days post op | cw- mode | superpulsed |
|---|---|---|
| no layer | 14,29% | 0% |
| small region | 21,43% | 33,33% |
| mostly covered | 21,43% | 41,67% |
| completely covered | 42,86% | 25% |

3 days post op the fibrine covering of the wound areas had increased in both groups.

| Fibrine layer 1 week post op | cw- mode | superpulsed |
|---|---|---|
| no more layer | 57,14% | 66,67% |
| still little layer | 42,86% | 33,33% |

1 week post op there was more reduction of fibrine layer in the superpulsed group, while the cw- mode group still had a partial fibrine covered area in 42,68 % of the patients.

## 5.2 Patient`s results

During laser treatment and directly after laser treatment no patient felt pain or discomfort because there was anesthesia given in every treatment case.

| Pain 1 day post op:<br>0= no pain<br>9= unbearable | cw- mode | superpulsed |
|---|---|---|
| 0 | 21,43% | 41,67% |
| 1 | 21,43% | 25% |
| 2 | 35,71% | 25% |
| 3 | 14,29% | 8,33% |
| 7 | 7,14% | 0% |

There were more patients without pain and the pain strength was on a lower level in the superpulsed group.

| Pain 3 days post op:<br>0= no pain<br>9= unbearable pain | cw- mode | superpulsed |
|---|---|---|
| 0 | 71,43% | 66,67% |
| 1 | 21,43% | 33,33% |
| 7 | 7,14% | 0% |

Now there were more patients without any pain in the cw- mode group and also patients with very mild pain were less in the cw- mode group. But still there was a special patient with continued heavy pain.

| Pain 1 week post op:<br>0= no pain<br>9= unbearable pain | cw- mode | superpulsed |
|---|---|---|
| 0 | 92,86% | 100% |
| 5 | 7,14% | 0% |

After 1 week all patients in both groups were free of pain, the only exception was the special patient of the cw- mode group.

For better understanding it has to be said that the mentioned patient was very algesic; a vestibuloplasty had been done and the extended denture was incorporated directly after laser treatment, so the healing was inhibited for a certain degree and the denture was grinding on the wound area all the time.

| Analgesic drugs needed | cw- mode | superpulsed |
|---|---|---|
| No | 57,14% | 66,67% |
| Yes, 1 day | 35,71% | 25% |
| Yes, 3 days | 0% | 8,33% |
| Yes, 1 week | 7,14% | 0% |

The need for analgesic drugs was higher in the cw- mode group, 42,85 %.

Need for medication in the superpulsed group: 33,33 % .

The above mentioned special patient needed a week of medication.

**Reduced masticatory or lingually function.**

| Reduced function | cw- mode | superpulsed |
|---|---|---|
| No | 0% | 16,67% |
| 1 day | 28,57% | 33,33% |
| 3 days | 57,14% | 50% |
| 1 week | 7,14% | 0% |
| more than 1 week | 7,14% | 0% |

The influence of the laser treatment on functional aspects as e.g. mastication  lasted in average 3 days.

In the cw- mode group even longer in 2 cases.

Only in the superpulsed group 16,67 % were without any functional limitations.

| Difficulties in oral hygiene | cw- mode | superpulsed |
|---|---|---|
| No | 0% | 8,33% |
| 1 day | 35,71% | 41,67% |
| 3 days | 57,14% | 50% |
| 1 week | 0% | 0% |
| more than 1 week | 7,14% | 0% |

Nearly the same result for difficulties in oral hygiene.

Average was as well 3 days.

Even here  there were patients without difficulties in the superpulsed group; 8,33 %.

# 6. Discussion

Classical surgical soft tissue treatment by scalpel has it`s relevancy, but in the last years soft tissue surgery by diode laser is in progress.

There are a lot of advantages for the surgeon:

- efficient and precise cutting with a calculated depth of cut
- good haemostasis- so nearly or completely without bleeding- and therefore better
  visibility of the place of interest.
-mostly no sutures needed
-only minimal destruction of the adjacent tissue ( in pulsed mode )
-uncomplicated handling due to fiber and variety of parameters
-shorter treatment time.

