Pulsed Shortwave Therapy with the Curapuls 670

Therapy manual

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Contents

Foreword **5**

Aims of this book **6**

1 Introduction **7**

2 Physical aspects of the Curapuls 670 ..... **8**
2.1 Introduction 8
2.2 Electromagnetism 8
2.2.1 Electromagnetic field *8*
2.2.2 Sources *8*
2.2.3 Tissues *9*
2.2.4 Heat *9*
2.3 Methods 10
2.3.1 Capacitive method *10*
2.3.2 Inductive method *10*
2.4 Additional aspects of the Curapuls 670 10
2.4.1 Signal *10*
2.4.2 Circuplode *11*
2.4.3 Adaptation *11*
2.5 Sources 11

3 Specific characteristics of the Curapuls 670 ..... **12**
3.1 Use of the inductive method alone 12
3.2 Simultaneous application with two Circuplodes 12
3.3 Greater choice of pulse repetition frequencies and pulse durations 12
3.4 Maximum peak power of 200 W per Circuplode 12
3.5 Contact monitoring for optimum energy transfer 12

4 Effects of high-frequency electrotherapy **13**
4.1 Thermal and non-thermal effects 13
4.1.1 Introduction *13*
4.1.2 Working hypotheses *13*
4.1.3 Effects with the capacitive method *13*
4.1.4 Effects with the inductive method *14*

5 Physiological and pathophysiological reactions to heat **15**
5.1 Introduction 15
5.2 Heat 15
5.3 Reactions of the human body to heat 15
5.3.1 General reactions to heat *15*
5.3.2 Local reactions to heat *15*
5.4 Tissue damage by heat 16
5.5 Heat and high-frequency electrotherapy 16
5.5.1 Supplementary information on the definitions *16*
5.6 Conclusion 16
5.7 Additional effects of heat on various tissues 17
5.7.1 Connective tissue *17*
5.7.2 Muscle tissue *17*
5.7.3 Articular capsules *17*
5.7.4 Nerve tissue *17*
5.8 Working hypotheses 17

6 Wound healing **18**
6.1 Introduction 18
6.2 Some aspects of wound healing 18
6.2.1 The phases of wound healing *18*
6.3 Working hypotheses 21

7 Effects of electromagnetic energy on wound healing **23**
7.1 Introduction 23
7.2 General effects of electromagnetic energy on wound healing 23
7.2.1 Effects during the bleeding phase *23*
7.2.2 Effects during the inflammatory phase *23*
7.2.3 Effects during the proliferation phase and production phase *24*
7.2.4 Effects during the remodelling phase *24*
7.3 Specific effects of electromagnetic energy on wound healing 24

7.3.1 Delayed wound healing ... 24
7.3.2 Fractures ... 24
7.3.3 Soft tissue lesions ... 25
7.3.4 General conclusions on the effects of electromagnetic energy on wound healing. ... 25

8 Dosage ... 27
8.1 Introduction ... 27
8.2 Duration of treatment ... 27
8.3 Frequency of treatment ... 28
8.4 Number of treatments ... 28

9 Indications and treatment examples ... 29
9.1 Introduction ... 29
9.2 Epicondylitis lateralis humeri (43, 46) ... 29
9.3 Fibromyalgia syndrome ... 30
9.4 Contracture of the iliotibial tract in coxalgia ... 31
9.4.1 Haematoma in the iliotibial tract ... 31
9.5 Rheumatoid arthritis (RA) with symptoms in both hands (30, 39) ... 32
9.5.1 Rheumatoid arthritis with inflammatory symptoms ... 32
9.5.2 Postoperative treatment following synovectomy in the hands in rheumatoid arthritis ... 32
9.5.3 Rheumatoid arthritis of the hands with replacement arthroplasty of the metacarpophalangeal joints ... 33
9.5.4 Rheumatoid arthritis matoid arthritis of the hands and gold medication ... 33
9.6 Fracture of the wrist and/or fingers (4, 46) ... 33
9.7 Rupture of the muscle fibre of the M. gastrocnemius ... 33

10 Contra-indications ... 36
10.1 General ... 36
10.2 Introduction ... 36
10.3 Implants ... 36
10.4 Pacemakers ... 36
10.5 Bacterial infections ... 36
10.6 Pregnancy ... 36
10.7 Tissues with a high mitosis rate ... 37
10.8 Sensitivity disorders ... 37
10.9 General remarks ... 37

Photo series of treatment examples ... 38

Bibliography ... 49

Foreword

Is there a ‘new’ approach to high-frequency electrotherapy?
In any case, there have certainly been several recent developments that seem to point in this direction.
In the first instance, the authors began by testing their current working hypotheses on the subject of high-frequency electrotherapy. Even while reading and discussing, it rapidly became apparent that the views expressed in the majority of text books remain stuck in the explanations of the 1950’s. These views now appear to be inadequate on a large number of points, and in others they have been superseded. It is therefore necessary to apply these new insights to the physiotherapy situation. This had led to radical reappraisal of short-wave therapy. The consequences are far-reaching, and new equipment has had to be developed. In the future, the electrodes and magnetodes should also be redesigned on the basis of the new insights.

The authors are greatly indebted to A.M.J. van Amelsfort and to T. Scharten for their contribution on physics (Chapter 2), for their clear explanations of this complex material, and for their patience in analysing physiotherapeutical queries in this context. Without their co-operation and effort this book could never have appeared in this form and content.

We also thank G.C. van Rhoon for his vision and clarification with respect to the use of hyperthermia with high-frequency electrotherapy.

Lastly, but by no means least, we also owe our thanks to the staff of Enraf-Nonius for the critical reading and correction of the texts.

Aims of this book

The authors have aimed at achieving a balance between the theoretical background and the practical applications.

The first part of the book describes the theory, and the justification of the working hypotheses. The second part presents the results of the theory in the form of a 'recipe book'. The 'recipe book' is based on several carefully selected cases, representing a high proportion of the practical applications in physiotherapy. A considerable number of other pathologies are derived from these cases. The positioning of the electrodes and the treatment parameters for most pathologies redescribed, and illustrated by photographs that have been specially taken for this book.

The book was initially written as a support for the Curapuls 670. However, the text goes somewhat further, and may rather be regarded as a review of high-frequency electrotherapy at 27 MHz.

The reader can approach the book in three different ways:

1. Reading the complete text
2. Reading only the practical applications
3. From the second option, studying the background to the choice of treatment parameters in the various cases.

The authors hope that the book will lead to renewed interest in high-frequency electrotherapy, which is a form of therapy that probably offers more possibilities than have been assumed in the past.

This book certainly does not answer every question. On the contrary, the authors hope that the text will give rise to further discussion leading, in turn, to further extension, study and adaptations to this complex subject.

Baarn, July 1990
M. van der Esch and R. Hoogland

1 Introduction

The medical application of electromagnetic energy dates back to 1892, when d'Arsonval conducted experiments on the human body using electromagnetic vibrations with a frequency of 200 - 300 KHz. The modern application of short-wave electrotherapy was developed in the 1930's, particularly by Schliephake. He mainly made use of the capacitive method, while the inductive method was developed in the United States in 1934. The frequency of 27.12 MHz used today was agreed on in 1947 at the Atlantic City Conference (U.S.A.). Pulsed short-wave electrotherapy has been known since 1940, and was developed by Ginsburg. In 1959, an apparatus was developed that emitted pulsed electromagnetic energy at a frequency of 27.12 MHz.

Initially, the primary purpose of electrotherapy was to obtain a curative effect by the creation of heat. Later, other authorities such as Liebesny concluded that there were also other "non-thermal or biological effects". By applying the electromagnetic energy in pulses, the non-thermal effects would become more pronounced, as the thermal effects would be suppressed by a relatively low mean power, while the peak power could be maintained at its maximum.

Over the last 10 years, the interest in short-wave therapy has declined in favour of low-frequency electrical stimuli. However, there have been new reports in the literature and new developments that can reawaken interest in high-frequency electrotherapy. It appears that high-frequency electrotherapy at 27 MHz is able to give rise to specific effects that can contribute to wound healing in the broadest sense, i.e. from haematomas to fractures. It also appears possible to exert a positive influence on sterile inflammatory processes, such as arthritis and capsulitis. The same principle can be applied to effective therapy of fibromyalgias.

Recent literature, including publications on such subjects as neurogenous inflammation, have led to the development of a new working hypothesis which is more in line with recognized clinical effects and permits more accurate formulation of the indications.

One of the most important contributions from physics is that the electrical field must now be recognized as the primary cause of the therapeutic effects. In addition, the creation of an electrical field via a magnetode, such as a Circuplode, appears to offer advantages over the direct creation of an electrical field via electrodes. Enraf-Nonius have taken these developments into account in the development of their latest unit for high-frequency electrotherapy: the Curapuls 670.

The Curapuls 670

2 Physical aspects of the Curapuls 670

2.1 Introduction

The Curapuls 670 generates electromagnetic energy at a frequency of 27.12 ± 0.16 MHz. This energy is transferred to the environment via a flat coil in a special housing. The pulse duration and pulse repetition frequency are adjustable, in order to obtain the desired therapeutic effect.

2.2 Electromagnetism

For a better understanding of the working of the Curapuls 670, we first consider the electromagnetic field itself, and the ways in which such a field is created. This is followed by a description of the behaviour of an electromagnetic field in body tissues, and the associated development of heat.

2.2.1 Electromagnetic field

In physics, the concept of a field has been introduced to describe the action of a force at a distance, without direct contact. A field is always two things at once: a region in which the operation of a force can be detected and, simultaneously, the local carrier of that force. Thus, an electric field is a region around the source throughout which an electrical force is exerted on charged particles such as ions. Similarly, a magnetic field is a region in which a magnetic force is exerted on the same particles. The closer the source, the stronger the field and the force exerted will be. This is true of both electric and magnetic fields. An important consideration is that electric and magnetic fields are interdependent if, and for as long as, the field strength is not constant but varies as a function of time. This is the case with the Curapuls 670. The field and its force are then referred to as being electromagnetic. In more precise terms, a time-dependent magnetic field appears to give rise to an electric field, and vice versa. This interaction becomes stronger as the frequency increases.

Finally, within an electromagnetic field, and due to the field, energy is transferred from the source to the environment. This effect is relatively weak with poorly time-dependent (low-frequency) sources.

2.2.2 Sources

A magnetic field is initially created by moving carriers of an electric charge, such as an electric current in a metal conductor, whether or not in the form of a coil. If the current strength is time-dependent, such as the high-frequency current through the coil of the Curapuls 670, the magnetic field will, in turn, give rise to an electric field. Thus, the whole forms an electromagnetic field. An electric field can be directly created by a build-up of electric charge on, for example, a metal plate (electrode). In practice, two electrodes, connected to a generator, are used. In this way, an excess of electrons on one plate is always accompanied by an equal deficit on the other. If this situation alternates in the course of time, an electromagnetic field is also created: the time-dependent electric field gives rise to a magnetic field.

To summarize, it appears that time-dependent sources will always create an electromagnetic field. In the case of electric currents (coils) the electromagnetic field will be created via the magnetic field, and in the case of electric charges (electrodes) it will be created via the electric field. An overview of sources and fields is given in Table 1.

Table 1: Sources and fields

SOURCE	Type:	Electric	Magnetic
	Principle:	End of conducting wire	Conducting wire
	Form:	Metal plate	Wire coil
	Name:	Electrode*	Magnetode**
	Effect:	Build-up of electric charge	Stream of electric charge
FIELD	Electromagnetic	Electric field creates a magnetic field	Magnetic field creates an electric field

* Electrode means ‘a path for electricity’. A pair of electrodes is referred to as a capacitor.
** By analogy with electrode, magnetode means a ‘path for magnetism’. An arrangement of two or more connected magnetodes is referred to as a coil.

2.2.3 Tissues

Like all matter, living tissue is affected by the field of an electromagnetic source. The effect is due to the action of the electromagnetic force on tissue molecules and ions. The electric component of this force appears to be by far the more important. The electric force is some ten billion times more powerful than the magnetic force. Thus, in the case of living tissue, we are exclusively concerned with the electric field. As described above, the electric field can be created by means of a coil (via the magnetic field), or directly by means of electrodes.

The question now is how living tissues are characterized electromagnetically. Units frequently used in this connection are the relationship between the wavelength and the depth of penetration in a specified tissue. The penetration depth is defined as the depth at which the field strength is reduced by a factor of 0.37. This effect is related to the energy dissipation (see Section 2.2.4 below). Some examples are given in Table 2.

The figures in Table 2 should be used with caution. In the first instance, they are idealized figures, valid for tissues in isolation with the application of 'flat' waves. In the real situation, where a sequence of different tissue layers is encountered, they cannot be used without adaptation. Secondly, the figures represent average values. In practice, there will be some distribution around the mean, depending on the individual patient. Nevertheless, it can be seen from Table 2 that both the wavelength and the penetration depth decrease with increasing frequency, and that both are greater in fat tissue than in muscle tissue.

Table 2: Wavelength and penetration depth

Frequency (MHz)	Wavelength (m)			Penetration (m)	
	Muscle	Fat	Air	Muscle	Fat
27	0.68	2.41	11.11	0.14	1.59
100	0.27	1.06	3.00	0.067	0.60
433	0.088	0.29	0.69	0.036	0.26
915	0.045	0.14	0.33	0.030	0.18
2450	0.018	0.052	0.12	0.017	0.097

2.2.4 Heat

The energy of the electromagnetic field that penetrates into the tissues is converted into heat by the currents created (dissipation). As a consequence, the field amplitude decreases with increasing depth. The time-averaged value of the locally dissipated energy P in tissue is given by the formula:
$P = 0.5\delta E^2$ (W/m³).

In this formula, δ is the specific electrical conductivity of the tissue concerned, and E is the amplitude of the local electric field strength. Table 3 shows that the conductivity of the tissues becomes greater with increasing frequency.

It can also be seen that the conductivity of muscle tissue at all frequencies is more than ten times greater than that of fat tissue. The local field strength in the tissue depends on the type of source, and its position (see Section 2.3 below).

The energy dissipation is often expressed in W/kg, by standardization using the specific mass density ρ. This gives the Specific Absorption Rate (SAR) as:

$SAR = 0.5\delta E^2/\rho$ (W/kg).

For muscle tissue ρ = 1070 kg/m³, and for fat tissue ρ = 940 kg/m³.

Table 3: Specific electrical conductivity

Frequency (MHz)	δ (1/ohm/metre)	
	Muscle	Fat
27	0.6	0.04
100	0.9	0.08
433	1.4	0.12
915	1.6	0.15
2450	2.2	0.21

2.3 Methods

Form Section 2.2 it can be seen that the tissue is affected by the electric field, and that the electric field can be created in two ways. This leads to a distinction between two methods of application: the capacitive method and the inductive method. These are dealt with briefly below.

2.3.1 Capacitive method

Two electrodes are placed on either side of the part of the body to be treated. Thus, the body part forms the dielectric in a plate capacitor. In transverse application, as in treatment of a knee joint, the electric field is practically perpendicular to the tissue layers. Consequently, the penetration of the field in this case is generally poor. The skin/fat layer forms a sort of shielding, as the perpendicular electric field causes a build-up of charges at the interfaces between the tissue layers. Thus, the heat production is also superficial. At 27 MHz the maximum SAR in the fat layer is approximately ten times as high as that in the underlying muscle layer. If the electric field is parallel to the tissue layers, the penetration is much better. This situation occurs in longitudinal application, for example in treatment of the lower leg. In this case, the heat production is no longer superficial, as is demonstrated by the much higher SAR's. At 27 MHz the SAR in muscle tissue is some 20 to 30 times greater than in the fat layer.

2.3.2 Inductive method

A characteristic of the inductive method is that the magnetic field, which serves as the 'carrier' for the electric field, penetrates deep into the tissue. The distribution of the field and the SAR is, however, also determined by the shape, construction and positioning of the electrode. As a general rule, the electric field close to the coil is relatively strong, and is aligned in the direction of the coil windings. Secondly, the electric field is at its minimum in the axis of the coil. Finally, the strength of the electric field induced in the tissues is at its highest in the more conductive tissues, such as muscle tissue.

The Curapuls 670 works on the inductive principle. The source is a flat spiral coil in a metal housing. The face of the housing, parallel to the coil, has a special construction that allows the field to pass through. This source is referred to as the 'Circuplode'.

The face of the Circuplode is a permeable screen, constructed of radial copper strips attached to the periphery of the housing. This screen suppresses the radial components of the electric field, while allowing the azimuthal field (circular field) to pass through virtually unhindered. The circular field gives rise to inductive eddy currents in the tissue. The Circuplode must, of course, be used with the permeable screen directed towards the part of the body to be treated, taking into account that there will be little effect in the centre of the treated area. The effective area of the field is ring-shaped.

2.4 Additional aspects of the Curapuls 670

2.4.1 Signal

The signal frequency of the Curapuls 670 is 27.12 $\pm$ 0.16 MHz. The signal is pulsed, with a pulse duration that can be varied between 65 and 400 µs. A pulse of 65 µs duration comprises ca. 1760 signal cycles or periods, while a 400 µs pulse comprises ca. 10850 periods (pulse width divided by the inverse of the frequency). The pulse repetition frequency is adjustable between 26 and 400 Hz, corresponding to a pulse repetition period of from 38.5 to 2.5 ms. Two extreme combinations of pulse duration and pulse repetition frequency are shown in Figure 1.

Heat generation is greatest when the power per pulse, the frequency and the pulse duration are set at the maximum. Conversely, heat generation is lowest when these parameters are set at the minimum. In addition to the generation of heat, other effects may occur, such as after local build-up of electric charge.

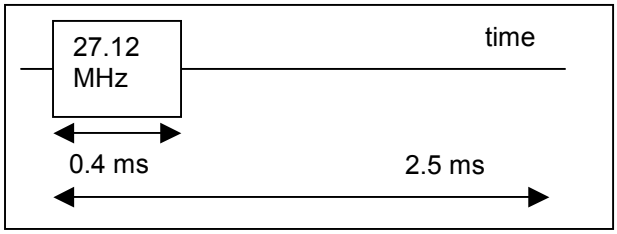


Figure 1a (signal forms of the Curapuls 670): One extreme, with a pulse duration of 400 µs and a pulse repetion frequency of 400 Hz (pulse repetion period of 2.5 ms)

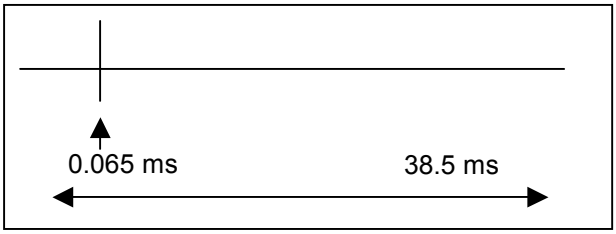


Figure 1a (signal forms of the Curapuls 670): The other extreme, with a pulse duration of 65 µs and a pulse repetion frequency of 26 Hz (pulse repetion period of 38.5 ms)

2.4.2 Circuplode

Two Circuplodes can be used simultaneously. The pulse of one Circuplode is delivered in the pulse interval of the other. This simultaneous use offers the following advantages:

- treatment of a larger area in one session
- simultaneous treatment of bilateral disorders (e.g. both hands in rheumatoid arthritis)
- simultaneous treatment of both sides of a joint.

