Microdialysis is a method by which compounds can be studied in the extracellular space in skin, in vivo. The microdialysis probe is inserted in the dermis using a guide cannula. It is expected that intradermal oedema associated with insertion trauma as well as the probe depth can influence the results of microdialysis studies. The aim of the present study was to assess the effects of insertion trauma and, additionally, the probe depth by ultrasound. High-frequency (20 MHz) ultrasound is a non-invasive method for measuring the thickness and echostucture of skin. Hairless rats were anaesthetized with either halothane (n = 7) or pentobarbital sodium (n = 6). The insertion of the microdialysis probe resulted in a 38% relative increase in skin thickness. At 120 min the skin thickness had not reached the pre-insertion value. Thus, significant skin thickening, representing traumatic oedema, developed due to insertion of the microdialysis probe in the skin. The microdialysis probe could be inserted reproducibly in the lower dermis. Key words: skin; ultrasound; halothane; pentobarbital sodium.

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LOTTE GROTH1,2, AKSEL JØRGENSEN3 and JØRGEN SERUP2

1Department of Dermatological Research, Leo Pharmaceutical Products, Ballerup, and 2Department of Pharmaceutics, The Royal Danish School of Pharmacy, Copenhagen, Denmark

Microdialysis is a technique to monitor levels of compounds in the extracellular space over time (1). The method has been used in experimental neuropharmacology for two decades, but is only recently been adopted in dermatological research (2, 3). Cutaneous microdialysis can be used to study in vivo skin penetration of drugs from topical formulations. A microdialysis probe is a tubular semipermeable dialysis membrane, connected to afferent and efferent tubings. The microdialysis probe is inserted in the dermis using a guide cannula. This causes trauma in the skin (4). Effects of trauma, especially oedema and vasodilatation, may influence the skin penetration and the microdialysis process with consequences for the results of the microdialysis experiment. Furthermore, the trauma may cause various mediators, e.g. histamine, which cause the oedema. It is thus important to determine the period the skin needs in order to recover after probe insertion.

High-frequency ultrasound is an advanced method for two-dimensional in vivo imaging of the skin (5). By using B-mode scanning in vivo distances can be measured on a purely non-invasive basis, including skin thickness and the distance from the probe to the skin surface, i.e. the probe depth. Ultrasound examination of the skin has been used as a standard method to investigate irritant reactions, allergic reactions and various types of oedema in human and animal skin (6–9).

In this study the effect of insertion of a microdialysis probe on skin thickness was measured in rats by ultrasound. In addition, the probe depth was measured to evaluate the reproducibility of the insertion procedure. Probe depth in the dermis is also expected to influence the results of a drug penetration experiment.

MATERIALS AND METHODS

Experimental conditions

Two groups of rats were studied, since anaesthesia might influence reactions of trauma, as the two anaesthetics may influence the vasodilatation and the release of mediators differently.

Method of anaesthesia

Halothane anaesthesia. Seven hairless rats (200 g, female, OFA-hr/hr, IFFA CREDO) were used. The rats were anaesthetized with halothane (Halothan “halocarbon”, Halocarbon Laboratories, North Augusta, SC, USA), evaporated by a vaporizer (PPV sigma, Penlon LTD., Abingdon, England) and connected to an open face mask. Oxygen and nitrous oxide were delivered with halothane at a total flow rate of 700 ml/min (1:1). At the induction of the anaesthesia the halothane concentration was 4–5%. Subsequently the concentration was adjusted depending on depth of anaesthesia, starting from approximately 2%.

Pentobarbital sodium (Mebumal, DAK) anaesthesia. Six hairless rats (200 g, female, OFA-hr/hr, IFFA CREDO) were anaesthetized with 50 mg/kg pentobarbital sodium injected in the peritoneal cavity, and placed on a temperature controller (CMA/150, CMA/Microdialysis, Stockholm, Sweden).

Insertion of the microdialysis probe

A microdialysis membrane obtained from an “artificial” kidney (Gambro GFE 12, Gambro Dialysats AG, Hechingen, Germany) was inserted horizontally (intradernally) within the dermis using a guide cannula (CMA/150, one probe on each side of the back). Two microdialysis probes were inserted into the skin of each of the 7 rats anaesthetized with halothane, i.e. one probe on each side. In each of the 6 rats anaesthetized with pentobarbital sodium, one probe was inserted on the right side of the back.