The patients have a lot of advantages also:
-they mustn`t be sutured
-no or only little post op oedema
-bactericidal reduction of the wound area
-no secondary bleeding
-low level of scar forming
-patients with haemorrhagic diathesis can be treated without or with only little substitution
-shorter treatment time
-biostimulation of the surrounding area
-reduced application of drugs because of pain reduction intra- and post op
   ( 1,3-10,12,17,25-27,42,43,57,72,106,129,141,145,146,153 ).

The reduction of pain during laser treatment and the better acceptance of laser treatment in comparison to conventional treatment could be proofed yet for restorative dentistry ( Matsumoto 1996, Keller- Hibst 1997-1998, Evans 2000, Takamori 2003 ) but in this cases the used lasers were not diode lasers.

Discussing the results from the study one certain thing has to be remembered.

The cw mode laser ( Vision MDL- 10 ) had always been used with 2,5 W and cw- mode.

So peak- and average power had always be the same; in every procedure.

That`s the main difference to the superpulsed laser ( Elexxion Claros ) which had been used with different parameters ; 10- 50 W peak power; 2,25- 11,00 W average power ; 12000- 20000 Hz; 10- 20 $\mu$s pulse duration.

The precise treatment parameters of the Elexxion Claros laser were :

| $P_{peak}$ | $P_{avg}$ | frequency | pulse duration |
|---|---|---|---|
| 6x  50 W | 3x  11,00 W | 6x  20000 Hz | 6x  10 $\mu$s |
| 1x  25 W | 3x  6,00 W | 3x  15000 Hz | 3x  11 $\mu$s |
| 3x  15 W | 1x  4,80 W | 3x  12000 Hz | 1x  16 $\mu$s |
| 2x  10 W | 2x  4,00 W | | 2x  20 $\mu$s |
| | 1x  3,75 W | | |
| | 2x  2,25 W | | |
| ⌀  **32,5 W** | ⌀  **6,00 W** | ⌀  **16750 Hz** | ⌀  **12,42 $\mu$s** |

The used peak power was sometimes 20 times higher than the peak power of the cw mode laser; and even the average power was more than double ( 2,4 times higher ). Regarding to this there was no doubt that the Elexxion laser would cut much easier and faster than the Vision laser. On the other hand the used powers were so high that normally a cw mode diode laser user would expect terrible thermal damage and necrosis of the tissue with a lot of carbonization ( 71,146,149,150,156). But thanks to the superpulsed mode of operation there was less carbonization and less damage of the adjacent tissue, which had been proven histologically in vitro by Bach et al. in 2008 (109). Bach used a cw mode diode laser, a pulsed mode diode laser  and a superpulsed diode laser with $P_{peak}$ 30 W; $P_{avg}$ 9,99 W; 20000 Hz to make soft tissue cuts in pig jaws . Unfortunately he didn`t mention the pulse duration. Peak power was nearly the same as in this study, average power 1,67 times higher as in this study and the average frequency also higher. Still the results were much better for the superpulsed laser than for the cw- mode laser.

Maiorana and Salina (153) did a clinical study with a superpulsed laser on 3 patients in 2006. Parameters were: 23,33 W peak power in average; 16667 Hz in average; 10 $\mu$s pulse duration in average; $P_{avg}$ not mentioned.

The conclusion was : clean cut without thermal side effect; instant coagulation; excellent post op conditions with minimal pain and swelling; minimal involvement of the adjacent tissues during surgery.

The parameters were similar to this study, only the peak power was significantly lower and the number of patients was only 3. But the summary of both studies correspond with the results achieved in this study.