2.4.3 Adaptation

The energy transfer from the Circuplode of the part of the body to be treated is automatically optimised. If, in spite of this, the energy transfer deviates by more than 10% from the set value, the Curapuls 670 is automatically switched off. To ensure good operation of the system, the face of the Circuplode should not be more than 1 cm from the part of the body being treated.

2.5 Sources

The figures in Tables 2 and 3 are derived from Johnson CC and Guy AW. Proc. IEEE 1972; 60: 692-71. The estimates of the maximum SAR's in Section 2.3.1 are based on flat-wave calculations.

3 Specific characteristics of the Curapuls 670

The specific characteristics of the Curapuls 670 can be summarized in five short paragraphs.

3.1 Use of the inductive method alone

The advantages of the inductive method should be clear from the physical aspects described in the preceding chapter. There are only a few applications where electrodes would be suitable, particularly now that there is the possibility of working with two Circuplodes simultaneously.

3.2 Simultaneous application with two Circuplodes

The simultaneous use of two Circuplodes enables a sufficiently large area to be treated in one session. It is also possible to treat bilateral disorders, such as rheumatoid arthritis in the hands, on both sides at the same time. Another possibility is the treatment of a joint, such as the knee from both sides. This ensures an adequate therapeutic effect in deeper-lying tissues. The two Circuplodes cannot affect each other with respect to intensification or attenuation of the field, as the pulse of one Circuplode is delivered during the pulse interval of the other.

3.3 Greater choice of pulse repetition frequencies and pulse durations

The Curapuls 670 offers a significantly more extensive choice of pulse repetition frequencies and pulse times than its predecessor, the Curapuls 419. This enables thermal and non-thermal effects to be used in combination, depending on the treatment situation. A higher peak power can be used with a shorter pulse duration, in order to minimize heat generation, or vice versa. Frequency-dependent effects can also be specifically selected, for example in the treatment of fractures.

3.4 Maximum peak power of 200 W per Circuplode

From measurements and subsequent practical experience it has been shown that the peak power of 200 W is amply sufficient, provided that it can be effectively transferred to the tissue. This has been achieved in the Curapuls 670. In older equipment, there may be a theoretical peak power of 1000 W, but the output is actually much lower, because the equipment has to be tuned to various electrodes (Enraf-Nonius internal information). It can also be expected that the new Curapuls 670 will significantly reduce the electro-magnetic interference around the equipment.

3.5 Contact monitoring for optimum energy transfer

From the preceding section, it is clear that effective energy transfer is essential. The primary aim of contact monitoring is to ensure optimum energy transfer by visual control. If the power output deviates from the preset value by more than 10%, the Curapuls 670 is automatically switched off. This is achieved by matching the impedance of the generator to that of the Circuplode(s) and the body part being treated.

An important requirement for contact monitoring is that the face of the Circuplode(s) **should never be more than 1 cm** from the body part being treated. It is better to ensure direct contact via a terry cloth placed between the Circuplode and the skin. Furthermore, the body part should be sufficiently large with respect to the Circuplode.

4 Effects of high-frequency electrotherapy

4.1 Thermal and non-thermal effects

4.1.1 Introduction

There are conflicting reports in the literature regarding the thermal and non-thermal effects of electrotherapy. Some authorities refer to pulsed application as non-thermal (2, 58) while others state that, in terms of thermal stimuli, there is no difference between pulsed and continuous application (11, 49).

A more important question is that of whether there is a difference in the clinical effects. Various investigations have, in fact, shown that a significant difference can be seen between the effects of pulsed and continuous application of electromagnetic energy (2, 54, 59).

In the development of the working hypotheses for the differences between thermal and non-thermal effects, **Maxwell's rule** played an important role. This rule, which was formulated by Maxwell during his investigations into electrostatics, is as follows: 'For every functional unit at rest, there is an equilibrium between the charges inside and outside semipermeable membranes. If this functional unit absorbs energy, a change in the charge occurs and the whole returns to the rest condition when the equilibrium has been restored'.

4.1.2 Working hypotheses

In this book, the following working hypotheses have been adopted with respect to thermal and non-thermal effects:

1. Definition of non-thermal or biological effects
These are therapeutic effects that occur as the result of an influence on local metabolic processes, without involvement of the central nervous system or the hypothalamus.

2. Definition of thermal effects
Theses are effects resulting from an increase in the blood temperature, stimulation of the thermo sensors in the skin, or local thermal tissue damage. These effects involve the peripheral nervous system, and sometimes the central nervous system.

From these assumptions, it follows that thermal effects occur in biological tissue in both pulsed and continuous application of high-frequency electrotherapy. It is not yet clear whether a therapeutic distinction can be made between the individual thermal and non-thermal effects. However, it is possible to make a distinction between the local and general reactions of the human organism to heat. This is dealt with in more detail in Chapter 5.

4.1.3 Effects with the capacitive method

In the Capacitive method, electrodes are used which, in the jargon of physiotherapy, are variously referred to as disc electrodes, Schliephake electrodes or plate electrodes. These electrodes have an electric field which gives rise to a magnetic field (see Chapter 2).

Not only theoretical considerations (26, 28), but also practical applications lead to the view that the electric fields most frequently indicated for therapy are those applied longitudinally, i.e. with the electric field oriented craniocaudally. The electric field takes the path of least resistance. In other words, it follows the best conductor, which is generally muscle tissue. There will be little thermal effect in deeper lying tissues, even when these are inherently good conductors, as the field strength decreases sharply with increasing depth (see Chapter 2).

It should be taken into account that, in practice, purely longitudinal application is impossible to achieve, as the first tissue layer encountered will always be parallel to the electrode. This means that, for optimum results, the electrode should be as large as possible. The field density at the skin will then be relatively low, so that the (thermal) effects there are, are as far as possible, suppressed.

It should also be noted that the electric field leads to a build-up of electric charge at the interfaces between different tissues, in particular at the transition between the skin and the subcutaneous fat layer. This forms a shield against the electric field, and the penetration of the electric field is therefore poor. **Consequently, the effects of the capacitive method mainly occur near the body surface.**

The form of the electric field and the actual field strength must be considered separately. At 27 MHz the field strength is high at the surface of the body, namely in the skin and fat tissue. As a result of the shielding effect, the field strength reduces sharply in the deeper-lying layers. Intra-articular temperature increases in transverse application are probably negligible, and in bone tissue they are virtually nil. The degree of shielding is related to the size of the object

and the length of the electromagnetic wave. In small objects, the shielding is relatively large with respect to the **actual** wavelength, and the electric field is therefore weak.

With respect to the actual wavelength, measurements and calculations (44, 47) both show that at 27.12 MHz the wavelength in tissues becomes considerably shorter. From Table 2 (Chapter 2) it can be seen that the 11.11 metre wavelength in air is reduced to around 68 cm in 'wet' tissue such as muscle, and to around 2.41 metres in 'dry' tissue such as fat.

Certain conclusions can be drawn from the foregoing:
In objects that are relatively small with respect to the actual wavelength, the shielding of the electric field is large and the field strength is therefore low. From this, it can be concluded that the intra-articular field strength, for example in the knee, is greatly reduced. There is thus scarcely any question of a heating effect at this depth. As another example, synovial fluid in the knee (fat globules) shows very little heating as the fat particles are too small with respect to the actual wavelength. Thus, there is virtually complete shielding of the electric field.

It has already been stated that, with the capacitive method, longitudinal applications are preferred. It may well be that this is, in fact, the only applicational possibility if deeper lying tissues are to be reached with this method.

The reduction in wavelength presents some interesting possibilities. If the conductor is the same length as the electromagnetic wave, a standing wave will be created within it. This gives rise to high field strengths, and consequently effects, where the wave is at its peak. On the other hand, there are also places where the field strength is zero. In a combination of a conductor and an insulator, as in the lower leg, it appears possible to influence both the muscle tissue and the tendons around the ankle. This method has already proved its value in practice for some time.

Further optimization of this application would require the frequency, and hence the wavelength, to be adapted to the dimensions of the tissues. By selecting the appropriate wavelength and the corresponding frequency it is possible to localize the therapeutic effects more precisely in the conductor (muscle) where the effect is required, while the other parts are not 'loaded' with electromagnetic energy. This form of application is not possible at present, as only a few fixed frequencies have been allocated for (para) medical applications.

4.1.4 Effects with the inductive method

In the inductive method, a magnetode is used to create a magnetic field which, in turn, creates an electric field in the biological tissue. Flat coils are used, such as the Circuplode. In the inductive method, the shielding effect observed in the capacitive method (27) cannot occur, as the electric field actually arises within the tissues. This electric field can be regarded as a **mirror image** of the flat coil **in the tissue**. Even the dimensions are the same. By analogy, a curved body surface can distort the electric field like the distorted image in a fairground mirror. The effect of a flat coil such as the Circuplode only occurs towards the periphery, i.e. where the coil windings are located. In the centre of the coil there is no magnetic field and, hence, no therapeutic effect. An important consideration is that, in transverse applications, the electric current is oriented in the craniocaudal direction. Consequently, with the inductive method, transverse applications are to be preferred. In this model the 'classic' disadvantage of the inductive method, namely its limited depth effect in comparison with capacitive method, is largely, if not entirely, eliminated. In the 'classic' application of the inductive method, using the Monode/Minode and Diplode, the radial electric field is not shielded as it is in the Circuplode. Because this field is not shielded, there is a strong build-up of electric charge in the transition between the skin and the subcutaneous fat tissue. As a result, a large quantity of heat and/or other effects is created at the surface of the body. If this effect is, in fact, desired, it is better to achieve it using the electrodes (capacitive method) as in this case the specific advantages of the inductive method are largely lost.

Another classic application is the use of the solenoid cable, or induction cable. In the solenoid cable, there appear to be no dielectric losses between the windings of the cable, or between the cable and the skin. There is also no difference in charge between the windings. The local heating effect occurs because there is a strong electric field around the cable. Consequently, the effects of the solenoid cable are also relatively superficial.

In the Circuplode, the radial electric field of the coil is shielded by enclosing the coil in a Faraday cage, in the form of a metal housing and a screen of copper strips, as described in Section 2.3.3. The azimuthal magnetic field (circular field) passes through the screen into the body, creating an electric field within the tissues, where the thermal and non-thermal effects can occur. At present, this construction appears to be the most efficient for application of the inductive method.

5 Physiological and pathophysiological reactions to heat

5.1 Introduction

This chapter is concerned with the physiological and pathophysiological reactions of the human body to heat. It is intended as a basis for the subsequent discussion of the influence and effects of high-frequency electrotherapy on various tissues in the different stages of wound healing. These effects are considered in Chapters 6, 7 and 8.

5.2 Heat

From the brief consideration of the physics in Chapter 2, it can be seen that the electromagnetic fields penetrate the tissues, where their energy is dissipated to produce a heating effect.

Definition:
Heat is an increase in the velocity of particles.

Heat can lead to a measurable or sensible temperature increase in tissues. Even if the temperature increase cannot be measured, significant reactions may have occurred at the cellular level.

5.3 Reactions of the human body to heat

Heat produces various reactions in the human body. These can be divided into general reactions and local reactions.

5.3.1 General reactions to heat

The body temperature is controlled by the ventral part of the hypothalamus. Consequently, the hypothalamus is the most important organ in the maintenance of homeostasis. For this reason, reference is sometimes made to the 'hypothalamic thermostat'. The hypothalamus reacts to every change in body temperature. The information for this control system is provided by:

1. The temperature of the blood
2. Thermo-detectors, particularly the cold detectors below the skin

If the temperature of the blood increases, or the thermo-detectors are stimulated, the hypothalamus activates various mechanisms that serve to keep the body temperature within the limits of the 'thermostat'. Thus, the deep body temperature is maintained between 36 and 37.5°C. this is also the temperature of a muscle at rest. The intra-articular temperature at rest is between 31 and 32°C. The superficial body temperature can vary within wide limits, depending on the ambient temperature. As the cold detectors react to the ambient temperature, the hypothalamus can regulate the body temperature before the deep temperature is affected. If the temperature increases, there are three mechanisms for keeping the deep temperature between the physiological limits:

1. Vasodilation.
   This is effected by inhibition of the sympathetic centres in the posterior part of the hypothalamus, which regulate vasoconstriction.
2. Sweating.
   An increase of one degree Celsius above 37°C results in sufficient sweating to counteract ten times the basic heat production.
3. Reduction in heat production.
   Shivering and chemical thermogenesis (adrenalin, thyroxine) are strongly inhibited.

5.3.2 Local reactions to heat

Heat has been defined above as an increase in the velocity of particles. In general, this has a catalytic effect on all chemical processes. Thus, application of heat results in an increase in the local metabolism of the cell, and increased transport through the cell membranes. For every increase of one degree Celsius within the physiological limits, the metabolic activity increases by about 13%. This local metabolic increase leads to an increase in the oxygen partial pressure (pO2), the carbon dioxide partial pressure (pCO2) and the acidity (pH). These three factors, pO2, PCO2 and pH, determine the local perfusion by their effect on the precapillary sphincters and/or the metarterioles.

The precapillary sphincters and the metarterioles in the tissues control the local homeostasis by alternate contraction and relaxation. This alternating activity controls the perfusion of the capillary bed. At the same time, the contraction forces the blood in the capillaries forwards. This process of autoregulation is referred to as 'vasomotion'. The degree and duration of vasomotion is principally determined by the oxygen concentration.

Dilation of the precapillary sphincters and/or the metarterioles increases the perfusion of the capillary network and, hence, that of the tissues. At the same time, the blood flow velocity decreases, resulting in an increase in the exchange of substances by diffusion and filtration. This maintains the local homeostasis.

5.4 Tissue damage by heat

If the temperature rises above 42°C, tissue death occurs. The tissue responds with an inflammatory reaction. In the first instance, the reaction is local; the axon reflex. If the damage is more extensive, a complete neurogenous inflammation results. These reactions are discussed in more detail in Chapter 6.

5.5 Heat and high-frequency electrotherapy

The following definitions have been derived from the preceding paragraphs. These are valid for continuous and pulsed application of electromagnetic energy at 27 MHz.

Non-thermal or biological effects.
These are effects that arise from the influence on local metabolic processes without involvement of the central nervous system or the hypothalamus.

Thermal effects.
These are effects arising from an increase in blood temperature, stimulation of the thermodetectors in the skin and local temperature increases. Local temperature increases can lead to local (thermal) tissue damage. The peripheral and, in some cases, the central nervous system are involved in these effects.

5.5.1 Supplementary information on the definitions

In temperature increases in the skin, the centralized response predominates over the local reactions. Temperature increases in the skin will therefore be directly followed by vasodilation, which is controlled from the hypothalamus. In muscle tissue and, probably, in joints the temperature regulation is virtually exclusively determined by local factors, namely the pO2, pCO2, and pH.

The consequences of the application of electrotherapy are as follows. The application of the **capacitive method** mainly results in heat in the skin and fat tissue. The hypothalamus will react to this, resulting in vasodilation in the skin. In deeper-lying tissues, either vasodilation or vasoconstriction may occur, depending on the reaction of the hypothalamus. In application of the inductive method with the **Circuplode**, it appears possible to create almost exclusively local effects, as the skin and fat tissue are scarcely warmed at all. Provided that the blood temperature in its totality does not increase, no reactions are to be expected from the central nervous system. The foregoing is, of course, dependent on the quantity of electromagnetic energy transferred into the body.

Both the inductive method and the capacitive method are capable of increasing the tissue temperature above 42°C. In the inductive method, such a temperature increase will not be directly perceived, as the skin is heated much less than the deeper-lying tissues. Such a traumatizing effect is also possible with pulsed application of 27 MHz waves with a high peak power. If it is accepted that treatment by electrotherapy should not cause pain or create any sensation of heat, it is reasonable to assume that any tissue damage will be limited, and that the axon reflex will be stimulated to repair the damage (see Chapter 6).

5.6 Conclusion

'Non-thermal effects', mainly created by magnetodes, can play an important role in tissue healing, due to the increased metabolism and axon reflexes resulting from local vasodilation. A number of non-thermal or biological effects in connection with wound healing are known from the literature (1, 9, 10 15, 18, 19, 24, 53, 58, 59). The explanation for these effects can be found in the following sections.
The effects described are:

- An increase in the extracellular CA++ level.
- Normalization of the pH.
- Changes in the cell membrane. These include changes in the membrane itself, as well as changes in the membrane
- potentials, leading to increased sensitivity to stimuli.
- Decrease of the glycogen content: increase in the number of leucocytes and lymphocytes.

Note:
As axon reflexes imply tissue damage, there may be an increase in the local inflammatory process. As a consequence, the patient may report a worsening of the condition following treatment. The treatment parameters must then be adapted. In this connection it is recommended that, in pulsed applications of electromagnetic energy, the peak power should be reduced.

5.7 Additional effects of heat on various tissues

5.7.1 Connective tissue

An increase in the temperature of connective tissue, in particular the collagenous tissue such as skin, muscle, tendon, ligament or articular capsule, will be accompanied by an increase in the elasticity. Heat can improve the elasticity of fibrous tissue by a factor of 5 to 10. At the same time, the viscosity of the matrix decreases. Consequently, connective tissue such as tendon tissue will also become more elastic.

5.7.2 Muscle tissue

The observations in Section 5.7.1 are valid for the connective tissue in muscles. In addition, there is also the effect of heat on hypertonia. It is assumed that the hypertonia is the result of nociceptor activity. Spasticity and hypertonia of emotional origin fall outside the scope of this book. The nociceptor activity results from damage of muscle tissue, and is therefore considered under the heading of Wound Healing (Chapter 6).

5.7.3 Articular capsules

Heat increases the elasticity of the collagenous tissue in the capsule. The capsule comprises a large quantity of collagen, in the form of fibres in a matrix. The matrix reacts most strongly to heat by reducing the viscosity. This enables movements of the joint to be performed with less kinetic energy.

5.7.4 Nerve tissue

Heat reduces the potential in nerve cells, leading to depolarisation. The depolarisation is not strong enough to induce an action potential. The sensitivity of the nerve tissue will eventually increase. The changes in the cell potentials also affect the cell metabolism. Within the physiological limits, the speed of transmission within a nerve will increase by a factor 1.7 to 2 per 10°C increase in temperature. This is referred to as the temperature coefficient Q10 (38).

5.8 Working hypotheses

- Heat results from the dissipation of electromagnetic energy. This leads to an increase in the velocity of particles and a rise in temperature in tissue. If the rise in temperature can be measured or felt, this is referred to as a thermal effect.
- Physiological reactions to heat, falling under the definition of non-thermal effects, result from the electric current created in tissue by the electromagnetic energy. In non-thermal effects, not only the heat generated is considered, but also the electric force on particles resulting from the build-up of electric charge. This force is actually very small, and alternates with the frequency of the source, namely 27 MHz. The extent to which this force contributes to the therapeutic effect is still unclear.
- Short pulses with a high peak power lead to strong, short-duration thermal stimuli at the cellular level. These can lead to (incipient) cell damage. The cells and the peripheral nervous system react to these potentially damaging stimuli. In this respect, pulsed application differs from continuous application.

These hypotheses imply that thermal effects occur in biological tissues with both pulsed and continuous application of electromagnetic energy. In order to enhance the non-thermal or biological effects, under the physiological conditions, a low pulse repetition frequency, a short pulse duration and a long pulse interval are required.

6 Wound healing

6.1 Introduction

In this chapter the various phases of wound healing are discussed, and a distinction is made between the physiology and pathophysiology. The influences of electromagnetic energy on the various phases of wound healing will be considered in the following chapter. These included both positive and negative influences.