Ultrasonic examination of the skin

Skin thickness was measured by 20 MHz ultrasound scanning using the Dermascan-C (Cortex Technology, Hadsund, Denmark). High-frequency ultrasound is a non-invasive method for in vivo imaging of the skin. The instrument consists of three main parts: the C-probe, the elaboration and visualization system and the memorizing and data-storing system. The probe is surrounded by water and sealed at the point of contact with an ultra-thin plastic diaphragm. The C-probe only touches the skin surface very gently and no rubbing is involved. The intensity of the reflection echoes is evaluated by the microprocessor and is visualized as a colour-coded two-dimensional B-mode image (Fig. 1). A-mode interfaces are shown as well-defined peaks. The accuracy of this method for skin thickness measurements is about 0.1 mm (10).

Skin thickness measurements. Skin thickness was measured prior to and immediately after probe insertion, followed by measurements at 15, 30, 45, 60, 90 and 120 min. Three B-scans were taken at every time point from different positions along the intradermal probe.
Fig. 1. A B-mode scan of rat skin. The marked white dot represents the microdialysis membrane within the dermis.

The Dermascan-C was operated with a linearly increasing gain, adjusted for each rat in order to individualize and optimize the operation of the instrument. A typical gain curve was 25dB to 55dB. The velocity of ultrasound in the skin was set at 1,580 m/s. Ultrasonic coupling gel was applied to the test area. The ultrasound probe was oriented so that the scan line was 90 degrees to the tubular dialysis membrane. A-mode scanning of the area over the microdialysis probe was used to calculate skin thickness, defined as the distance between the epidermis entrance echo and the interface between dermis and subcutis. Ultrasound image analysis of scans was performed using the ROI function and the inbuild software of the Dermascan C. The individual scans were stored on floppy disks. All assessments were based on the mean of three recordings of any inserted probe.

Probes depth measurements. The probe depth, i.e. the distance from the skin surface to the dialysis membrane, was measured on the B-scans used for total skin thickness measurements. The microdialysis membrane is echo-dense in structure and can easily be visualized by ultrasound (Fig. 1). The microdialysis membrane appears as a white hyper-reflecting dot. In A-mode scan probe depth corresponds to the vertical distance between the epidermis entrance echo and the echo of the microdialysis membrane, which can be calculated by image analysis (Fig. 2). Triple measurements along every probe at any time served to assess the variation in probe depth, i.e. intra-probe variation in depth.

Animal experiments were performed at a constant room temperature of 25°C. Temperature and humidity in the animal room were recorded by a thermohygrograph throughout the study. Three ml saline were delivered to the rats every hour during the experiment.

Statistical analysis
Increase in skin thickness after probe insertion was evaluated as the difference between skin thickness before and after cannula insertion. Additionally, the difference between the skin thickness before and 15 min after insertion was calculated. A one-sample t-test was used to analyze the increase in skin thickness. Probability of <0.05 was considered significant. Finally, to elucidate if skin thickness reached the pre-insertion value over time, the difference between skin thickness before and at 120 min after insertion was calculated.

RESULTS
Effect of insertion of the microdialysis probe on total skin thickness as a measure of traumatic oedema
Halothane group. The mean basal skin thickness (before insertion) on the back of the rats was 1.12 mm ± 0.08, range 1.00–1.26 mm. Fig. 3 shows mean skin thickness as a function of time following 14 probe insertions. Increase in skin thickness after probe insertion is obvious. The skin thickness peaks around 15–30 min. The mean increase in skin thickness was 0.32 ± 0.14, range 0.08–0.61 (p < 0.05, difference between thickness before and immediately after probe insertion). The
As the skin thickness increases, the probe depth becomes We found a significant increase in skin thickness after probe insertion as a function of time in the same plot as the mean total skin thickness. The probe depth was dependent of skin thickness.

The microdialysis membrane has an outer diameter of 0.216 mm. If the probe was subtracted from the skin measurements, the skin thickening at 15 min was still significant, i.e. 0.20 mm ± 0.09, range 0.08–0.40.

Pentobarbital sodium group. The skin thickness before insertion was 1.00 mm ± 0.10, range 0.85–1.13 mm. The mean skin thickness as a function of time following six probe insertions is shown in Fig. 3. After insertion the skin thickness increased, mean skin thickening 0.31 mm ± 0.07, range 0.21–0.42 (p < 0.05) in 6 rats. Fifteen minutes after the insertion the mean increase was 0.38 mm ± 0.09, range 0.27–0.50 (p < 0.05), which is a relative increase of 38.0%. The increase was still significant even if the outer diameter of the probe was subtracted, i.e. skin thickening 0.17 mm ± 0.09, range 0.05–0.26.

Skin thickening was fully developed after only 15–30 min after probe insertion. After 120 min the skin thickening had not reached the basal level. The difference between the pre-insertion skin thickness and thickness 120 min after probe insertion was 0.25 ± 0.13, range 0.10–0.45.