The results out of this comparative in vivo study are sometimes not very different for the used lasers, but sometimes very significant, so in case of the

**cutting speed :**

The use of high powers, short pulse durations and high frequencies offered a high speed for cutting and a deeper cut as it did in cw-mode. The margins of the cut were more defined and more straight using superpulsed mode. This was already described several times in literature. ( 26,34,145 ). When using the superpulsed diode with high power and frequency for cutting the first time, the normal treatment behaviour had to change; the movement speed of the fiber had to be increased because of the rapid cutting velocity. When using the cw- diode laser the cut was flattish and the cutting speed was low. Certainly the low peak power of the Vision MDL- 10 was one great inhibition factor for speed. Another one may have been the wavelength of 980 nm. As known the cutting efficiancy of an 810 nm diode laser is better than it is with a 980 nm diode ( Gutknecht N; script M6- Master of Science in Lasers in Dentistry,ED2006; AALZ- Aachen; 02/2008 ).

The 810 nm diode has less penetration into the depth, a lower absorption in water, a lower absorption in $HbO_2$ and nearly the same absorption in Hb as a 980 nm diode. The 980 nm diode creates more thermal energy at the surface and penetrates more into depth. The zone of necrosis is larger and it is more dangerous for cutting.
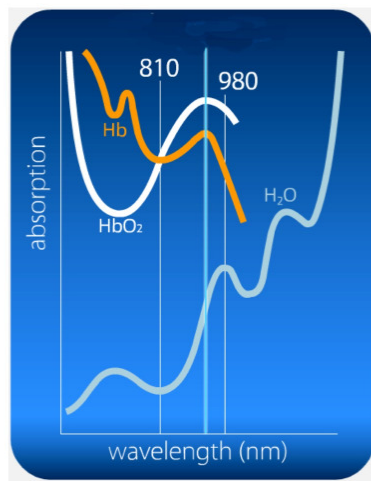


( Pict. from Ezlase brochure; Biolase Technologie Inc. 2007 )

Surprisingly Bach et al. ( 109 ) could prove 2008 in in vitro studies, that there was no difference from the histological point of view between 810 nm and 980 nm diode lasers, when both are used in the same mode of operation.

If we assume that Bach`s results were correct and we neglect the difference between in vitro and in vivo studies, we can conclude together with the attained results from this study that superpulsed mode of operation will lead to faster cutting speed and a more precise cut with less tissue damage.
There are a lot more parameters apart from the wavelength, power, frequency, pulse duration, fiber diameter and mode of operation that will influence the cutting ability,

so as e.g. : kind of tissue, pigmentation, race, blood circulation in tissue, applied dose, treatment time etc. but these parameters are of subsidiary relevance in this study.

The above shown reference cases are done with patients of the same race and same gender. The soft tissue region was the same, both patients with similar pigmentation. The treated sites were mirror- inverted at the inner lip of the lower jaw.

**Carbonization :**

Next point to view is the carbonization of the tissue. If there is a lot of carbonization the destruction of the surrounding tissue is large (37,45,71,109).

Carbonization is changing the absorption of the treated tissue; it is increasing due to the dark color which absorbs the diode laser light much better than light colors do.

This means there is more thermal energy applied in the surface  and necrosis of  the adjacent structures is created.

As we can see from the study the changing of parameters could influence the degree of carbonization and coagulation; which had already been described in literature(145).

In 1999 Goharkhay et al.(7) stated that the horizontal and vertikal dimension of the tissue destruction is neither addicted to the diameter of the fiber, nor related to the mode of operation ( cw or pulsed ) but is only depending on the average power used.

Both assumptions could be rebut until today. Using the same power settings the dose applied in a defined treatment time is lower with a larger fiber diameter. In using smaller fiber diameters the applied energy is distributed in a smaller area, the dose is higher, the effect is larger, there is more thermal energy brought into the tissue.

The risk of carbonization is increasing.

So the tissue destruction is certainly related to the diameter of the fiber.

The used average power in case of the Vision MDL-10 laser was 2,5 W; in case of the Elexxion Claros 6,0 W.

According to Goharkhay the tissue damage must be larger when using the Elexxion Claros

because of the higher average power, but it was just the opposite, because the mode of operation was changed.