The healing process follows a similar course in different types of wound. There is no fundamental difference in the process of wound healing in a bone fracture or in the rupture of a muscle. However, there is a difference in the type of cells involved. In a bone fracture, osteoblasts play an important role in the healing process, while a similar role is played by fibroblasts in muscle tissue, and by chondroblasts in cartilage.

The generalized process of wound healing can be divided into three phases (13, 14, 23, 34, 42). The different phases are characterized by the activity of specific types of cell, by the presence of certain intercellular structural macromolecules, and by signal materials that co-ordinate the wound healing processes. Passing through the various phases is a requirement for normal physiological recovery.

It is important to consider the duration of the various phases. In physiology, the various phases occur over a period of time in a fairly clearly defined sequence. In pathophysiological circumstances, this sequence is disturbed. For example, the healing process can remain stuck in the inflammatory phase. In this case, the inflammatory and proliferation phases can pass into a destructive phase with degeneration of the affected tissue, considerable swelling, and a serious increase in nociceptor activity or pain. If this process is allowed to continue for months or years, the body will adapt, for example with fibrous or bony ankylosis, often with the affected joint in a non-functional position. Finally, such a process can end up years later in a ‘burned out’ phase, with absence of swelling, severe deformity, non-functional joint positions, contractures and a severe limitation of function (17, 30, 39, 55).

6.2 Some aspects of wound healing

6.2.1 The phases of wound healing

The following (considerably overlapping) phases can be distinguished:

The bleeding phase	20-30 minutes
The inflammatory or resolution phase	24-36 hours
The regeneration phase, subdivided into:	
the proliferation phase	2-4 days
the production phase	4 days-3 weeks
the remodelling phase	3 weeks-3 months

The bleeding phase

The bleeding phase is characterized by a short period of bleeding, stanched by counterpressure from the surrounding tissues. At the same time the damaged blood vessels react with a vasoconstriction that continues for about 20 to 30 minutes. This vasoconstriction is initiated by serotonin and prostaglandin. Under the influence of thromboplastin, the prothrombin in the serum is converted into thrombin. Thrombin is an active enzyme which can convert the fibrinogen in the outflowing blood to fibrin. This results in clotting of the blood, forming a physical barrier which prevents further blood loss. In many cases of non-traumatic lesions, this part of the bleeding phase may be absent.

Every lesion of any significance is registered by the nervous system via the nociceptor activity resulting from the lesion. This nociceptor activity is important for initiating the inflammatory phase.

The inflammatory phase

Neurogenous inflammation

The nervous system plays a clearly defined intermediary role in an inflammatory reaction. Such a reaction in the skin is also known as the ‘triple response’ of Lewis.

If damage occurs in a tissue, the polymodal nociceptors at the site of the injury are activated. These polymodal nociceptors lead to a local inflammation of the damaged tissue. This local inflammatory reaction is initiated by the release of tachykinins from the nerve endings, including substance P (SP) and other neuropeptides. These peptides stimulate the mast cells and other factors of the immune system (Fig. 2), resulting in the release of histamine and serotonin (25, 62).

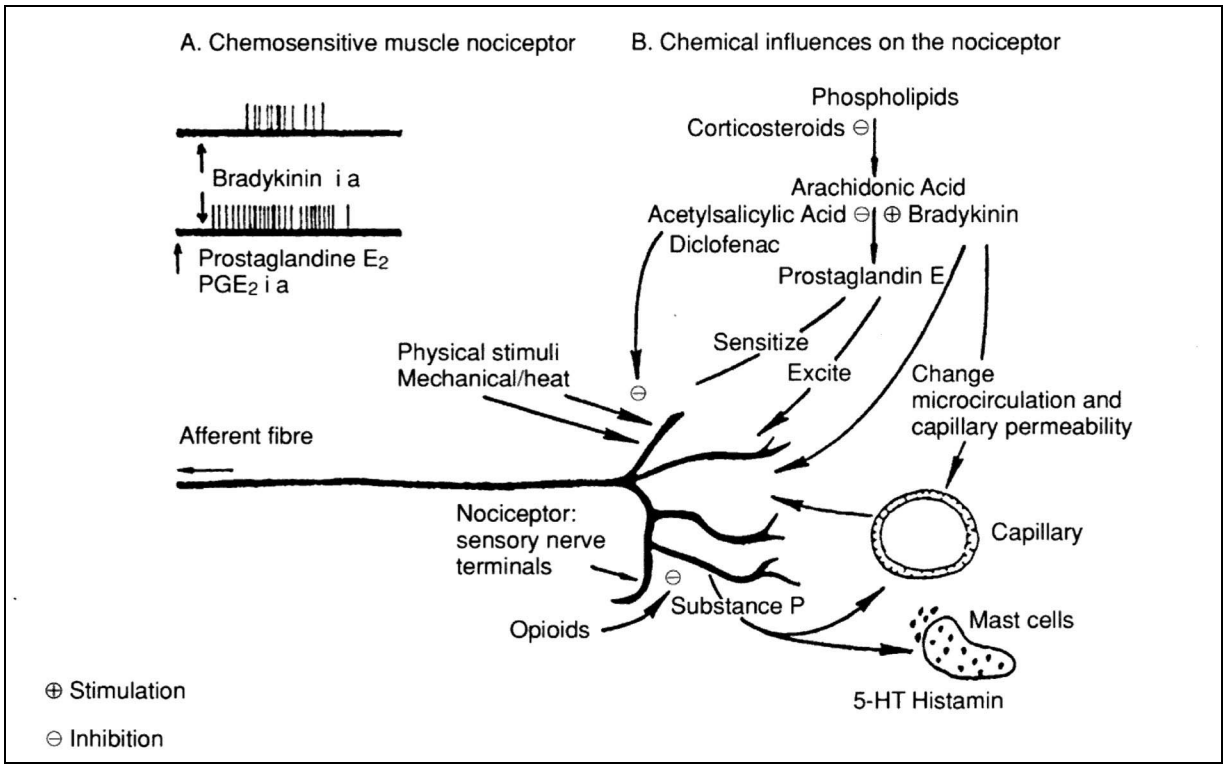


Figure 2: Zimmerman (62): the nociceptor and its (micro) environment

Almost simultaneously the action potential from the polymodal nociceptor returns via one of its collaterals to the surrounding blood vessels, initiating vasodilation. This phenomenon is referred to as antidromic vasodilation or **axon reflex** (25) (Fig. 3).

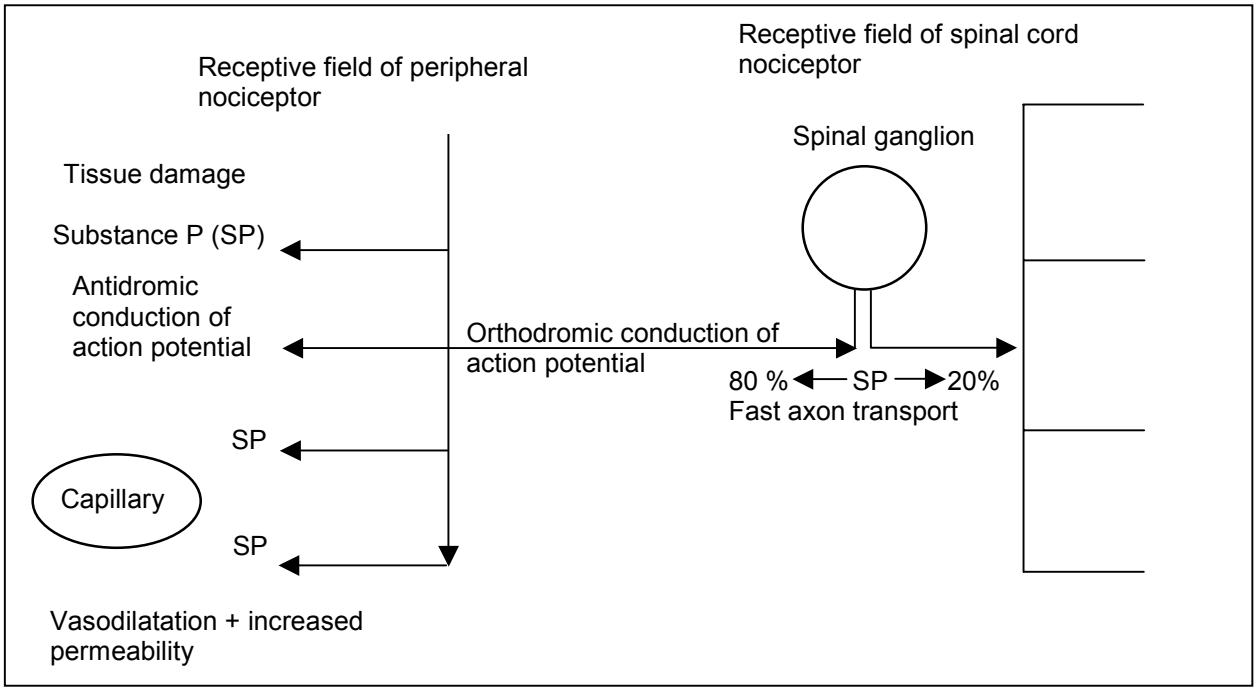


Figure 3: Axon reflex: some aspects

In the case of a minor injury the inflammatory reaction remains localized, and the central nervous system is not involved in the repair of the tissues. The action potential conducted from the polymodal nociceptors is extinguished in the posterior horn of the spinal cord. With a stronger inflammatory reaction, the afferent stimulus from the polymodal nociceptors is conducted via the anterolateral tracts in the spinal cord and the hypothalamus to the sensory cortex. In this case, nociceptor activity is experienced as pain. The activity in the limbic system, including the hypothalamus,

increases and contributes to the inflammatory reaction. Two routes can be distinguished: a hormonal route via the adrenal cortex, and a nerogenous route via the sympathetic nervous system (Fig. 4).
Here, we shall confine ourselves to considering the neurogenous route. The sympathetic nervous system releases phospholipids from all the cells in the region of the tissue damage. This effect is calcium-dependent. Next, via a series of steps, prostaglandins are formed. The prostaglandins support the inflammation by sensitising the polymodal nociceptors and by vasodilation. Other mechanoreceptors are also sensitised (8, 25, 27, 35, 61, 62).

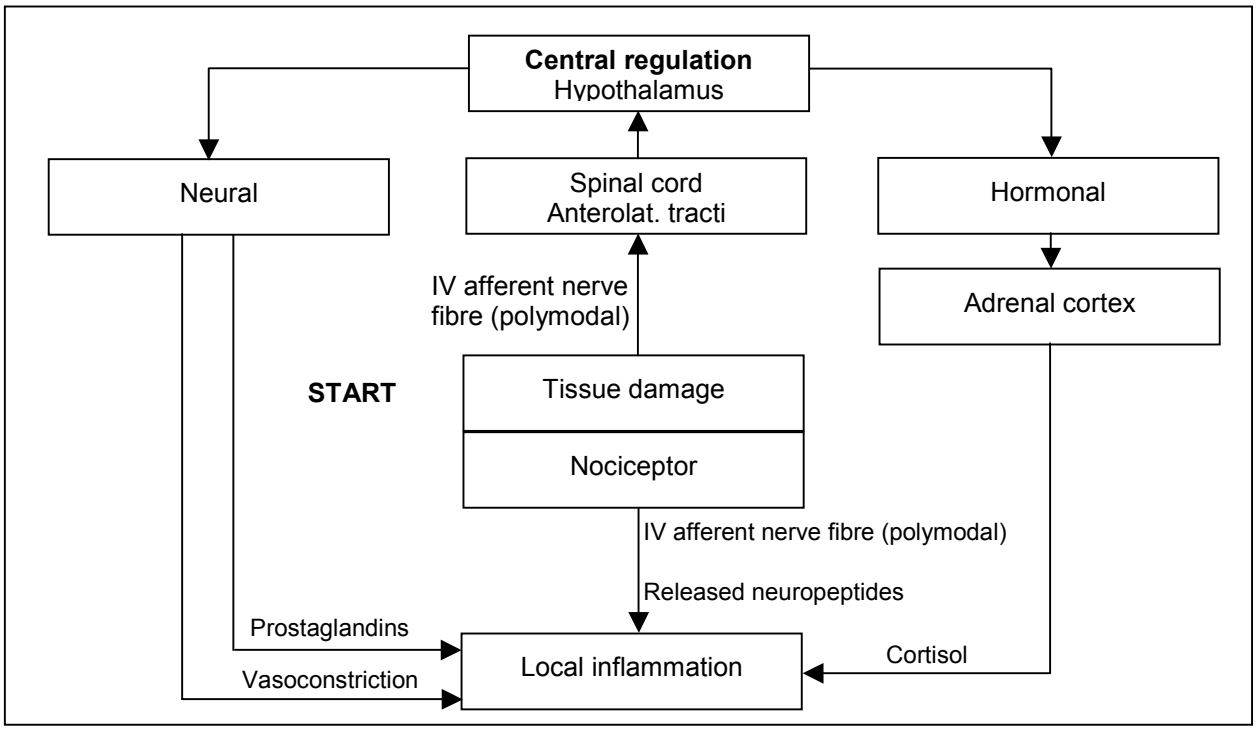


Figure 4: Neurogenous inflammation

The clinical characteristics of inflammation are all of neurogenous origin. The classic signs of rubor, calor, dolor, tumor and functio laesa are all present to a greater or lesser degree. In superficial inflammation, the redness is generally visible, as in superficial bursitis. The same is true of the swelling. The temperature increase is sometimes palpable. There is pain at rest, due to sensitisation of the group IV nerve fibres. This pain can increase on movement due to sensitisation of the group IIIb fibres. This sensitisation leads to the experience of pressure-pain. Inflammation of the tissue of an organ, such as a muscle, leads to loss of function at organ level. This can lead to movement disturbance. Thus, one can speak of muscle function disturbances that lead to disturbances of movement. These characteristics are dependent on the degree of inflammation.

In the inflammatory phase the neurogenous inflammation leads to secondary vasodilation in the intact blood vessels around the area of the wound. This vasodilation occurs under the influence of, inter alia, histamine and bradykinin, and is supported by substance P (SP) which also increases the permeability of the vessel wall (25). The local vasodilation and the increase in permeability allow macromolecules such as proteins to pass through the vessel walls. This alters the osmotic pressure relationships, and fluid passes out of the blood stream. This exudates forms a swelling around the wound area, and provides an infiltration of antibodies against viruses and other micro-organisms. In addition to the secretion of mediators, PDGF (Platelet Derived Growth Factor) is also released, which already stimulates the division of fibroblasts and causes chemo-taxis of neuthrophil granulocytes, monocytes and fibroblasts towards the wound area. The granulocytes move to the edge of the wound area and penetrate through the wall, finally migrating into the clot (13, 34, 42).

The granulocytes absorb particles of the clot by phagocytosis, breaking it down. Due to the altered osmotic relationships, the debris cannot flow back into the blood vessels. Thus, the debris is removed by the lymphatic system, where the immune system ensures its further destruction. During this phase, acidosis occurs due to the burning of sugars. The liberated H+ ions bond with the negative proteoglycans and glycosaminoglycans (GAG's), causing the matrix of the connective tissue to lose its gel character, and become watery. This enables antibodies, blood cells and macromolecules to move freely. However, as a result of the same process, the collagen becomes mechanically fragile. Consequently, normalization of the pH is a prerequisite for recovery of the connective tissue. Under the influence of PDGF, moncytes leave the blood circulation and migrate to the clot. Once outside the blood stream they differentiate into macrophages with a high phagocytic capacity. The macrophages produce Macrophage Derived Growth Factor (MDGF), which encourages division of the fibroblasts, thus initiating the proliferation phase. The inflammatory phase generally lasts for 24 to 36 hours, before the activity of the fibroblasts begins. At this stage, the monocytes have already begun synthesizing type IV collagenous connective tissue to limit the extent of the wound. This type of collagen is amorphous, and has no tensile strength.

The regeneration phase

The regeneration phase can be subdivided into the proliferation phase, the production phase and the remodelling phase.

The proliferation phase

After two days, there is an increase in fibroblast activity, and granulation tissue is formed. Due to the absence of tissue tension, the tissue is laid down irregularly. After four days, endothelial cells start to infiltrate, and formation of the blood vessels begins. Next, the fibroblasts begin to form matrix molecules and collagen, and cross-links occur in the form of weak electrostatic connection. The collagen is mechanically very fragile at this stage, and the cross-links are easily broken. At the same time, myofibroblast activity appears. These cells provide for contraction of the wound, and form collagen fibres. Finally, the myofibroblasts provide connections between the cells by means of fibronectin and so-called 'microtendons'.

The production phase

In the production phase, which can last from four days to three weeks, new blood vessels are formed. These blood vessels transport the materials required, e.g. for the production of collagen fibres. The production of collagen fibres is now well under way. However, the production of matrix molecules or proteoglycans is also dependent on the infiltrating blood vessels. The clot is replaced by connective tissue with fibroblasts, blood vessels, collagen fibres and proteoglycans. This tissue has a granular appearance, and is therefore referred to as granulation tissue. The tensile strength of the connective tissue increases in about three weeks, and is proportional to the number of fibres formed. The cross-links between the fibres are still weak, and are easily broken (immature cross-links). For the production phase to follow its optimum course, oxygen is needed, as well as a number of essential nutrients. These include vitamins C and B6, copper, magnesium, zinc, and iron. Deficiency of these materials leads to poor-quality collagen with inadequate mechanical properties (13, 14, 17, 34, 42).

The remodelling phase

In the remodelling phase, which can take from three weeks to three months, the tissue is converted into a tough, durable structure. The fibres formed in the proliferation phase are generally not aligned in the direction of the functional loading. Intra- and extramolecular cross-links are, at this time, no more than electrostatic connections with H+ ions. The collagen fibres are mechanically weak, and the cross-links are easily broken.

