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# Sweat analysis following pressure ischaemia in a group of debilitated subjects

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**Abstract**—This article examines the application of a simple technique for the collection of sweat to the investigation of tissue metabolites in 11 debilitated subjects attending a rehabilitation unit. It is applicable to subjects with a range of clinical conditions. Sweat was collected at the sacrum with the subjects either seated in a wheelchair or lying in bed, which was representative of their usual daily routine. The tissues could be loaded during sweat collection by sacral support in either of these positions. Collections were made for about 10 hours and interface pressures were recorded on at least two occasions. After the prescribed period, the sweat pads were removed and a quantitative analysis of a range of metabolites was performed. Metabolite concentrations may reflect local tissue viability and responses to loading. In unloaded tissues the metabolite concentrations were similar to those observed in nondisabled subjects in an earlier study. During prolonged loading at relatively low levels of pressure, there was elevation in the levels of some metabolites; for example 39 and 28% increases for lactate and urea respectively. Successive measurements on an individual over a period of months showed variations, which were small compared to those observed in either groups of nondisabled or debilitated subjects. These observations suggest that the technique may be best applied in clinical practice to monitor sequential changes in individual subjects.

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**Key words:** *pressure ischaemia, pressure sores, rehabilitation, sweat metabolism, thermal sweating.*

## INTRODUCTION

When the body interfaces externally with load-carrying devices, the intervening soft tissues are generally subjected to a nonuniform distribution of pressure. These externally applied pressures produce interstitial stresses and strains within the tissues that may be sufficient to impair the integrity of the blood supply and lymphatic drainage. With impaired circulation, the breakdown products of metabolism accumulate within the tissues. In the nondisabled subject, regular movement relieves these pressures at local tissue areas, and there follows a period of increased blood flow after vascular occlusion, termed reactive hyperaemia. However, many immobile and disabled subjects are less able to relieve pressures, and their tissues are often compromised. This makes them a prime group for the development of pressure sores.

### Related Studies

Measurement of metabolites in sweat may reflect biochemical processes in underlying tissue, providing a marker of tissue viability. This principle has been used in studies of vascular occlusion (1,2). There are only a few reports of changes in sweat composition resulting from ischaemia induced by external loading (3,4). The former

study used the Macroduct™ system (incorporating an artificial means of inducing localized sweat) a system that was bulky and could not be employed at the loaded tissue-support interface. By comparison, Polliack et al. (4) employed a simple pad system that collected thermally induced sweat at various body sites, such as the sacrum and ischial tuberosity, on a group of nondisabled subjects. Sweat was collected from both unloaded and loaded tissues, the latter condition involving the subject supported in a wheelchair or on an examination couch. Results indicated that ischial tissues subjected to pressure ischaemia produced a general increase in concentrations of some metabolites, such as lactate, urea, and urate, associated with a decrease in sweat rate. In the reperfusion phase, when the load was removed from the tissues, these metabolites returned to basal levels.

This work has been extended to assess the feasibility of using this technique in a group of debilitated subjects to analyze the sweat from both unloaded and loaded tissues adjacent to bony prominences. The subjects in this group are often immobilized for prolonged periods, unable to relieve pressure regularly, and possess many of the intrinsic factors, such as tissue sensory loss, that can contribute to the development of pressure sores.

## METHODS AND MATERIALS

The study was conducted in the normal environment experienced by the subjects during their admission at the Mary Marlborough Lodge (MML), at the Nuffield Orthopaedic Centre, Oxford. The MML is a 21-bed rehabilitation research unit, providing for the assessment and rehabilitation of persons with severe and multiple physical disabilities. Subjects are generally assessed for a 1- or 2-week period and often return for subsequent assessment.

Subjects participating in the study underwent two distinct collection phases: a period of collection during nighttime sleep and another during the day. The two collections were performed within a 24-hour period. Each period of collection was at least 8 hours in duration and all trials were conducted in ambient conditions of 23±2°C—the constantly regulated temperature throughout the year in the rehabilitation unit.

A sweat pad was applied to the sacrum as described in detail elsewhere (4). Before use, each sweat pad was inserted into a screw-capped 30 mL "universal" conical bottomed tube (Universal, Sterlin Limited, Hounslow, UK), which contained a removable, perforated plastic disc at the top of the conical portion, and weighed on an analytical balance. At the end of the collection period, the pad was rapidly re-inserted into the tube for determination of the sweat weight by difference. The samples were stored at −20°C, prior to chemical analysis.

Upon completion of the first period of collection, the sweat pad was replaced by a fresh pad for the second collection period. This changeover took place either when the subject prepared for night rest or awoke to prepare for the day. The interface pressure distribution between the support surface and the sacrum was measured by the Oxford Pressure Monitor (Talley Group Limited, Romsey, Hampshire, UK) on at least two separate occasions during the collection period involving sacral loading. The test procedures, involving the application and removal of sweat pads and the measurement of interface pressures, did not disturb the normal nighttime or daytime routine of the subjects.