Also in literature a much smaller degree of carbonization and destruction is described when using pulsed instead of cw- mode  ( 24,26,34,35,41,61,62,109,145,153 ).
This can be consolidated by the results achieved here.
The cw- mode laser produced carbonization in every treatment case, 100 % .
The superpulsed diode laser only in 66,66 % of the cases.
No patient with heavy carbonization in the superpulsed group.
In the cw- mode group, 35,71 % had severe carbonization,
The total amount of carbonization was much higher in the cw- mode group.

Maybe carbonization could have been less in the superpulsed group regarding to the treatment practice, because the fiber had to be moved much faster as in cw- mode and the surgeon had to adapt to the  new procedure technique.

The fiber diameter is another factor for the applied dose and perhaps the carbonization could have been decreased by using a larger fiber; but for better comparison both lasers were used with 400 $\mu$m fibers. All other parameters which could influence the degree of carbonization, such as peak power, average power, frequency, pulse duration etc. were accepted in the way the manufacturers had programmed the diode laser units.
Exception was, as just said, only the fiber diameter of 400 $\mu$m which was prescribed by the manufacturer of Vision MDL-10 diode laser for surgery. In case of the Elexxion Claros the prescribed fiber diameters should have been changed from 200 to 400 or 600 $\mu$m according to the planned surgical treatment.

**Coagulation :**

Next aspect to discuss is the coagulation ability of both modes of operation.
In literature the coagulation efficiancy is described as good ( 17,30,42,67,68,131,145 ) to very good ( 7,37,51,72,142 ) for cw- mode.

For superpulsed mode the coagulation mentioned is very good (17,35,143) and good with minimal bleeding (34).

Geldi C et al. (35) described 2006 in a study, that superpulsed diode lasers have a larger coagulation area but smaller carbonization area as cw- mode diode lasers.
In this study the gained results from the surgeons questionnaire demonstrated in direct comparison that coagulation was stronger by using cw- mode.
During treatment the coagulation was very good in 42,86 % of the treated patients and good in 57,14 %. For superpulsed there was no very good coagulation, but 83,33 % good and 16,67 % little coagulation which meant that a few patients had a minimal bleeding.
In cw- mode there was none.
In literature often no bleeding after surgical treatment is mentioned ( 17,26,29-31,37,72 ) but in this study there was an oozing bleeding in 21,43 % of the cw- group patients after surgery and also in 41,67 % of the superpulsed group after finishing the surgical treatment , which is a significant difference.
This might have been a derivation of the higher thermal damage of the cw- mode laser.
The blood vessels were sealed better by the influence of the larger amount of thermal energy delivered by the cw- mode of operation.
Therefore a patient with anticoagulant therapy ( Quick 20 %; INR > 2,5 ) was treated with the cw- mode diode laser without any substitution; and there was no bleeding at all.
Mentionable in comparison to other studies is that 7 of 26 patients have been treated with a simple diode laser cut for a following osteotomy.
These patients were sutured after osteotomy and therefore a minimal oozing bleeding occured. This has to be kept in mind for better understanding of the given results.

**Swelling :**

Swelling of the wound area and adjacent tissue 1 day after surgery was significantly less in the superpulsed group, 41,67 % with no swelling.
Only 28,57 % with no swelling in the cw- group.
The size of swelling didn`t differ much in both groups.

3 days after treatment there were :

Already 91,67 % of the patients free of swelling in the superpulsed group.

Only 57,14 % of the cw-mode group; which is a significant difference.

The reason for this could be the degree of tissue damage caused by laser irradiaton.

Regarding to the lower degree of carbonization and thermal damage in the superpulsed group it was explainable that there was less swelling.

The literature review showed different kinds of results which varied from no swelling ( 17,72 ) to little swelling ( 26,37,41,46,142,145,153 ) for both kinds of lasers.

Swelling is a result of the inflammation reaction of the body and, often described in literature, the inflammation reaction is more serious using diode laser surgery than it is by using a traditional scalpel (26,31,32 ).

**Pain :**

A second characteristic sign for inflammation is pain.