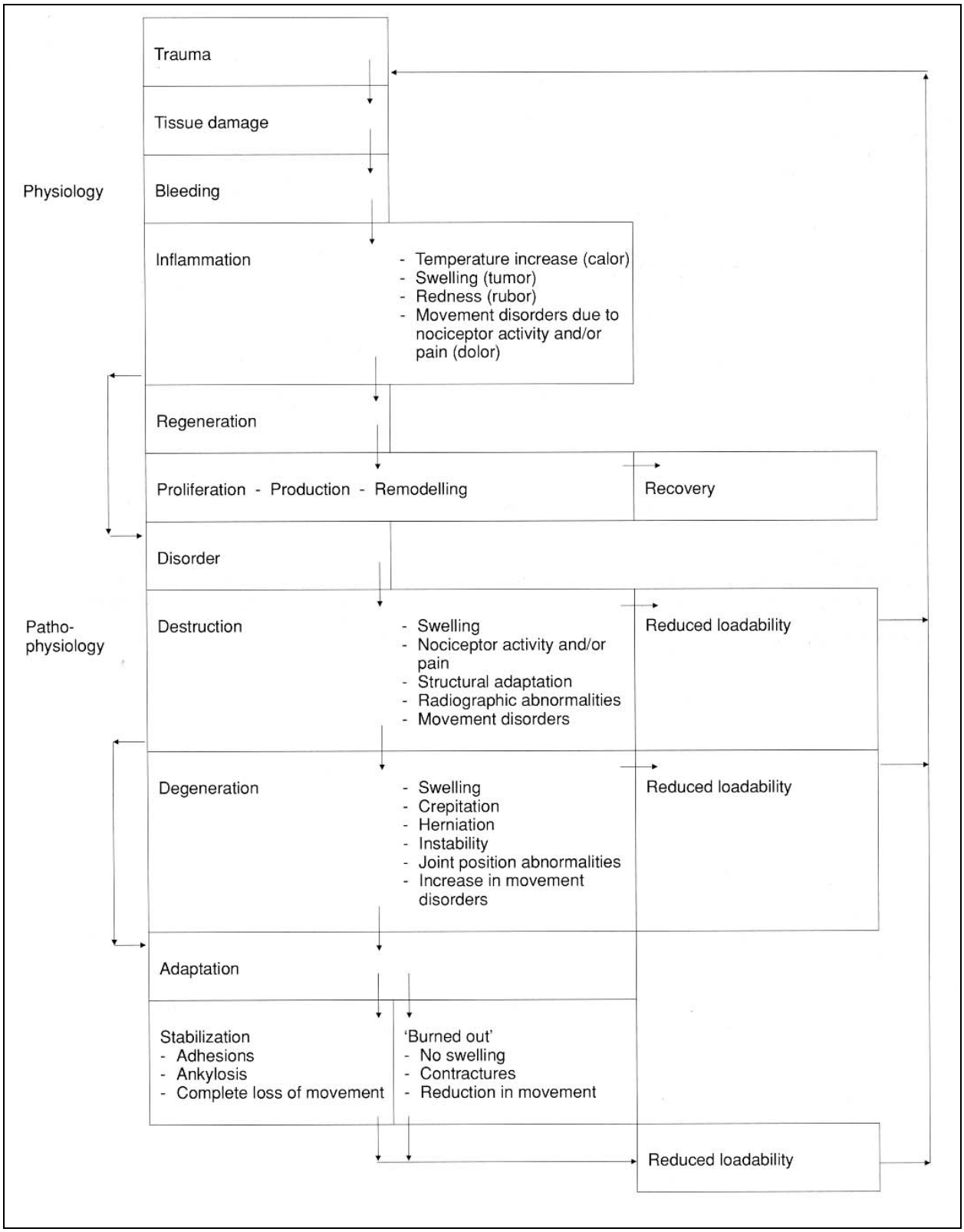
By breakdown and synthesis (turnover), the orientation of the fibres is adapted to the function, and more and stronger cross-links arise between the collagen molecules of the fibres, and between the fibres themselves (mature cross-links). The mechanical stability increases rapidly as the collagen fibres are aligned in the direction of tension, become thicker and have more stable cross-links. Regulated application of tension to the affected tissue is therefore a prerequisite for the formation of an optimum connective tissue structure. The collagen fibres should not tear under load, but the elasticity limit will be reached more quickly. Finally, the collagen network will have a tough structure that can accommodate tension in very required direction. Overloading generally leads to an overproduction of collagen, with the possibility of keloid formation. The tissue, i.e. the collagen fibres, must not be traumatized in this phase, as every injury will initiate new inflammation.

The great variation in the duration of the remodelling phase is, as in the production phase, dependent on the trophic supply and the nutrients. The remodelling will also be determined by the applied load (over- or underloading) and, finally, by medication, particularly the use of anti-inflammatories such as corticosteroids and NSAID's.

6.3 Working hypotheses

In disorders of the motor apparatus, accompanied by pain and motor disturbances, neurogenous inflammation is always present. The phenomenon of neurogenous inflammation provides an understanding of the origin, course and extension of pain in the motor apparatus, as well as the short- and long-term consequences. An understanding of the phenomenon of neurogenous inflammation is important for the physiotherapist, as it provides diagnostic and therapeutic insight in the investigation and treatment of many disturbances of the motor apparatus.

The creation of an optimum environment for the course of the inflammatory reaction is essential for its initiation and continuation and, hence, for the recovery of the affected tissue structure.



Physiological and pathophysiological processes following tissue damage

7 Effects of electromagnetic energy on wound healing

7.1 Introduction

This chapter considers the various effects of electromagnetic radiation on the different stages of wound healing. Background information on these stages, required for understanding the various effects is given in Chapter 6. As in other applications, the effects of electromagnetic energy on wound healing can be divided into thermal and non-thermal or biological effects.

7.2 General effects of electromagnetic energy on wound healing

7.2.1 Effects during the bleeding phase

Treatment with high-frequency electrotherapy is contra-indicated during the bleeding phase, as heat would lead to undesirable vasodilation. Even pulsed application is inadvisable. Local increase in metabolism can lead to vasodilation in the region of the damaged tissue, while the injured blood vessels are functionally in a state of vasoconstriction under the influence of serotonin.

7.2.2 Effects during the inflammatory phase

Local stimulation of the metabolism by heat (i.e. an increase in the velocity of particles) by non-thermal application of electromagnetic energy can be beneficial in this phase, as it can support, accelerate or initiate the physiological processes. The last is true in the case of excessively slow development of the inflammatory reaction.

Note:
In the case of a strong inflammatory reaction, some restraint should be observed, as auto-immune processes could also be initiated.

Local heating processes can best be initiated by the application of high-frequency electrotherapy via a magnetode (Circuplode). In this case, there is little or no stimulation of the thermosensors in the skin. As a consequence, there is virtually no reaction from the central nervous system. The effects are therefore largely confined to the local processes.

Although the origins of the non-thermal or biological effects are still largely unclear, the existence of a number of these effects has been confirmed experimentally. A well-known investigator in the field of wound healing is B.M. Cameron, who studied the effects of pulsed electromagnetic energy in dogs as long ago as 1961. It was shown that a ‘speed up’ effect was obtained in various phases of wound healing, particularly in the proliferation and production phases. The methodology of the investigation was rather weak, and there was no control group. Nevertheless, the investigation led to many subsequent studies, with many contradictory results. However, few investigations were carried out on living human tissue.

The following non-thermal or biological effects can be derived from the literature (2, 10, 11, 15, 18, 33, 36, 40, 41, 51):

1. Increase in the quantity of leucocytes and phagocytes.
   This increase is probably due to an increase in diapedesis.
2. Normalization of the pH.
   Normalization of the acidity is probably the result of improved perfusion.
3. Increase in the extracellular Ca++ level.
   This increase is ascribed to increased transport through the cell membranes. Parathyroid hormone (parathormone) may also play a role (2).
4. Reduction in the glycogen content.
   This is a consequence of the increased metabolism.
5. Cell membrane changes.
   These include changes in the cell membrane itself, as well as changes in the intra- and extracellular ion concentrations, with consequences for the cell membrane potential and sensitivity to stimuli.

To sum up, it appears that a number of processes in the inflammatory phase are favourably influenced by the electromagnetic energy, provided that the application is non-thermal.

7.2.3 Effects during the proliferation phase and production phase

In principle, the same conditions apply as in the inflammatory phase. However, the thermal tolerance of the tissues increases, so that somewhat more electromagnetic energy can be applied. This increased tolerance is due to the fact that the perfusion is being restored. However, the newly formed blood vessels are still weak. The reperfusion can be encouraged by applying a small amount of heat via electromagnetic energy. This stimulates the growth of blood vessels (capillaries).

Initiation of perfusion is important in this phase, in order to provide the affected tissues with oxygen and essential nutrients. This requires activation of the blood circulation which, in turn, requires a reaction from the central nervous system. The stimulation must therefore, in the first instance, evoke a **slight sensation of** heat. Subsequent dosage should be adapted so that the treatment takes place without a sensation of heat, i.e. just below the threshold of heat perception (submitis).

During the production phase, in other words about four days after the injury, the 'thermal load' can be gradually increased. The treatment parameters should now be selected in such a way that the patient experiences a **mild sensation of warmth.**

7.2.4 Effects during the remodelling phase

In this phase, electrotherapy affects the properties of the collagen matrix. When the matrix is heated within the physiological limits (see Chapter 5) the lubricative properties of the collagen fibres become optimal and the elasticity increases. This favourably influences the functional alignment of the fibres, provided that correctly regulated tension is applied to the connective tissue. To achieve these effects, a definite 'thermal treatment' is required. The patient should experience a definite sense of warmth, but never heat. In general, good perfusion can be assumed in this phase, so that this type of treatment also results in the recovering tissue being supplied with blood.

7.3 Specific effects of electromagnetic energy on wound healing

The effects of heat on various types of tissue are described in Chapter 5. This section is principally concerned with some specific aspects concerning lesions in various types of tissue.

7.3.1 Delayed wound healing

From the preceding chapters it could be assumed that treatment with high-frequency electrotherapy would cease to have any effect about three months after the occurrence of a lesion. In practice, however, inflammation may persist for a longer time after the injury, or the wound may fail to heal properly or at all. In the last case the loadability remains low, and recidivation can rapidly occur. Slow-healing fractures also fall into this category. The slow healing of the wound can be due to intrinsic or extrinsic factors. Depending on the clinical findings, an assessment can be made of the phase of wound healing reached. The treatment parameters are then selected in accordance with this assessment.

7.3.2 Fractures

In the first place, a bone fracture is almost always accompanied by injury to the soft tissues. This can be treated as described under the general effect of electromagnetic energy on wound healing (Section 7.2).

For the treatment of the fracture itself, certain specific factors appear to be important. From the literature it appears that treatment has little or no effect on the normal physiological course of the fracture healing. However, the positive effect of electromagnetic energy on delayed fracture healing has been clearly demonstrated (1, 2, 6, 7, 41). Optimum support of the fracture healing appears to depend on frequency. According to Adey (1), the pulse repetition frequency (PRF) should be between 70 and 75 Hz. There also appears to be an optimum pulse duration of 325 µs.

Note:
It seems reasonable to assume that other tissues will also be optimally influenced within specific pulse repetition frequencies and pulse durations. Unfortunately, there is no further information on this.

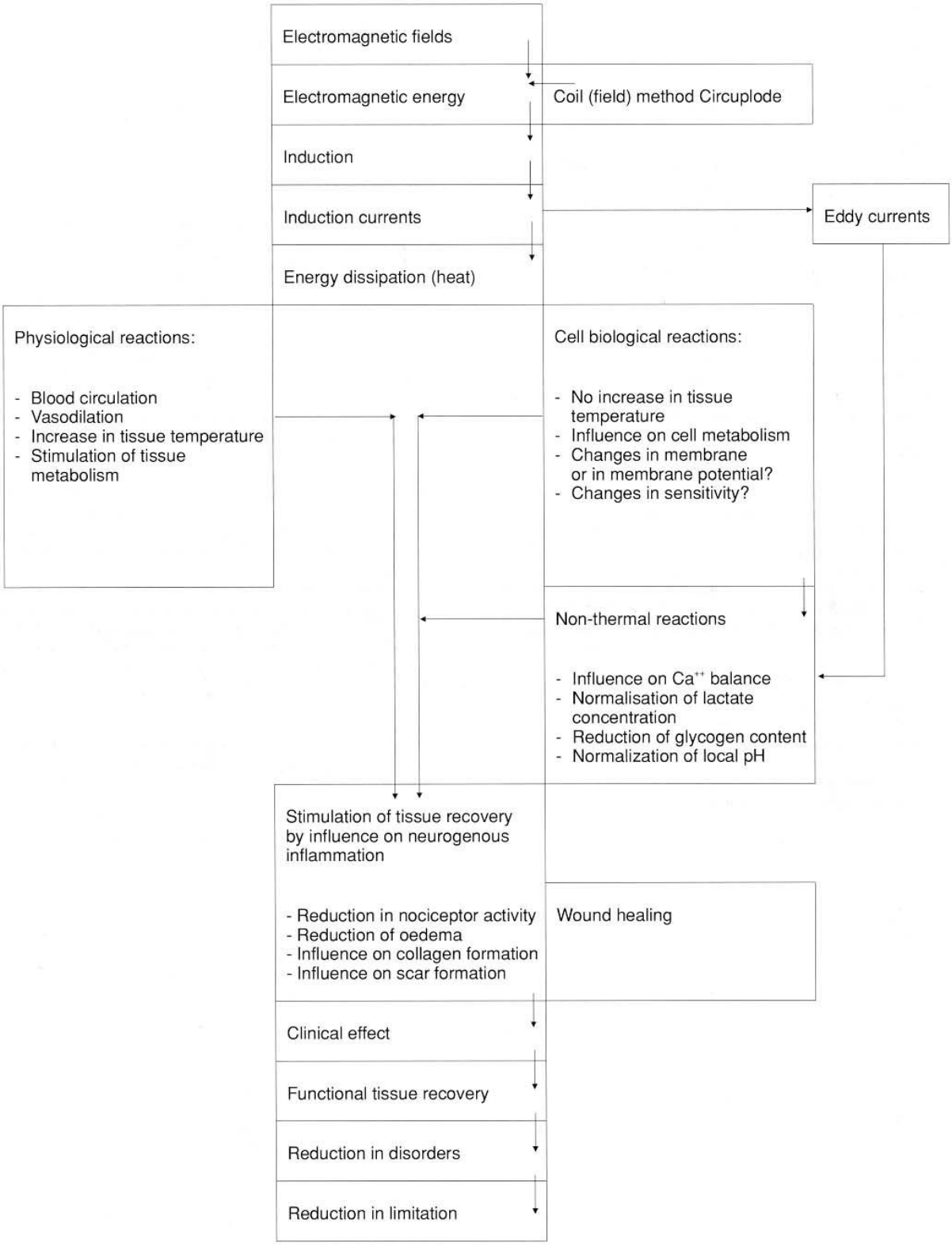
In the treatment of fractures the position of the magnetode is also important (50). This should be positioned in such a way that the electric field created should have the greatest effect on the fracture. This means that the magnetode should be placed **alongside** the fracture. The Curapuls 670 offers the possibility of positioning two Circuplodes on opposite sides of the fracture.

7.3.3 Soft tissue lesions

Although the general principles for treating these tissues apply, the degree of perfusion must be taken into account. Tissues with a good blood supply, such as muscle tissue, increase more slowly in temperature than tissues with a poorer blood supply. This means that muscle tissue can be treated with relatively more electromagnetic energy than, for example, tendon tissue. In joints, the articular capsule is well perfused, while the intra-articular parts are not. When heat is applied to the articular capsule, conduction of heat can lead to the intra-articular parts of the joint becoming (too) hot. This applies particularly to superficially located joints, such as the knee and wrist.

7.3.4 General conclusions on the effects of electromagnetic energy on wound healing.

- With the exception of the bleeding phase, electromagnetic energy can have a therapeutic effect on all phases of wound healing.
- In the inflammatory phase, the pulsed application of electromagnetic energy can stimulate non-thermal or biological effects.
- In the proliferation phase, there is a change of emphasis from non-thermal or biological effects towards slight warming of tissue or even a clearly perceptible warmth.
- Assessments should be made, on the basis of anamnesis (interview) and physical examination, of the phase that the healing process has reached, and of any factors hindering the physiological repair.
- In the inflammatory phase, electromagnetic energy is often the only physiotherapeutic means available, while in other phases there is a range of therapeutic possibilities.



Therapeutic effects of electromagnetic energy

8 Dosage

8.1 Introduction

In physiotherapy practice it is not possible to measure rises in temperature, particularly when the rises are very slight. The patient can only register temperature changes in the skin. Deeper-lying tissue types have no thermoreceptors. Methods such as infrared temperature measurements do not appear to be sufficiently reliable in practice. What remains is the patient's own subjective perception which, in this context, is the absolute determining factor. In circumstances characterized by existing severe inflammatory reactions, any form of created or applied heat is absolutely contra-indicated.

It is also impossible to measure non-thermal or biological effects in physiotherapy practice. Only observation and recording of clinical effects in the course of time, measured before, during and after treatment, can provide information on whether the aims have been achieved. Clinical effects are often described in the literature, in the sense of pain reduction, swelling reduction, temperature changes or increased mobility. While many investigators direct their attention towards changes in biological systems, very few are concerned with changes in the day-to-day functioning resulting from pain reduction or increased functionality.

The literature (1, 2, 3, 4, 5, 9, 10, 11, 15, 18, 19, 20, 21, 26, 27, 31, 22, 41, 48, 51, 53, 54, 56, 57, 59) gives little guidance for determining the specific dosage under pathological conditions. Only generalized information is given on the method of treatment. In the case of inflammation in ion-rich tissues, an estimate is made of the extent to which the blood circulation is severely reduced and the trophic supply is diminished, the electromagnetic energy will have to be applied in pulsed form. A setting with short pulse durations and low pulse repetition frequencies will be needed in order to keep the thermal load to the minimum. The high peak power must be regarded as being sufficient to activate the tissues and/or cells. When the inflammatory activity reduces, the thermal load can be increased, in order to stimulate the blood circulation and the trophic supply for optimisation of the healing process. Under these circumstances it is possible, and often desirable, that the patient will experience a slight feeling of warmth. Long-duration chronic inflammations may often be an indication for the creation of some heat, resulting in an increase in the inflammation. This type of treatment should only be applied where the nervous system is able to react adequately and very selectively to the increase in the inflammation. If the nervous system reacts to the stimuli non-selectively, there is a great chance that the inflammatory reaction will no longer be inhibited, and that a severe inflammatory reaction will occur which can no longer be controlled, thus missing its target.

From the practical point of view, in order to reduce the number of parameters to be set, the 'pulsed short wave' with maximum peak power has been selected for the treatment. In the Curapuls 670 the maximum peak power is 200 W. If this parameter is fixed, the dosage can be determined by altering the pulse duration and pulse repetition frequency. It is important for the user to be able to assume that the power output is as close as possible to the indicated 200 W. The equipment may only deviate from this within reasonable (technical) limits. Lehmann (36) reports that the greatest limitation in a range of existing equipment is the fact that insufficient energy is emitted, and that this cannot be checked in the clinic. This makes many items of equipment safe, but ineffective. Incorporation of an indication of energy emission in high-frequency electrotherapy equipment is therefore of great practical importance for the clinic. In the Curapuls 670, in addition to the maximum peak power of 200 W, a mean power of between 0 and 32 W can be determined by selecting the pulse duration between 65 and 400 µs, and the pulse repetition frequency between 26 and 400 Hz.

8.2 Duration of treatment

The duration of a treatment with electromagnetic energy is generally from 20 to 30 minutes. According to the literature (27, 33), provided that the patient's blood circulation is able to function normally, a significant vasodilation will have reached its maximum within this period. If the treatment duration is longer, there is an increased chance of a 'rebound effect'. Barth and Kern (5) even recommend that, when the inductive method is used for stimulation of the blood circulation, the treatment should never last longer than 10 minutes. Longer treatment times may, however, be effective for stimulating non-thermal or biological effects, but the time periods within which these effect occur are still unknown.

The 'rebound effect' referred to above is an effect that can occur in the vascular system under the influence of the application or withdrawal of energy in living tissue. It results in a significant decrease or increase in the tissue temperature, and is therefore undesirable. This effect will not occur under normal physiological conditions with a normally functioning nervous system and circulation system. An exception is where the heat causes a high degree of nociceptor activity. Whenever nociceptor activity results in pain and hypertony in muscles, the maximum peak power and, hence, the mean power must be reduced.

Conclusion:

- Treatment duration is dependent on the (local) blood circulation and the trophic supply.
- Disturbance in thropic supply can cause increased nociceptor activity, possibly resulting in pain.
- The treatment duration generally varies between 20 and 30 minutes, depending on the mean power selected.

8.3 Frequency of treatment

With a low dosage, treatment can be applied daily. In fact, stimulation of non-thermal effects several times a day can be considered, without affecting the blood circulation. Daily treatment may be essential, particularly in situations with severe inflammatory reactions. This is generally confined to the first five to eight days following acute trauma, in order to influence the inflammatory process.