**Probe depth**

**Halothane group.** The dialysis membrane was detected very easily with the ultrasound. Fig. 4 shows the mean probe depth (14 microdialysis membranes, probe depth measured from epidermal surface to probe echostucture within the dermis) as a function of time in the same plot as the mean total skin thickness. The probe depth was dependent of skin thickness. As the skin thickness increases, the probe depth becomes larger. The mean probe depth of the 14 insertions was 0.92 mm ± 0.12, showing little variation in insertion.

No significant linear relationship between probe depth and the increase in skin thickness 15 min after probe insertion was found.

**Pentobarbital sodium group.** The mean probe depth of six insertions was 0.78 mm ± 0.07, range 0.70–0.85. Probe depth depended on skin thickness, as the probe depth followed skin thickness.

**Intra-probe variation in depth**

In both groups the variation of probe depth of any single probe, measured at three different sites along the probe, was occasionally high (e.g. 0.43 mm, 0.68 mm, 1.06 mm; mean 0.72 mm ± 0.32 mm), illustrating that the probe cannot be inserted in exactly the same depth along the full four centimetres of length. The microdialysis probe was generally inserted in the lower level of the dermis.

The mean probe depths in the halothane- and pentobarbital sodium-anaesthetized groups were different, 0.92 mm and 0.78 mm, respectively. However, the basal skin thickness also differed between the two groups of rats, as the rats in pentobarbital sodium anaesthesia had a thinner basal skin thickness.

**Laboratory experiments, probe echostructure and reflection**

The microdialysis membrane was placed on a plane material and the distance between the outermost peak of the membrane and the background material was 0.22 mm by ultrasound scanning. The exact outer diameter of the probe is 0.216 mm, i.e. in close agreement with ultrasound. Thus, probe depth measurements with A-mode scanning of closest probe reflection were accurate, with no special acoustic artifacts.

**DISCUSSION**

We found a significant increase in skin thickness after probe insertion in rats anaesthetized with halothane or pentobarbital sodium. The oedema and resultant thickening appeared rapidly and were fully developed 15–30 min after insertion. Oedema was still prominent 120 min after probe insertion. No significant difference in skin thickening between rats anaesthetized with halothane and pentobarbital sodium was found.

The microdialysis probe was inserted reproducibly in the lower dermis. None of the probes were placed in the subcutaneous tissues. The reproducibility of the insertion procedure is most important, since the microdialysis process of a skin-penetrating drug is dependent of probe depth. Andersson et al. (11) studied skin penetration of ethanol by cutaneous microdialysis. The concentration of ethanol in the dialysate decreased with increasing probe depth. Based on our practical experience it is possible to comprehend a special manual feeling of probe depth during the insertion, but it is still difficult to control the exact position of the probe along the full four centimetres of insertion length.

The increase in skin thickness is believed to be due to oedema formation of the skin, as a result of the insertion trauma created by the cannula. During the experiments low echogenic picture elements were obvious, especially 15 to 30 min after probe insertion. The black and blue areas, which correspond to low echogenicity on the ultrasound image, appeared around the probe (Fig. 5). It has previously been demonstrated that the number of low echogenic pixels is proportional to the degree of skin oedema, since the low
皮肤血流和组胺释放后已达到基线水平。在这项研究中，皮肤血流在整个实验期间保持恒定，即2 h。它并不知道皮肤厚度将保持何种水平和哪种变化。然而，它不确定哪种程度的水分百分比影响血流。很可能，这种水分百分比的变化，对血流影响不大。然而，它显示了探针插入后立即达到稳定状态。因此，插入微透析探针后，水肿似乎会立即达到稳态。水肿在移除探针后会持续一段时间。水肿的持续时间不确定，也无法确定水肿将维持多长时间，以及皮肤血流和组胺研究的结合。

结论

1. 它可能通过20 MHz超声波成像测量到一个0.216 μm微透析膜插入皮肤。
2. 超声波成像显示，皮肤厚度的平均值为1.08 mm ± 0.10 (mean ± SD, n = 20)。
3. 损伤性水肿和皮肤增厚会立即微透析探针插入后，厚度会迅速保持恒定。
4. 两个麻醉剂，异氟烷和戊巴比妥钠，在探针插入后，皮肤厚度会正常化，但没有影响到通过皮肤插入探针时。
5. 微透析探针的插入，可能会在插入后达到深度，将一个探针沿着完整的4-cm厚度。
6. 它被优先允许开始微透析程序，直到30 min后，通过皮肤插入探针，作为标准程序，这提供了一个更稳定的实验环境。

参考文献


Acta Derm Venereol (Stockh) 78

图5. 超声波成像后，探针插入15 min。表色度：白色 > 黄色 > 红色 > 绿色 > 蓝色 > 黑色。

在皮肤科血液流（14）。它被结成为皮肤侵入方法和皮肤探针。Boca Raton: CRC-Press; 1995。