During and directly after laser treatment there was no pain because all patients had been given local anesthesia before surgery. Surgical treatment with a diode laser always requires anesthesia, because the thermal energy applied always generates pain.

In literature classifications as mild pain (37), less pain (26,34,145), reduced pain (30,41,46,72,142,145), minimal pain (153) and no pain (17) are found and all authors agree that the degree of pain is reduced after laser treatment in comparison to classical treatment by scalpel.

Looking to the results of the questionnaire a recognizable larger percentage of patients had no pain 1 day post op in the superpulsed group:  41,67 % .

Only 21,43 % in the cw group had no pain.

Nearly double of the patients in the superpulsed group were painfree.

The remaining 58,33 % of the superpulsed group only had pain on the 1st - 3rd niveau.

In the cw group 78,57 % of the patients were also on the 1st - 3 rd niveau.

Only 1 patient ( the very algesic one, as described above ) was on the 7th niveau of pain.

After 3 days the situation was completely different.

Now more patients without pain could be found in the cw group, 71,43 %,

while only  66,67 % of the superpulsed group were painfree.

But the difference of the percentages was not as significant as it was after the first day.

The rest of the patients could be found on pain niveau 1 in both groups, exception, of

course, the very algesic patient, still on pain niveau 7.


Saaleh et al. (37) noticed an average of 3 days of pain for all patients in their study

after cw- mode treatment.


1 week after surgical laser treatment no patient felt pain any longer

( exception: the very algesic patient on niveau 5 ).


**Need for drugs** :


After laser treatment the patients had been supplied by an analgesic drug,

Ibuprofen 400 mg.

42,85 % of the patients in the cw group needed medication, but

only 33,33 % of the patients in the superpulsed group.

With a high percentage only 1 day.

That corresponded to the findings for pain that have been done before.


In general we can say that the pain sensation was less in the superpulsed group.


These results and the following conclusions for reduced masticatory and lingually function

so as the difficulties in oral hygiene were subjective and will differ by treating other patients

because the degree of sensation is very different from person to person.

There will be no reproducable results but only a hint to the right direction.

**Reduced masticatory and lingually function :**

In order to the traumata set during laser treatment there was a functional reduction for masticatory and/ or lingually function in both groups.

In the cw group every patient was affected.

In the superpulsed group at least 16,67 % of the patients had no functional limitations.

50- 57,14 % of the patients were handicapped for 3 days in both groups.

That corresponded once again to the study of Saaleh et al. (37), who described a 3 day period of painful mastication and speech after cw- mode treatment.

**Difficulties in oral hygiene :**

Nearly the same results for oral hygiene.

In average 3 days of limitation, but this time

only 8,33 % of the patients in the superpulsed group without any difficulties.

In the cw group all patients with difficulties.

Now three of the five signs for inflammation were reviewed. ( dolor, tumor, functio laesa )

2 others, calor and rubor were not registered during the study.

But a sign of healing, better secondary healing, should be discussed subsequently.

The **Fibrine layer :**

The building of fibrine is a part of the secondary haemostasis, a part of the plasmatic haemostasis. The thrombocytes were connected by a dense network of fibrinous fibers.

The grade of fibrine layer relies in a certain extent to the grade of healing.

The faster the fibrine layer is removed, the faster the wound healing is in progress.

2- 4 hours after trauma the extravasation starts , a coagulum is build

with blood- and plasmacells on the wound surface. Fibrin fibers are connecting the thrombocytes and build a dense network of fibers. This normally lasts to the 4th day .

Then proliferation starts, granulated tissue is build and the fibrin fibers are reduced.

From the 5th day on regeneration starts and there is no more fibrine layer.

The faster the fibrine layer is removed, the faster the wound healing is in progress.

The observed results regarding the fibrin layer differed from the normally seen wound healing after classical treatment by scalpel.

In this study 26 patients were treated, but 7 of them only by simple laser cut for osteotomy. The cut was sutured afterwards, so there was primary wound healing and no visible fibrine layer could be seen.