The effect of a treatment with electromagnetic energy can often persist for a considerable time. Wessman and Kottke (56) found that, following 'indirect' stimulation with the inductive method in the abdominal region, the blood circulation in the calf increased considerably some 15 minutes later. The blood circulation in the treated area sometimes continued to increase ten minutes after the application, reaching a maximum at an average of 57 minutes after the start of treatment. The test subjects were all healthy human beings. Hedenius (24) investigated the effect of pulsed electromagnetic energy at 27 MHz on intermittent claudication. The results were an increase of 3°C in the skin temperature, measured at the toes, and a considerable improvement in the walking tolerance test. This effect was obtained by treatment of the epigastrium. The pulse duration was 65 µs and the pulse repetition frequency was 600 Hz, with a mean power of 38 W. A total of 12 daily treatments were carried out.

The persistence of non-thermal effects following the application of electromagnetic energy is not known. For this reason, a decision on whether a variation in the number of treatment days is justified must be based on the clinical results.

Conclusion:
- Acute inflammations can be treated.
- Treatment of acute traumas can be given daily for the first five to eight days in order to stimulate the non-thermal or biological effects during the inflammatory phase.
- The persistence of the effects is clinically unknown.
- The frequency of treatment is determined by the clinical results.

8.4 Number of treatments

With respect to the number of treatments, the literature is very unclear and a standard table cannot be given. Consequently, the question of whether continuation of treatment is justified or not is determined solely by the clinical results. Under normal physiological conditions the wound healing over the first five to eight days will consist entirely of inflammatory reactions, proliferation and production. Simultaneously, the fibroblasts will begin to produce new collagenous connective tissue. During the second phase, the blood circulation can be subjected to some degree of thermal load. Subsequently, mechanical loading of the new tissue will stimulate the formation of a tough connective tissue structure. At this stage, daily treatment with electromagnetic energy appears to be no longer justified.

Conclusion:
- The number of treatments is determined by the clinical results.
- The physiological phases of tissue healing can be an indication for the number of treatments.
- The application of high-frequency electrotherapy without any clinical effect is contra-indicated.

9 Indications and treatment examples

9.1 Introduction

From the foregoing chapters it can be seen that electromagnetic energy can be applied in various phases of the wound-healing process. In the inflammatory phase, the primary task of the physiotherapist is to protect the tissue and the associated joints. Consequently, electromagnetic energy is often the only form of therapy that can be applied in this phase.

Furthermore, as stated above, the term 'wound' must be regarded in a very general sense, as there are many conceivable pathologies in which the wound-healing process plays a role. This is best known in orthopaedics, with such examples as bone fractures or ruptured tendons. High-frequency electrotherapy has also a wide range of indications in sports traumatology.

In rheumatology, many forms of inflammation and degenerative processes are encountered, and the application of high-frequency electrotherapy has, for many years, had a firm place in the physiotherapeutic treatment of rheumatic diseases. This area of indications can be extended still further by optimalization of the high-frequency electrotherapy equipment, so that short-wave therapy can also be applied in cases of severe inflammation. In short, a wide variety of indication areas could be mentioned. However, the authors prefer to present a sort of 'recipe book; with examples of the various pathologies that can be treated. These examples can provide the reader with **guidelines** for the various treatment possibilities.

These examples have been selected to give an impression of the ways in which a treatment can be carried out. The chart on page 31 is intended to provide the reader with a strategy for decision-making with respect to the treatment.

9.2 Epicondylitis lateralis humeri (43, 46)

Situation 1.

Anamnesis:
The anamnesis (interview) provides information on the duration of a lesion in the tenoperiosteal transition of the Mm. Extensor carpi radialis longus and brevis.

Symptoms:
If the inflammation is the result of a sprain, and is only three days old, the symptoms will be: pain at rest, local swelling, redness and provocation of the pain by tension of the musculature. Pressure-pain occurs on palpation.

Aim of treatment:
To support the processes of neurogenous inflammation.

Method:
A Circuplode is applied at the level of the attachment of the musculature. The treatment is fully non-thermal; the patient feels no warmth.

Treatment parameters
Pulse duration:…….. ……65 µs
Pulse repetition frequency:…….. ……..26 – 62 Hz
Intensity…… ……..200 W
Duration of treatment……. …..20 – 30 minutes
Frequency of treatment……. ……..Daily

Note:
In addition to the treatment with electromagnetic energy, measures should be taken to relieve load on the lesion.

Situation 2.

Anamnesis:
If the diagnosis of epicondylitis was already made six months ago, it can be assumed that morphological changes have now occurred in the connective tissue structures of the muscles concerned and the articulatio cubiti.

Symptoms:
Pain after short duration loading, with palpable cords of connective tissue. The position of the actual inflammation is characterized by a region of poor trophic supply. Depending on the degree of the inflammation, some loading of the blood circulation is possible.

Method:
The electrode is applied in the same way as in Situation 1. Subjectively, the patient experiences slight warmth.

Treatment parameters

Pulse duration:……..	……200 µs
Pulse repetition frequency:……..	……...150 – 200 Hz
Intensity……	……..200 W
Duration of treatment…….	……...20 minutes
Frequency of treatment…….	….....Alternate days

General remarks:

- If the degree of inflammatory activity in the tissue is particularly high, the peak power of 200 W may, as a last resort, be decreased. It should be noted that this adaptation is one of the last possibilities available.
- In mobilization of the Mm. extensor carpi radialis longus and brevis by traction exercises, it is useful to warm the muscle tissue in advance in order to favourably influence the collagenous matrix. In this case, the patient may experience a marked sensation of warmth.
- Comparable situations naturally include similar injury related disorders such as epicondylitis medialis humeri, tendonitis of the long head of the M. biceps brachii, tenoperiostitis of the Achilles tendon and tenoperiostitis of the M. pectineus and the adductor muscles of the femur.

9.3 Fibromyalgia syndrome

Anamnesis:
The fibromyalgia syndrome is almost always difficult to diagnose. The anamnesis is long, and goes far back in time (16, 30, 60).

Symptoms:
A characteristic of the fibromyalgia syndrome are the various myofascial trigger points in the following muscles:

- M. sternocleidomastoideus
- M. levator scapulae
- M. trapezius (pars descendens)
- M. masseter
- M. gluteus maximus (attachment at the iliac crest)
- M. gastrocnemius
- M. tibialis anterior

The syndrome involves virtually all muscles which have a high proportion of ‘slow twitch’ firbres and a tonic function (28, 32).

Examination:
Trigger points that have been in existence for a long time exhibit fibrotic nodules, which are palpable.

Aims of treatment:
In trigger points that have been in existence for some time, electromagnetic energy is applied to create warmth, in order to stimulate the metabolism with the aim of improving the trophic supply. Thermal overloading of the blood circulation should be avoided.
Treatment with electromagnetic energy should be regarded as a preparatory therapy, creating better conditions for mobilization of the musculature by massage and/or traction.

Method:
As thermal overloading of the blood circulation should be avoided, the Curapuls 670 appears suitable, as it permits pulsed application of the electromagnetic energy. The use of two Circuplodes enables several muscles to be treated simultaneously, for example the M. trapezius pars descendens on both sides.

Treatment parameters

Pulse duration:……..	……200 - 400 µs
Pulse repetition frequency:……..	……...150 Hz
Intensity……	……..200 W
Duration of treatment…….	……...20 minutes
Frequency of treatment…….	……Daily or on alternate days depending on the acuteness

9.4 Contracture of the iliotibial tract in coxalgia

Anamnesis:
Pain in the region of the iliotibial tract after load. Inability to place weight vertically on the leg during walking, resulting in instability symptoms in the pelvis, including the hip.

Symptoms:
High tonus in the M. tensor fascia lata and cord formation in the iliotibial tract, resulting in increasing compression in the hip joint. During the mobility examination a disturbance is found in the adduction of the hip joint, accompanied by a feeling of stiffness and pain.

Aims of treatment:
Mobilization of the connective tissue structures, provided that the condition has not existed for more than three to six months. To warm the collagenous connective by electromagnetic energy in preparation for mobilization techniques.

Note:
The iliotibial tract is, in general, poorly perfused with blood, and extends over a relatively large area.

Method:
One or two Circuplodes are applied to the M. tensor fasciae latae and the region of most pronounced hardening of connective tissue in the iliotibial tract.

Treatment parameters

Pulse duration:……..	……200 µs
Pulse repetition frequency:……..	…….62 – 300 Hz
Intensity……	……..200 W
Duration of treatment…….	……...30 minutes
Frequency of treatment…….	……2 – 3 times per week

9.4.1 Haematoma in the iliotibial tract

Anamnesis:
Haematomas in the iliotibial tract resulting from external violence. Resorption of the blood is impeded by the limited blood circulation.

Symptoms:
Connective tissue often forms hard cords in the haematoma sites. In serious cases, calcification can occur.

Aim of treatment:
To stimulate the repair processes as fast as possible by the application of electromagnetic energy. Early treatment is essential.

Method:
Patients must experience no warmth at the beginning of treatment. Later, there may be a slight sensation of warmth. In the treatment of scar tissue, thermal effects are required, and the patient may then experience some degree of warmth.

Treatment parameters

Pulse duration:……..	……65 µs
Pulse repetition frequency:……..	……...26 – 110 Hz
Intensity……	……..200 W
Duration of treatment…….	…..10 – 15 minutes
Frequency of treatment…….	…..……..Daily, later 2-3 times weekly

9.5 Rheumatoid arthritis (RA) with symptoms in both hands (30, 39)

9.5.1 Rheumatoid arthritis with inflammatory symptoms

Anamnesis:
Pain and loss of function due to articular and extra-articular rheumatoid arthritic processes. Strength of the hands has decreased due to muscular atrophy, resulting partly from disuse atrophy, but mainly from long-duration nociceptor activity.

Symptoms:
Histological examination has shown that the inflammatory phenomena are mainly in the interstitial spaces, where there are nodular concentrations. All signs of inflammation can be found during the function examination and palpation.

Aim of treatment:
In the present acute situation, the aim is to stimulate the immune system via non-thermal or biological effects, in order to reduce the (neurogenous) inflammation.

Note:
For many years, ice application has been used to reduce inflammation. Application of heat by electromagnetic energy using the capacitive method has the disadvantage that the already increased intra-articular temperature of the hand joints has a stimulating effect on the destruction of the joint cartilage under the influence of the enzymes collagenase and hyaluronidase. For this reason, the period before pulsed application of electromagnetic energy became available, most literature on rheumatology advised against 'ultra-short waves'.
In addition to medication, stimulation of the immune system by pulsed application of electromagnetic energy can make a significant contribution to the total treatment. When the inflammatory phase is clearly present, there must be no further stimulation of the already existing vasodilation. The patient must not experience any sensation of warmth.

Method:
Two Circuplodes can be used to treat both hands simultaneously. The positioning is dependent on the places where the inflammatory process is most clearly marked.

Treatment parameters

Pulse duration:……..	……65 µs
Pulse repetition frequency:……..	……..26 – 62 Hz
Intensity……	……..200 W
Duration of treatment…….	…..20 – 30 minutes
Frequency of treatment…….	……..Daily

9.5.2 Postoperative treatment following synovectomy in the hands in rheumatoid arthritis

Synovectomy is an orthopaedic measure for the prevention of further destruction of the cartilage and bone tissue by the grossly inflamed synovial tissue. Following the operation, the extra-articular tissue shows all the signs of a wound with inflammatory activity.

Aim of treatment:
Stimulation of the various phases of wound healing, with simultaneous stimulation of the immune system.

Treatment parameters

Pulse duration:……..	……65 µs
Pulse repetition frequency:……..	……..26 Hz
Intensity……	……..200 W
Duration of treatment…….	…..10 – 20 minutes
Frequency of treatment…….	……..Daily

Note:
A few weeks after synovectomy, the membrane has regenerated. Inflammatory reactions after this period must be regarded in this light.

9.5.3 Rheumatoid arthritis of the hands with replacement arthroplasty of the metacarpophalangeal joints

The utmost caution is called for. It is not yet known whether electromagnetic energy can damage the plastic. At present, the view is that high-frequency electrotherapy should not be applied, and that other physiotherapeutic procedures should be used instead. As a rule, short-wave therapy can be used for the treatment of other structures at a distance of one metre of the arthroplastic.

9.5.4 Rheumatoid arthritis matoid arthritis of the hands and gold medication

Gold salts play a central role in medication for rheumatoid arthritis. The effect of gold salts on rheumatoid arthritis must be regarded as anti-inflammatory, although it is not yet clear how the anti-inflammatory effect is achieved. High concentrations of the gold salts can be found, particularly in the peripheral joints such as those of the fingers and toes. The effect of electromagnetic energy on this medication is unclear. Caution is called for, and in clinical practice the experience is that treatment with electromagnetic energy can only be begun about six months after the termination of gold medication.

Note:
Arthritis from other causes can also be treated with the Curapuls 670. For determining the phases in which treatment can be carried out, please refer to Chapter 6 on Wound Healing.

9.6 Fracture of the wrist and/or fingers (4, 46)

General:
This pathology is not often encountered by the physiotherapist during the period of immobilization. However, these problems frequently occur in sports medicine, and the sports physiotherapist will try to heal the patient as quickly as possible.

In recent years, many investigations have been carried out into the effects of electromagnetic energy on wound healing (1, 6, 7). Both low- and high-frequency energy is used for this purpose. The Ca++ balance is stimulated, and the pH is normalized in the region of the lesion. The fracture lines consolidate more rapidly, and the repair process is improved. Pulse repetition frequencies of 70-75 Hz are often mentioned in the literature. It is noteworthy that the pulse repetition frequencies are fairly closely defined. Adey (1) describes the influence on osteogenesis at a pulse repetition frequency of 75 Hz, a pulse duration of 325 µs and an intensity of 35 gauss.

Method:
Treatment with Circuplodes can take place through plaster, provided that it is not too thick (1 cm). The half value depth for a magnetic field in muscle is about 2 cm. If the layer of plaster is thick the distance to the lesion will be increased, and the effect will be reduced. In the Curapuls 670, this can lead to problems with the contact monitoring system.

Treatment parameters

Pulse duration:……..	……ca. 300 µs
Pulse repetition frequency:……..	……...62 Hz
Intensity……	……..200 W
Duration of treatment…….	…..30 – 60 minutes
Frequency of treatment…….	…..1 to 3 times per day

9.7 Rupture of the muscle fibre of the M. gastrocnemius

Synonyms: ‘tennis leg’, ‘whiplash’

Anamnesis:
Pain in the medial head of the M. gastrocnemius following acute trauma (‘missed step’).

Symptoms:
Swelling, hypertonia, pressure-pain and raised temperature at the level of the musculotendinous junction, where the M. gastrocnemius and M. soleus unite. A haematoma is sometimes visible, often below the site of the lesion. The rupture, which may range from micro- to total rupture, leads to complete loss of function, and gait abnormalities. There is generally a high degree of fibroblast activity in the musculotendinous junction, as a result of which an optimally functioning structure can be encountered. The applied load should be directed as well as possible. The musculotendinous junction has a relatively reduced blood perfusion. Disturbances in the blood circulation in this

region, in particular, can reduce the trophic supply, resulting in reduced resistance to tension and load bearing capacity.

Causes (45):

- Metabolic factors such as protein deficiencies
- Influence of cortisol in continued stress, or multiple corticosteroid injections
- Age
- Inadequate co-ordination (of musculature) leading to muscular imbalance.

Aims of treatment:
Immediately after the trauma, to optimise the various phases of wound healing and the action of the immune system. To prevent excessive scar tissue formation in the muscular fascia, myositis ossificans and possible cyst formations.

Method:
The treatment can begin from 24 to 36 hours after the trauma. The superficial site of the lesion makes it suitable for treatment with a Circuplode.

Treatment parameters

Pulse duration:……..	……65 - 110 µs
Pulse repetition frequency:……..	……...26 – 110 Hz
Intensity……	……..200 W
Duration of treatment…….	…..20 – 30 minutes
Frequency of treatment…….	…..1 or 2 times per day

If the wound healing has advanced sufficiently after about two weeks, a start can be made with thermal loading of the tissue. The pulse duration is lengthened and the pulse repetition frequency is increased until the patient has a slight sensation of warmth. In the first phase of wound healing the tissue is relieved of mechanical stress, and in the second phase carefully regulated loading can be applied. The clinical results indicate when treatment can be stopped.

	Medical diagnosis	
	Tissue-specific changes	
	Symptomatology	
Characteristics	Severe inflammatory activity o Oedema o Heat o Redness o Strong nociceptor activity	Slight inflammatory activity o Strong fibroblast activity o Much collagen formation (III) o Structural abnormalities
Clinical examination	Pain at rest/in movement Increased pain during movement before end position of joint is reached. Decreased loadability.	Pain before/after movement mainly in end position of the joint. Increase in tissue Loadability is possible.
Aim: Influencing metabolism	Stimulation of immune system	Stimulation of blood circulation
Aim of treatment	Stimulation of non-thermal effects	Stimulation of thermal effects
Dosage: Treatment parameters	Low mean power o High peak power o Short pulse durations o Low pulse repetition frequency	High mean power o High peak power o Long pulse durations o High pulse repetition frequency
Treatment duration	10 – 20 minutes	20 – 30 minutes
Treatment frequency	One or more times daily	Once every two or three days
	Depending on the therapeutic effect	

General guidelines for treatment with the Curapuls 670

10 Contra-indications

10.1 General

HEAT MUST NOT BE STIMULATED IN ANY SITUATION WHERE THE BLOOD CIRCULATION IS UNABLE TO DISSIPATE THE HEAT AND WHERE THERE IS A POSSIBILITY OF AN UNDESIRABLE INCREASE IN INFLAMMATION.

10.2 Introduction

There is no standard in medical applications for the maximum permissible electromagnetic power that may be converted into heat within the body tissue. This power is represented by the Specific Absorption Rate (SAR), expressed in watt per kilogram of body tissue (see Chapter 2). The following rules should therefore be observed when using electromagnetic sources, including the application of electrotherapy.

The electromagnetic power absorbed must never cause pain. Even a sensation of heat must be avoided.
No heat may be stimulated where there is a possibility that an inflammation may be exacerbated or where the blood circulation is unable to dissipate the heat created.

In addition to the foregoing, there are also safety guidelines (ANSI 1982)(27.47). These are of importance for the personnel involved in the treatment. The guidelines are concerned with the incident electromagnetic energy, or intensity, generally expressed in mW per cm². The frequency is also taken into account, and a distinction is made between the following four frequency ranges:

Frequencies up to 30 MHz. At low frequencies, only a relatively small proportion of the incident electromagnetic energy is absorbed by the body. This proportion increases with frequency. Guideline: in continuous exposure the intensity must not exceed 10 mW/cm². Treatment with the Curapuls 670 (27 MHz) falls well within this limit.

Frequencies from 30 to 300 MHz. In this range, energy absorption reaches its maximum value. Guideline: in continuous exposure the intensity must not exceed 1 mW/cm².

Frequencies from 300 to 3000 MHz (3 GHz). In this range, ‘hotspots’ can occur. The optimum is at about 910 MHz. Guideline: in continuous exposure the intensity must not exceed 1 mW/cm².

Frequencies above 3 GHz (microwaves). With increasing frequency, the energy absorption becomes increasingly confined to the skin layer. The temperature increase with microwaves is comparable to that of sunlight of equivalent intensity.