The first day no fibrine layer was seen on the wounds in 28,57 % of the cw group and only 16,67 % of the superpulsed group.

A small region was covered in 50 % of the superpulsed, but only in 35,71 % of the cw group.

Mostly covered wounds were noticed in 33,33 % (superpulsed) and 35,71 % (cw) in both groups.

This meant that in the superpulsed group already 83,33 % of the wounds had a fractional fibrine layer. In the cw group only 71,42 % of the wounds were partially covered with fibrine.

After 3 days all wounds; 100 % were covered with fibrine in the superpulsed group: 41,67 % were mostly covered; 33,33 % partially and 25 % completely.

In the cw group already 42,86 % were completely covered; 21,43 % mostly; 21,43 % partially, but still 14,29 % were not covered yet.

So far fibrine layer building was faster and more complete in the superpulsed group.

In comparison to healing after conventional surgical treatment there was a delay of healing time, because fibrine layer building started later and needed more time to cover the wounds. In consequence of delayed wound healing there was still a fibrine layer seen after 1 week in 33,33 % of the superpulsed group and in 42,86 % of the cw group.

Delayed wound healing after surgical diode laser treatment has been described in literature already (26,31,32) and as we could see from the results above the wound healing of the cw group started later and lasted even longer as the prolonged wound

healing of the superpulsed group.

This might have been an effect of the stronger thermal damage and increased carbonization in the cw group. The cells and blood vessels in the adjacent tissue were much more damaged and needed longer to reorganize for healing.

Superpulsed treatment left more intact tissue at the wound margins, so healing could begin earlier as in cw mode.

Even if there was an improvement in healing time there was still a difference to normal healing, where fibrine layer removal begins already at the end of the 4th day.

So the intactness of the tissue seemed to be essential for regular wound healing.

Superpulsed diode laser treatment did not cause much carbonization, but there was as well coagulation, which meant applied thermal energy on the blood vessels and cells; causing damage and therefore delayed healing.

As option for surgical laser treatment an Er:YAG laser with waterspray and air can be used instead. The Er:YAG laser also generates a soft tissue cut, but with a resulting bleeding. There will be no carbonization and nearly no coagulation, therefore no or only minimal damage of the tissue and as effect a much quicker and nicer wound healing and less discomfort for the patient as after diode laser treatment.

In summary we can say that superpulsed diode laser treatment is contrary to cw- mode diode laser treatment much more gentle for the tissue ( less damage, quicker healing ), more comfortable for the patient ( less pain and swelling ) and an improvement for the surgeon ( more precise and deeper cut, less burnt smell, shorter treatment time ).

Only the coagulation ability of the superpulsed diode laser seems to be minimal inferior of the cw- mode diode laser.

In combination with the findings of the Bach study (109) and the case reports of Maiorana and Salina (153) we can conclude that superpulsed diode lasers should be the state- of-art treatment nowadays if there is spoken about surgical diode laser treatment.

Of course these are only 2 further studies and the results have to be reconfirmed by various studies with a larger amount of patients, but the direction to go is clearly given.

# 7. Conclusion

Clinical in vitro and in vivo studies have shown that soft tissue surgery done by superpulsed diode lasers is more reasonable as doing the same procedures by cw- mode diode lasers. Carbonization and thermal damage of the adjacent tissue can be reduced to a minimum, the soft tissue cut can be generated faster, the cut is more precise.
Because of the lower amount of tissue destruction the healing is faster as in cw- mode.
It is more comfortable for the patients regarding to the post op pain and swelling, the patients will need less drugs and the functional abilities are not reduced as much as in continuous wave mode.

In terms of Bach`s histological investigation of the treated soft tissue (109) we probably have to share his opinion, that cw- mode diode lasers are no longer suitable for soft tissue cutting in dentistry.

The advantages of the superpulsed diode lasers in soft tissue surgery are evident and with the meanwhile achieved peak powers, the very short pulse durations and the high frequency the surgical treatment can be improved and probably the range of treatment can be expanded.

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