10.3 Implants

Treatment should never be applied in the vicinity of implants that could alter the position and, hence, the intensity of the field. The risk of local overdose arising near a metal must be avoided. This applies to implanted, injected or traumatically introduced metals. The influence of plastic implants on electromagnetic fields is not entirely clear. From calculations, it appears that virtually no influence is possible. However, this has been insufficiently investigated under clinical conditions. For this reason, the authors advise against applying electromagnetic energy in the vicinity of endoprostheses.

As a general rule:
The distance between the coil and the implant must be greater than 1 metre before treatment is applied. The reason for this is that the wavelength in the body will be reduced to less than 1 metre. All possible applications within a distance of 1 metre are contra-indicated, unless the contrary has been proved.

10.4 Pacemakers

Disturbances in the rhythm of pacemakers are known to occur. These result not only from the direct exposure to electromagnetic fields, but also from being in the immediate vicinity of equipment producing electromagnetic energy (26, 52).

10.5 Bacterial infections

In bacterial infections, an increase in temperature and the consequent increase in blood circulation can diminish the inflammatory process. It is unclear whether the stimulation of non-thermal effects in localized bacterial infections can lead to faster healing processes. For example, in the older literature, furuncles are described.

10.6 Pregnancy

It is unclear whether electromagnetic energy has an unfavourable influence during pregnancy. However, electromagnetic energy has been reported in the literature as being able to influence the oxygen balance of the

placenta in pregnancy in apes. Thermal treatment of the abdominal region during pregnancy should always be avoided (12, 26).

Disturbance of the menstrual cycle can result from treatment in the lumbar and sacral region, as well as from treatment of the abdominal region itself. The mechanism responsible is unclear, but a definite possibility is the complex process of reflex reactions.

10.7 Tissues with a high mitosis rate

Electromagnetic energy must not be used in treatment near the epiphyseal discs or haematopoietic organs. Pathological cellular changes could result, particularly in the period up to the 18th year of life.

In tumours, it can be assumed that the mitosis rate may increase still further, and that there is a risk of metastasis. However, in certain tumours, hyperthermia induced by high-frequency electrotherapy can contribute to the healing process (26, 44).

10.8 Sensitivity disorders

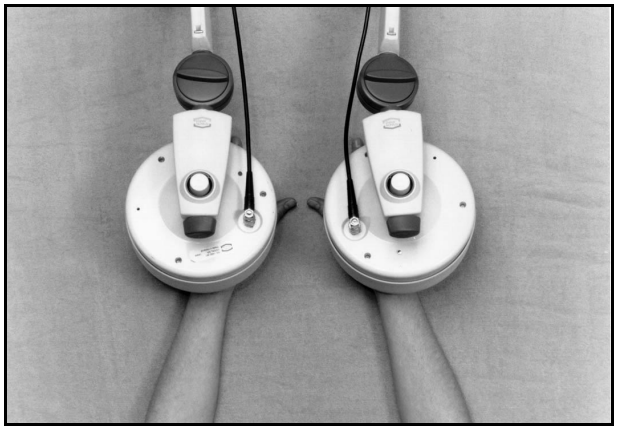
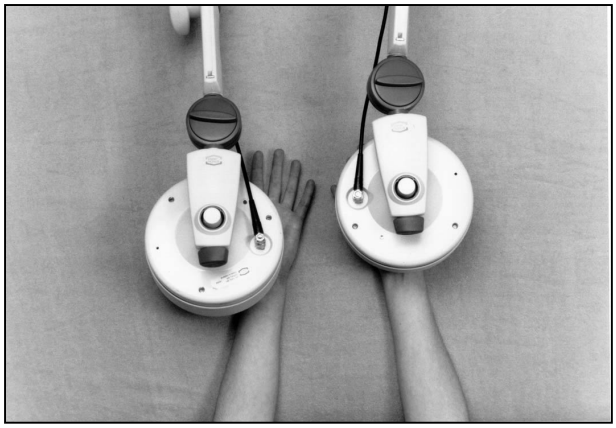
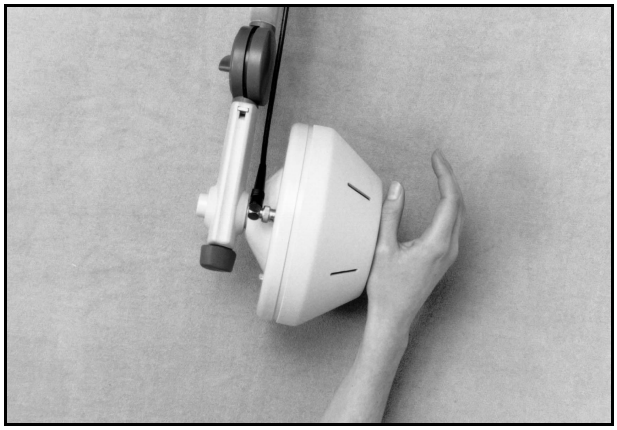
If the patient should be able to detect a slight sensation of warmth, but has a disturbance in the sensitivity to heat, there is a chance of overdosage. Sometimes, the correct dosage can be derived from the contralateral side. However, it should not be forgotten that accurate comparison is very difficult, as pathophysiological tissue conditions are present on the affected side. In general, the intensity for treating the affected side should be reduced by 30% in comparison with the unaffected side.

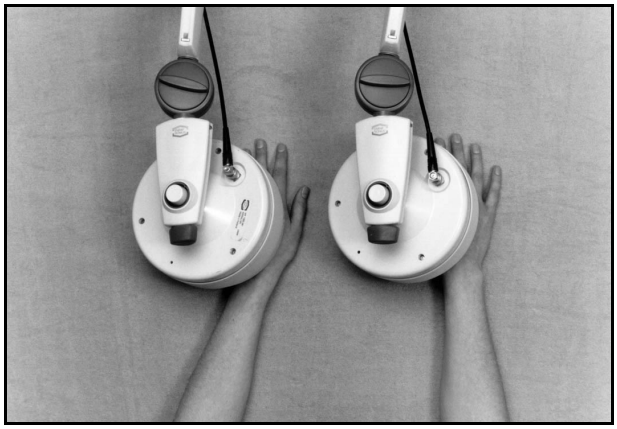
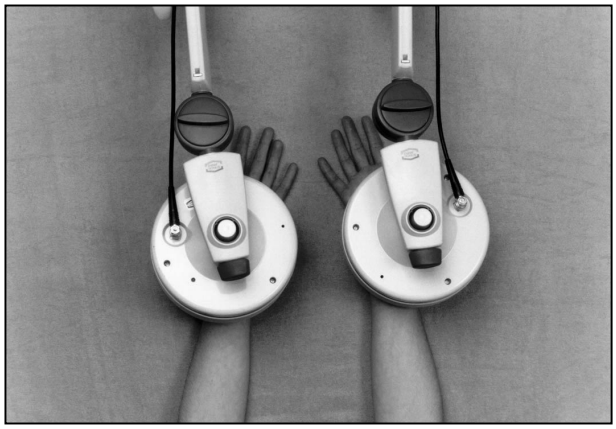
10.9 General remarks

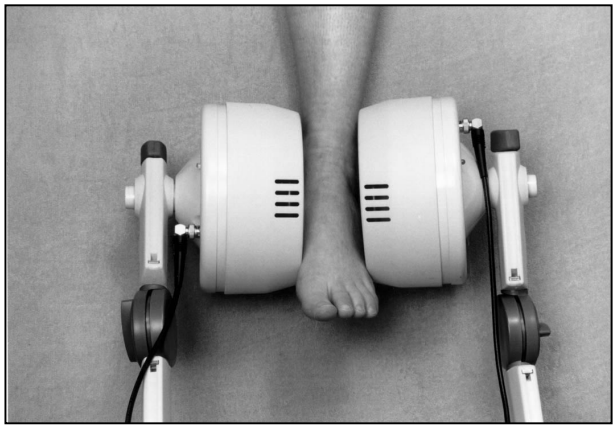
In every situation, full attention should be paid to the changes in the reaction capability of the pathological tissue. The reaction of the central nervous system to a stimulus is not always predictable, particularly in situation where the selectivity of the central nervous system is impaired. This is particularly true of reactions which are not only present at the cellular level, but also affect the whole neuro-psychohormonal system.

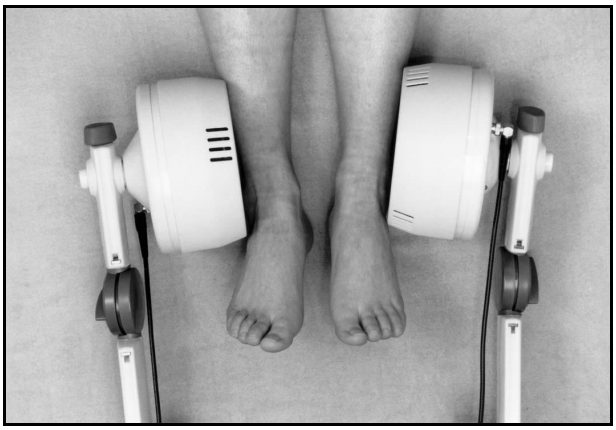
Photo series of treatment examples

Symptoms of arthritis in the wrist joints, the carpometacarpal joints of the thumb and the fingers, accociated with rheumatoid arthritis.





Treatment by high-frequency electrotherapy in various phases of wound healing. For a detailed description, please refer to the corresponding chapters.

During the bleeding phase

No treatment
Possible treatment with ice, compression and physical support.

Note:
In the first 20-30 minutes the injured blood vessels are already in vasoconstriction. The application of ice is then only affective for the acute pain.

During the inflammatory phase]

Support of the physiological processes and biological effects by non-thermal application.

Curapuls 670
Method: The selected method is transverse application of a magnetode (Circuplode)

Dosage Pulse duration:	65 µs
Pulse repetition frequency:	26 Hz
Duration of treatment:	10 minutes
Frequency of treatment:	1 to 2 times daily
Intensity:	200 W

Note:
Transverse applications with an electric field (plate or disc electrode) are ineffective in soft tissues!

During the proliferation and production phase

The aim in this phase the stimulation of physiological processes. Mild thermal stimuli can now be applied, as perfusion is being restored. However, the newly formed vessels are still weak. The treatment parameters then change as follows:

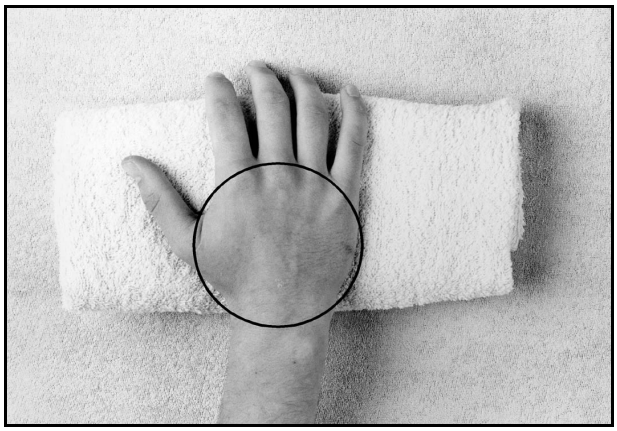
Curapuls 670:
Method: The selected method is transverse application of a magnetode (Circuplode)

Dosage Pulse duration:	100 µs
Pulse repetition frequency:	62 Hz
Duration of treatment:	10-15 minutes
Frequency of treatment:	Daily
Intensity:	200 W

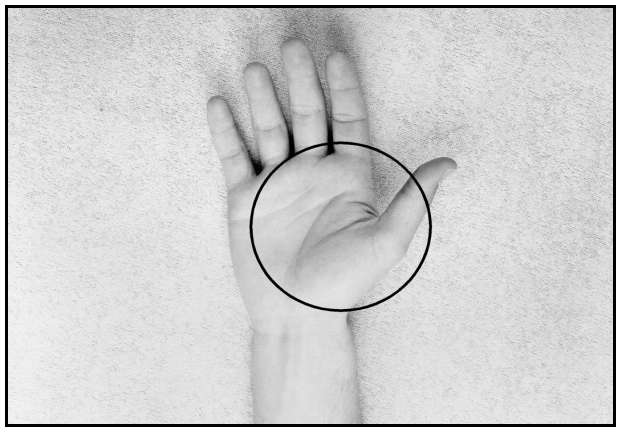
During the remodelling phase

Thermal stimuli optimise the properties of the collagenous matrix, facilitating the functional orientation in the tissues. The dosage remains the same as in the proliferation phase. In short-wave therapy the dosage can be gradually increased until a **slight sensation of warmth** occurs. This is achieved by increasing both the pulse duration and the pulse repetition frequency.

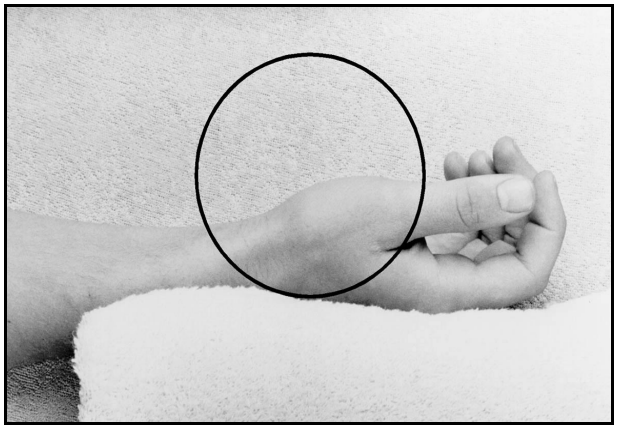
In the disorders described below, and the corresponding photographs, the position of the Circuplode is represented by a circle. The centre is shown as a dot. The effective part of the electromagnetic field is in the region of the line. For added clarity, the positioning is shown in the drawings. For further information, please refer to the brochure text.



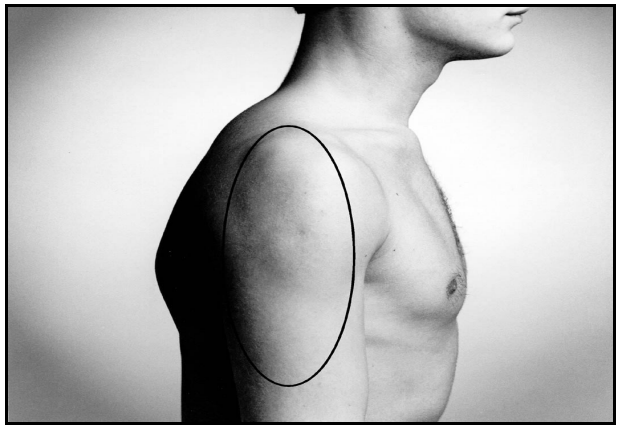
1. *Single-sided arthritis of the wrist, e.g. in rheumatoid arthritis.*



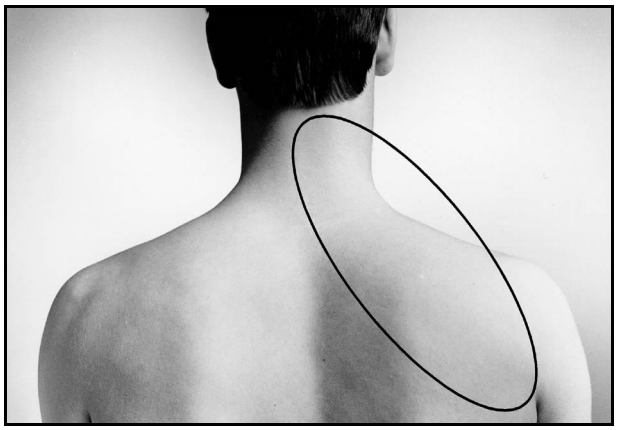
2. *Arthritis of the metacarpophalangeal I joint. Fasciitis palmaris (Dupuytren's symptom).*



3. *Arthritis of the metacarpophalangeal I joint*

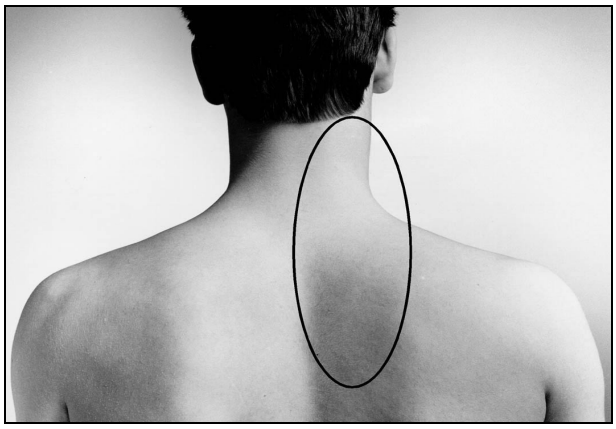


4. *Various soft-tissue lesions of the shoulder, e.g. bursitis deltoidea and/or subacromialis.*

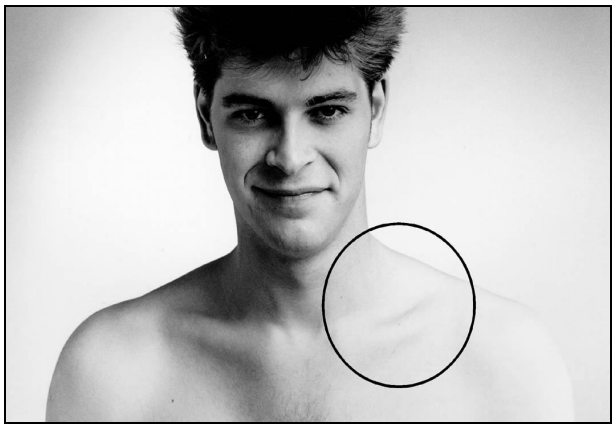


5. *Musculotendinous and muscular lesions at the level of the scapulae, e. g. myositis or tendinitis of the M. levator scapulae. Hypertonia or strain of the M. trapezius pars descendens.*

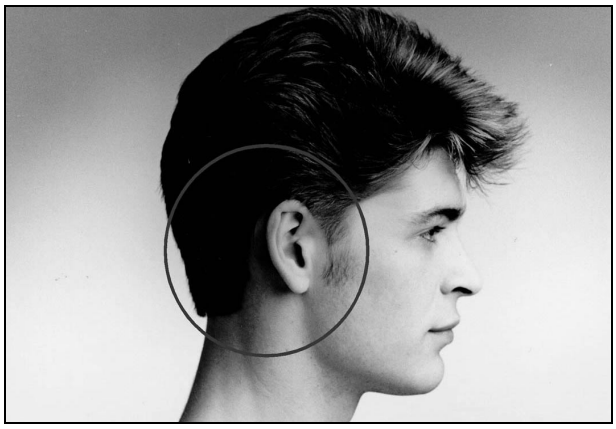
6. *Influencing the soft tissues on the lateral side of the cervical spine, e.g. in hypertonia of the M. sternocleidomastoideus (a 'myofascial trigger point').*



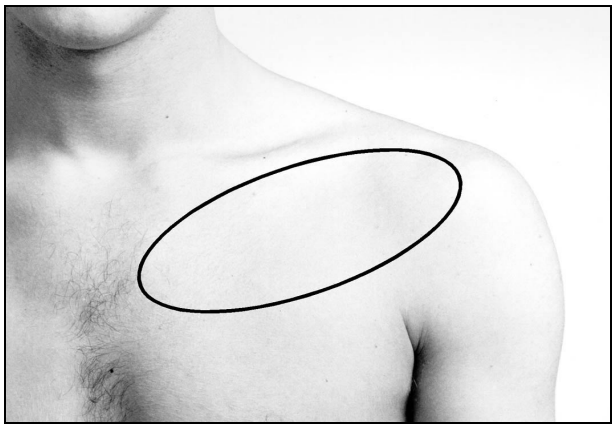
7. *Irritation of the vertebral joints as a consequence of arthrosis and/or postural abnormality (scoliosis) and/or trauma.*



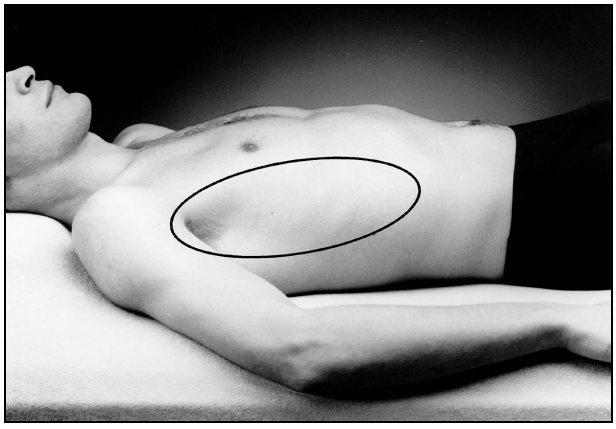
8. *Symptoms at the level of the costosternal transition indicative of osteochondritis, capsulitis of the sternoclavicular joint or an attachment irritation of the M. pectoralis major (see also photo 10).*



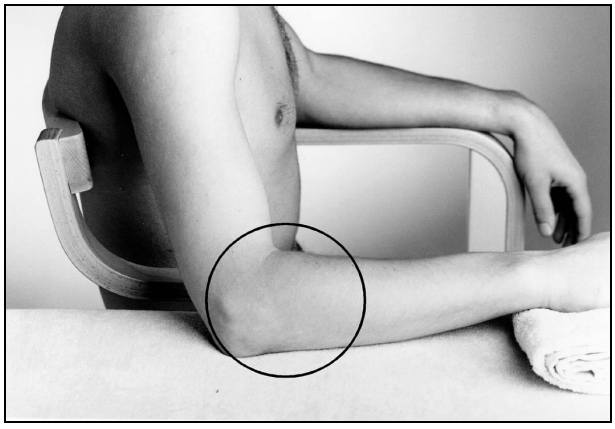
9. *Capsulitis of the temporomandibular joint. Musculotendinous symptoms in the Mm. pterygoidea, M. masseter and M. temporalis.*



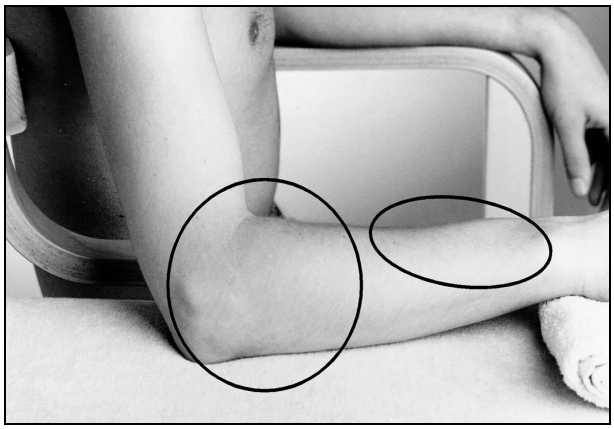
10. *Symptoms at the level of the costosternal transition indicative of osteochondritis, capsulitis of the sternoclavicular joint or an attachment of the M. pectoralis major (see also photo 8).*



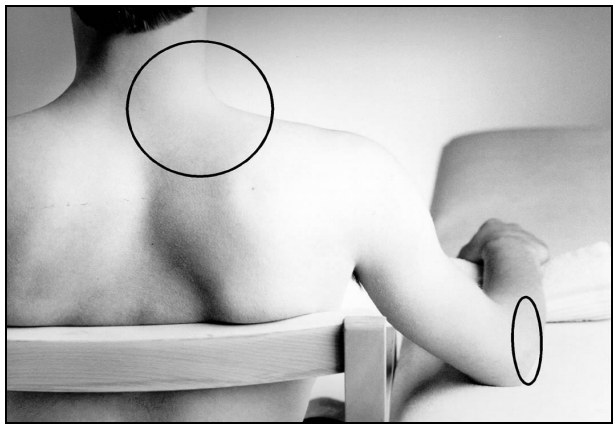
11. *Musculotendinous symptoms in the M. serratus anterior. The various phases of a rib contusion.*



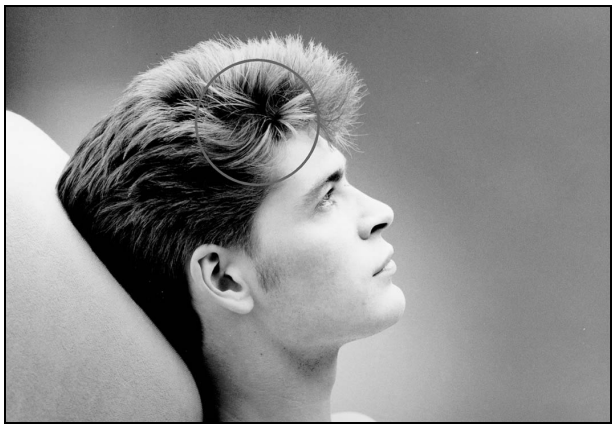
12. *Various forms of epicondylalgia, e.g. epicondylitis lateralis humeri. Affected cervical and thoracic soft tissues can be influenced at the same time (see also photos 13 and 14).*



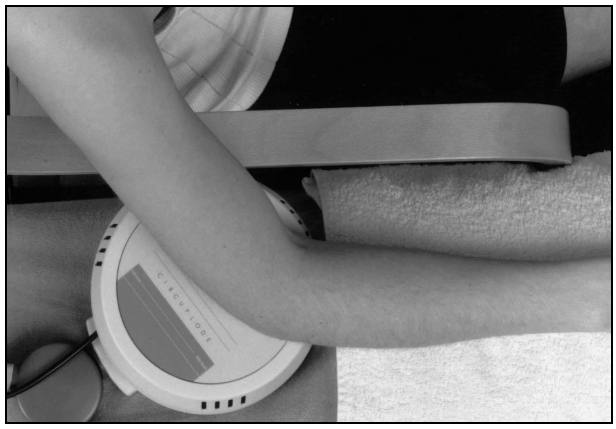
13. *Various forms of epicondylalgia, e.g. epicondylitis lateralis humeri. Affected cervical and thoracic soft tissues can be influenced at the same time (see also photos 12 and 14).*



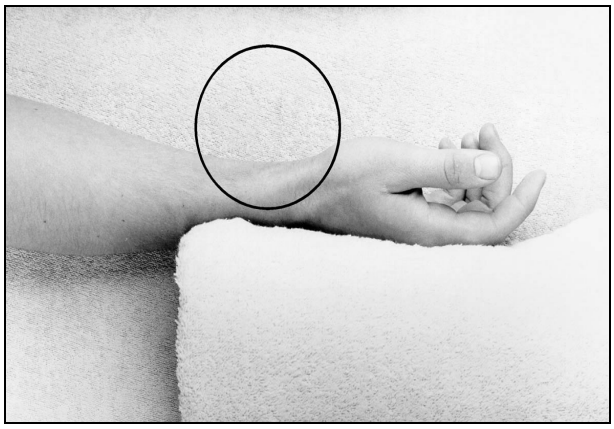
14. Various forms of epicondylalgia, e.g. epicondylitis lateralis humeri. Affected cervical and thoracic soft tissues can be influenced at the same time (see also photos 12 and 13).



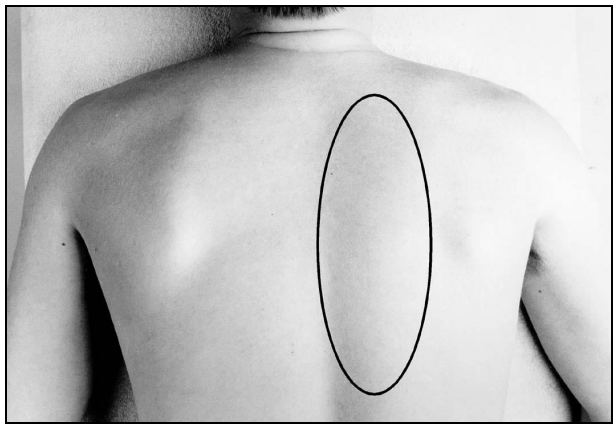
15. Chronic or recurrent sinusitis frontalis.



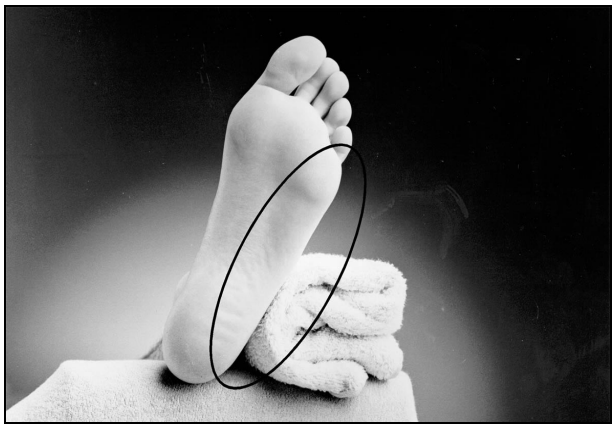
16. Arthiridite on the elbow. Epicondylalgia medialis humeri or other soft-tissue pathologies.



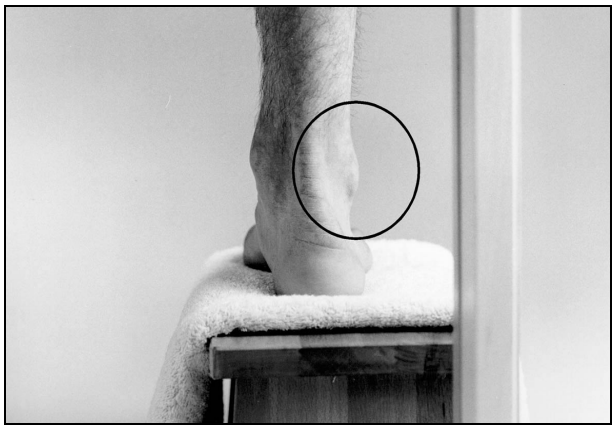
17. Tenovaginitis stenosans of the M. abductor pollicis in various stages of an inflammation.



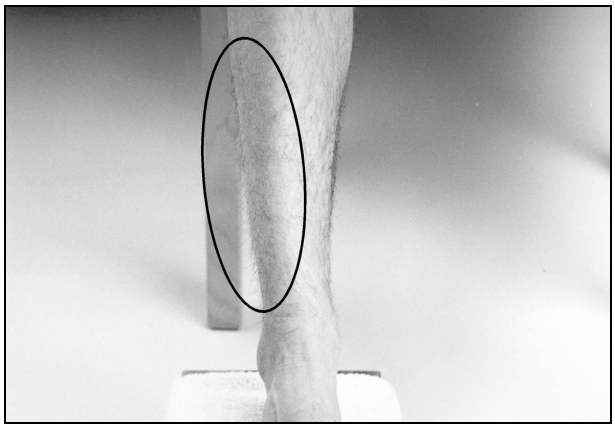
18. Symptoms of Scheuermann's disease. Irritation of soft tissues at the level of the costotransverse joints.



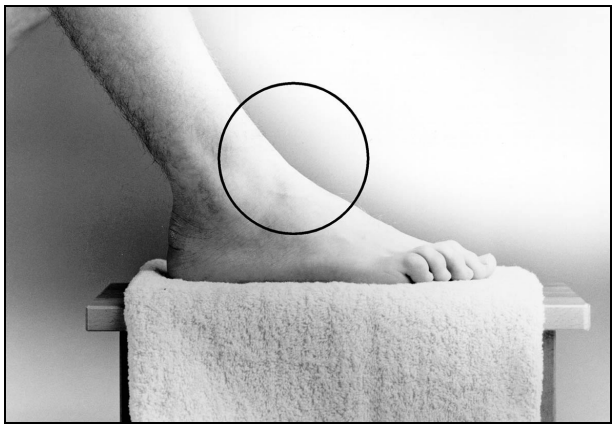
19. Symptoms of arthritis in the metatarsophalangeal joints.



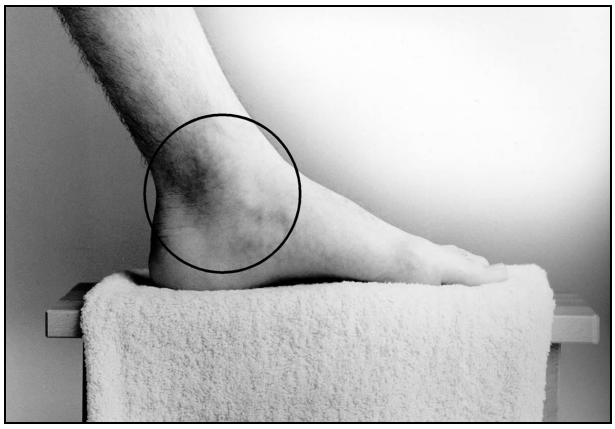
20. Bursitis and tendonitis of the M. triceps surae or M. flexor hallucis longus, at the level of the Achilles tendon.



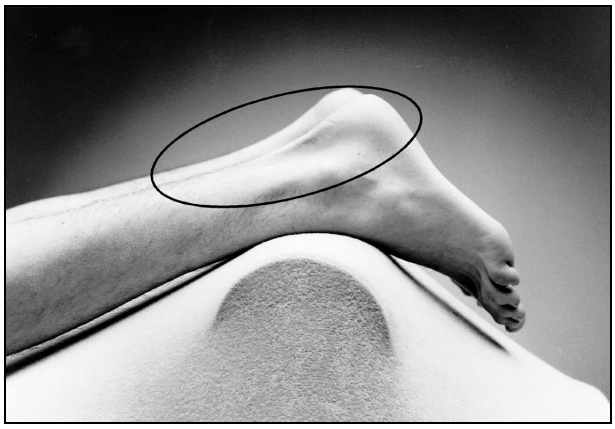
21. Hypertonia, strain or haematoma in the M. tibialis anterior.



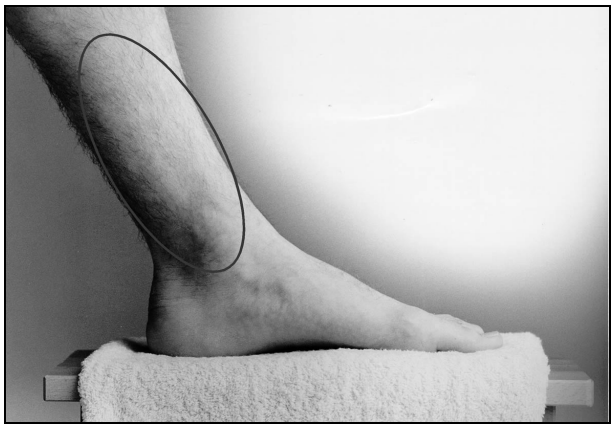
22. A haematoma at the level of the sinus tarsi following contusion of the ankle ligaments.



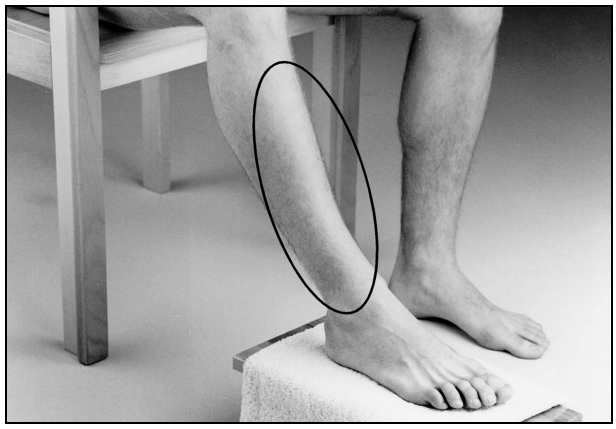
23. Irritation of the deltoid ligament following posture abnormality in the foot.



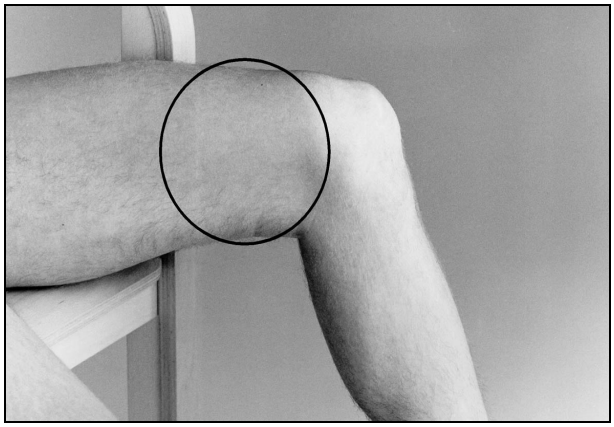
24. Tenovaginitis of the Mm. peronei in various stages following inversion trauma. Musculotendinous symptoms in the Mm. peronei (see also photo 26).



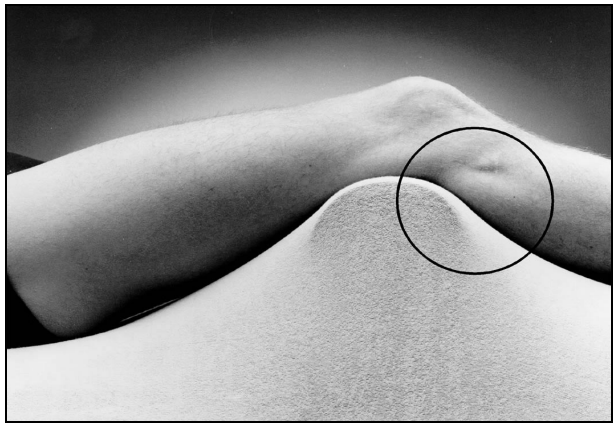
25. Strain symptoms in the soft tissue of the foot at the level of longitudinal arch. Irritation of the M. tibialis posterior ('shin splint').



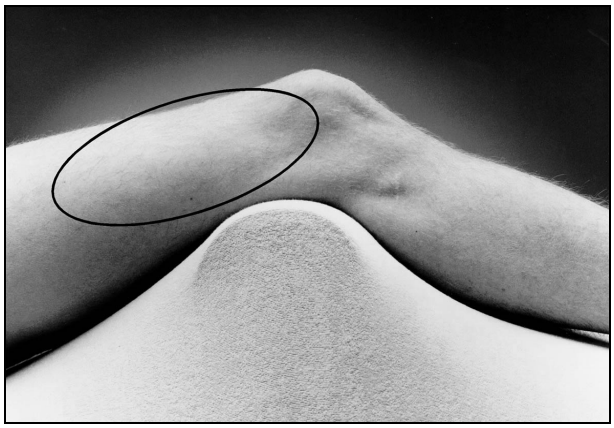
26. Tenovaginitis of the Mm. peronei in various stages following inversion trauma. Musculotendinous symptoms in the Mm. peronei (see also photo 24).



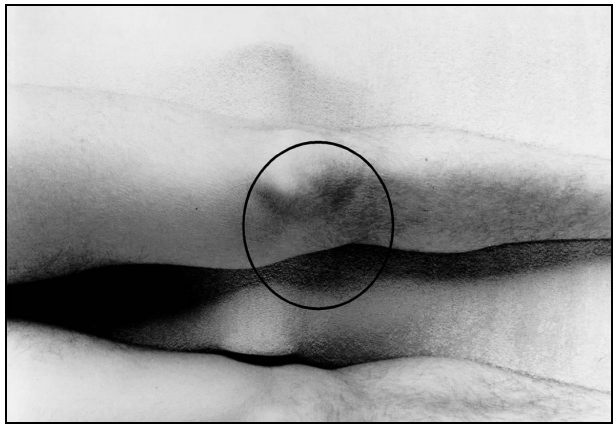
27. Insertion tenoperiostitis of the M. adductor magnus.



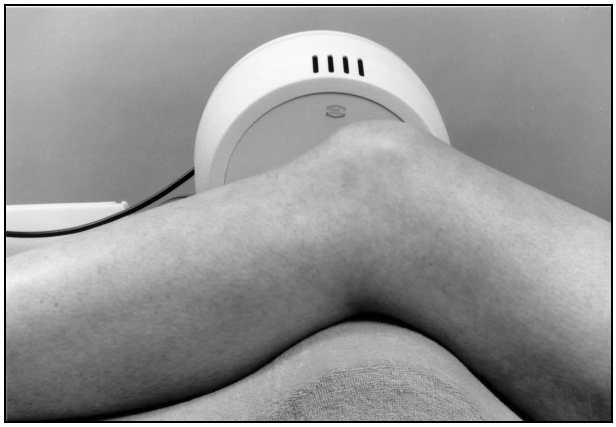
28. Entrapment neuropathy of the N. peroneus communis at the level of the caput fibulae.



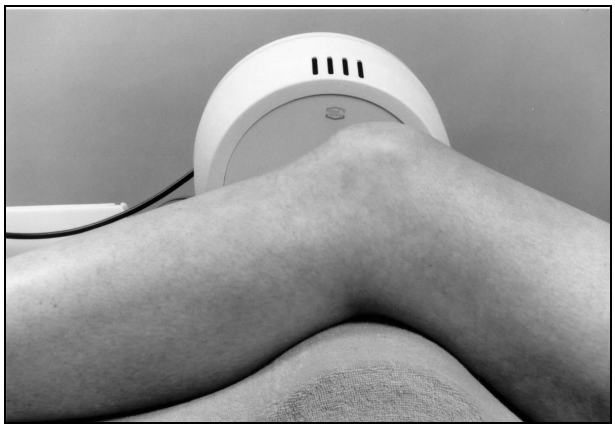
29. Irritation in, or at the level of, the iliotibial tract, often following a knee or hip operation.



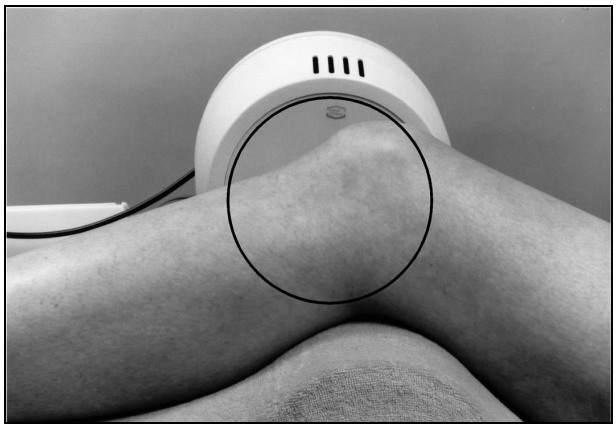
30. Various pathologies of the soft tissues at the level of the ventral part of the knee, generally at the level of the patella-femoral joint. Examples are 'jumper's knee' and the symptoms of Osgood-Schlatter disease.



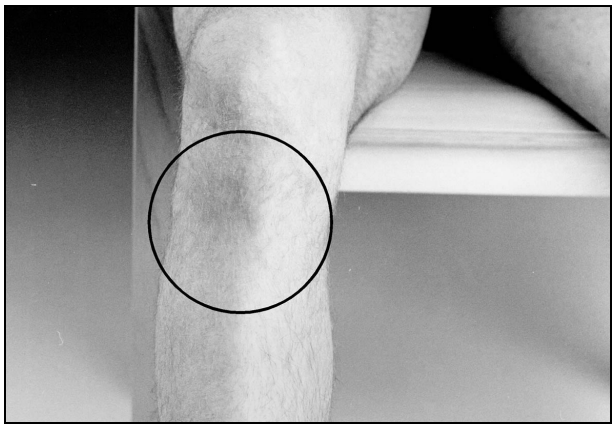
31. A strain of the medial and lateral collateral ligaments of the tibia-femoral joint. Capsulitis of the tibia- and patellofemoral joint. Single-sided treatment (see also photo 32).



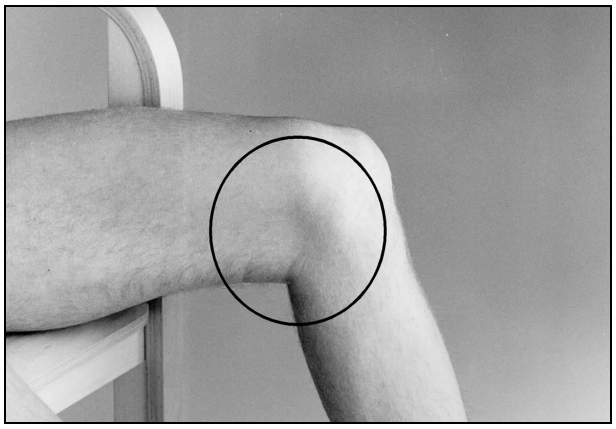
32. A strain of the medial and lateral collateral ligaments of the tibia-femoral joint. Capsulitis of the tibia- and patello-femoral joint. Double-sided treatment (see also photo 31).



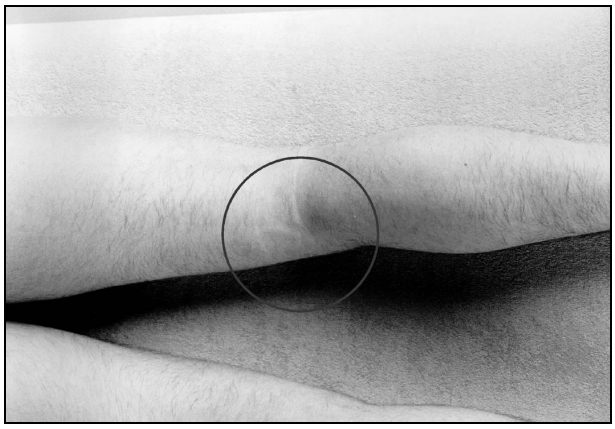
33. Hydrops in the patello-femoral joint.



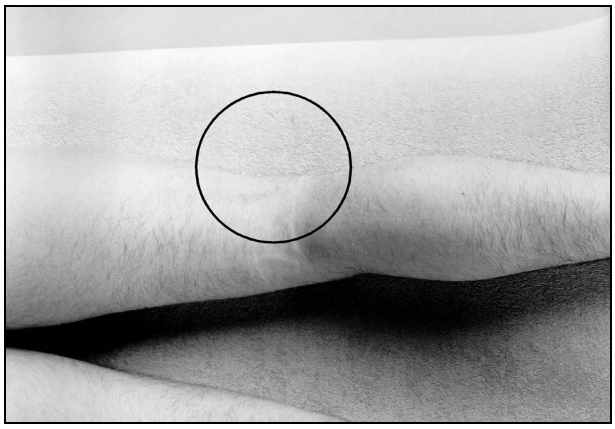
34. Bursitis infrapatellaris resulting from overloading of the knee.



35. Symptoms of arthrosis of the patello-femoral joint.

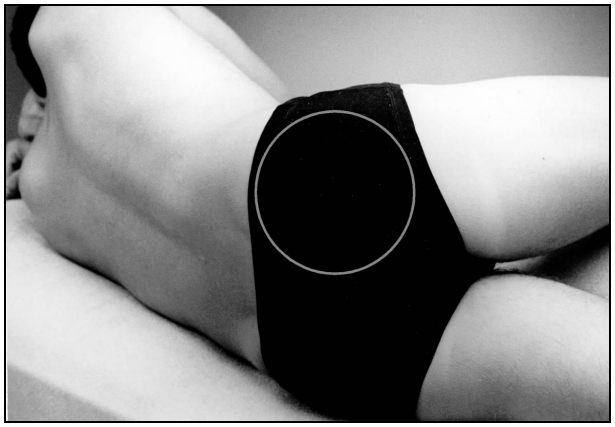


36. Various pathologies of the soft tissues behind the knee, such as a Baker's cyst and the associated symptoms.

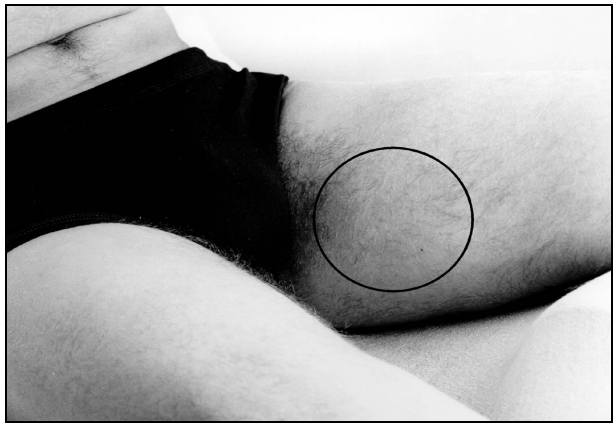


37. *Tendinitis and/or bursitis of the M. biceps femoris.*

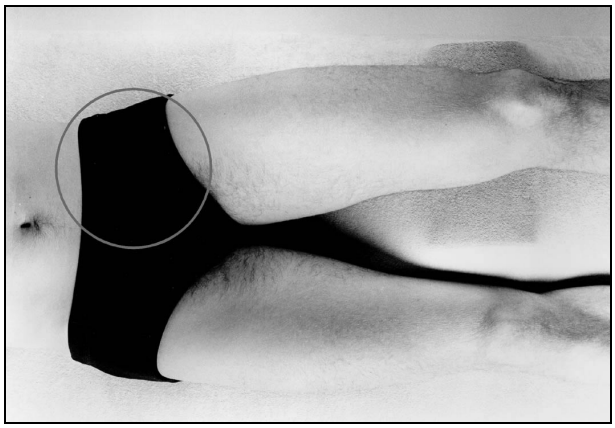
38. *A strain, haematoma and/or calcification in, or at the level of, the iliotibial tract.*



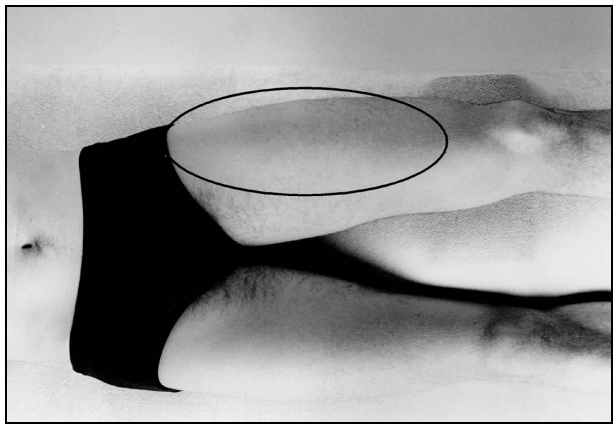
39. *Hypertonia of the M. piriformis and musculotendinous symptoms in the gluteal musculature.*



40. *Irritation at the level of the attachment of the M. adductor longus and brevis, and the M. pectineus (adductor strain).*



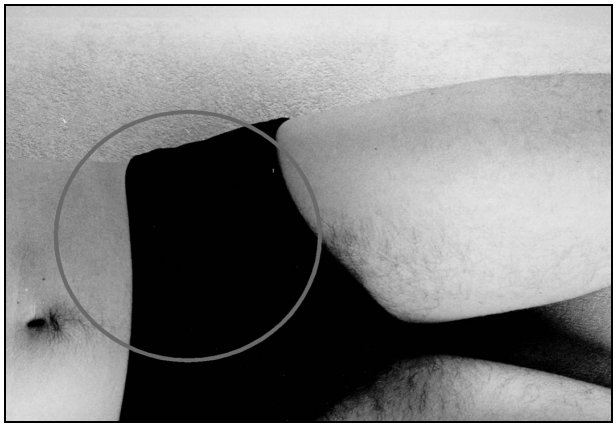
41. *Bursitis at the level of the tendon of the M. iliopsoas.*



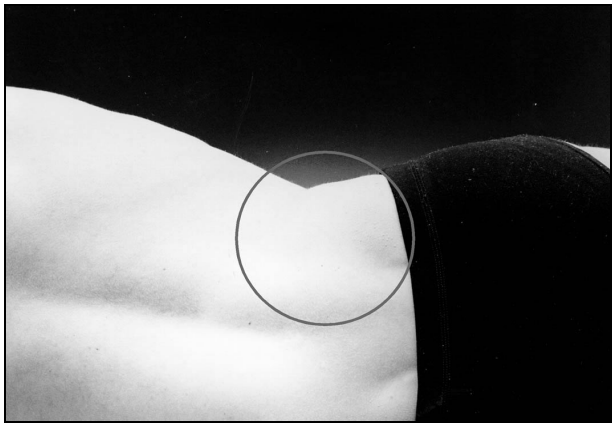
42. *Tendinitis, tenoperiostitis and/or muscular symptoms in the M. rectus femoris, e.g. as the result of overloading (see also photo 45).*

43. Symptoms of a 'pulled hamstring' (see also photo 44).

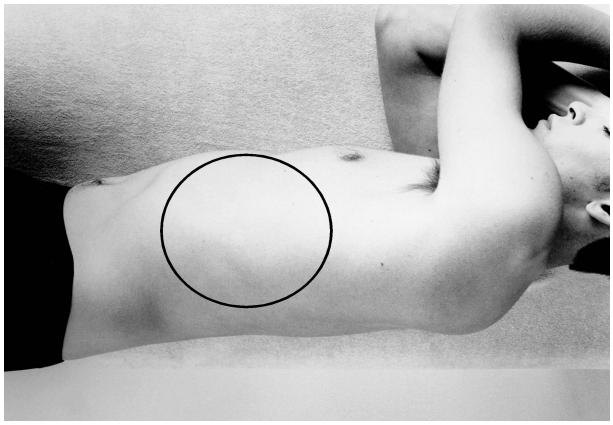
44. Symptoms of a 'pulled hamstring' (see also photo 43).



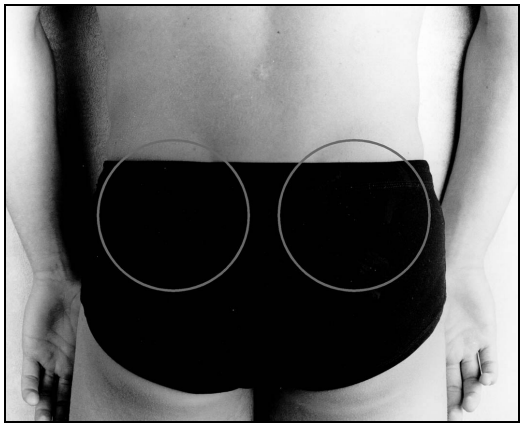
45. Tendinitis, tenoperiostitis and/or muscular symptoms in the M. rectus femoris, e.g. as the result of overloading (see also photo 42).



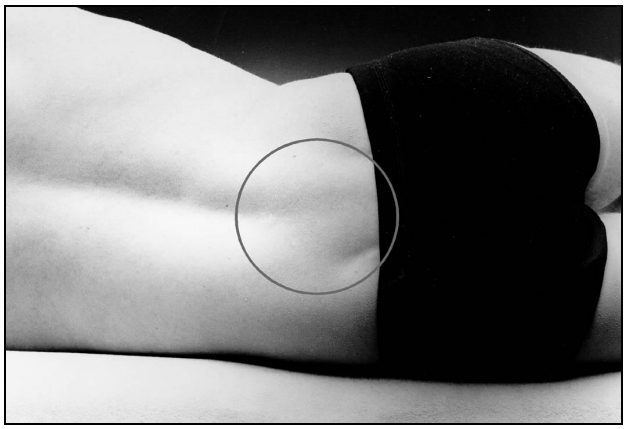
46. Periostitis of a transverse process of L3 following long-duration irritation of the M. quadratus lumborum.



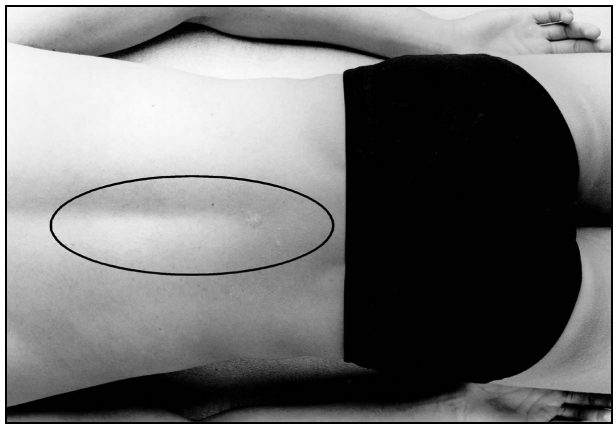
47. Rib contusion.



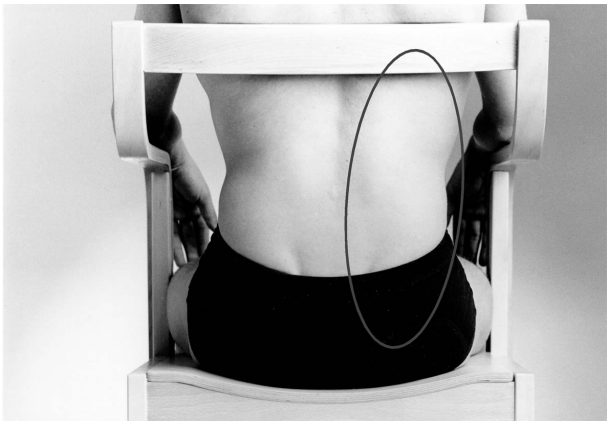
48. Irritation of the fascia glutea, at the level of the iliac crest.



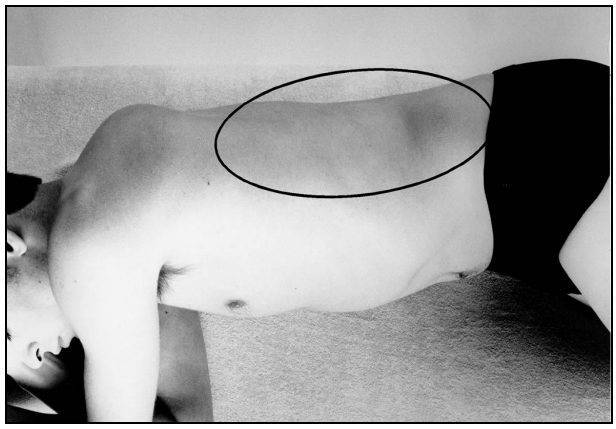
49. Overloading of interspinal ligament at the level of the L5-S1 transition.



50. Various pathologies of the soft tissue at the level of the lumbar spine, e.g. as a consequence of intervertebral disc pathology, strain of the iliolumbal ligament or Bechterew's disease (see also photo 51).



51. Various pathologies of the soft tissue at the level of the lumbar spine, e.g. as a consequence of intervertebral disc pathology, strain of the iliolumbal ligament or Bechterew's disease (see also photo 50).



52. Musculotendinous symptoms in the oblique and vertical parts of the M. quadratus lumborum, an accompanying symptom of HNP or instability of the pelvis.

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