### Biochemical analysis

The collected sweat was eluted from the paper pad by adding five times the volume of distilled water. The tubes were centrifuged and the eluate collected from the conical portion of the tube after removal of the paper and perforated disk. The diluted sweat samples were quantitatively analyzed using established methods for serum and urine analysis, all of which required modification for the low analyte concentrations or sweat volumes available (5). For each analyte, all samples from each subject in an experiment were analyzed in the same analytical run to minimize analysis error. Lactate, urate, and urea were measured by enzymatic assays and chloride with mercuric thiocyanate reagent on a Cobas FARA automated centrifugal analyzer (Roche Diagnostic Systems, Welwyn Garden City, UK). Sodium and potassium were measured using a Corning 455 flame photometer (Ciba Corning Diagnostics Limited, Halstead, UK) with lithium nitrate internal standard. The filter paper eluate was centrifuged and aspirated directly without further dilution.

Recovery of all analytes was close to 100 percent, despite a minimum eluate volume of only 0.6 mL (5). All methods showed excellent linearity.

### Selection Criteria

The study allowed for the involvement of any persons regardless of age or medical condition, provided they were admitted for rehabilitation assessment. Any known to develop an adverse skin reaction or allergy to any type of medical tape were excluded from the study.

In addition, other criteria were based on the experimental protocol that required two complete and continuous periods of sweat collection during loading and no loading conditions at the sacrum. For this, subjects fell into one of two categories:

1. Subjects adopted a supine position during night sleep, which provided prolonged loading of the sacrum. During the day, subjects sat in a chair with no sacral support for the majority of the collection period, only occasionally getting out of the chair and walking.
2. Subjects adopted a lateral or side-lying position during the night sleep with no loading of the sacrum. During the day, subjects sat in a chair with the backrest providing sacral loading (**Figure 1**) at all times as a result of their immobility, except for when they were toileted with the assistance of aides.

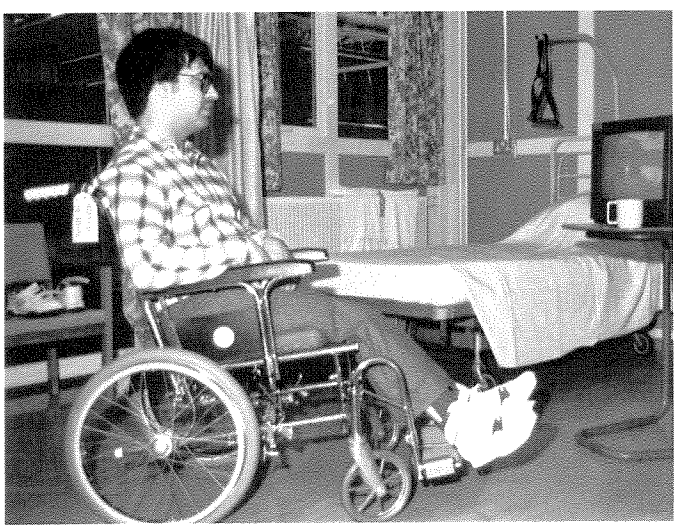

**Figure 1.**
A subject seated in a wheelchair during the day, with load transmitted through the sacrum.

Eleven subjects, 7 male and 4 female, with a mean age of 41.2 years (range of 20 to 71 years), met the selection criteria and were assessed on at least one complete measurement session. A summary of subject details is given in **Table 1.** One (subject 11) was evaluated on six separate occasions during two admissions over a 4-month period. This 35-year-old male with cerebral palsy and a history of pressure sores was admitted for general assessment and for the fitting of an ankle-foot orthosis. Sweat collection was performed at the sacrum and the procedures on each occasion were identical to those described above.

Descriptive statistics were employed for all the data collected in both periods. However, as there were some repeated measures on individual subjects in both unloaded and loaded groups, inferential statistical analyses on differences in metabolite concentrations with and without loading were not appropriate.

## RESULTS

The median interface pressure across the sacrum of all test subjects was 3.1 kPa (23 mmHg), with a corresponding range of 2.3 to 6.9 kPa (16 to 49 mmHg). The mean periods for sweat collection for all test subjects in both unloaded and loaded conditions was 10.8±3.0 and 11.8±4.4 hours respectively. The data for the sweat metabolite concentrations at the sacrum are presented in **Table 2,** in association with the authors' previous data for nondisabled subjects (5). In view of the non-Gaussian distribution of the combined data, median values are indicated for all metabolites in both unloaded and loaded conditions. The corresponding data for sweat volume and sweat rate are presented in **Table 3,** indicating no significant changes in either parameters in the loaded conditions.

It is evident from **Table 2,** that when the sacral tissue of debilitated subjects was subjected to load, the median values for lactate, urea, urate, and potassium were 39, 28, 28, and 21 percent higher, respectively. By comparison, the sodium concentration decreased by 40 percent. The chloride concentration was similar to that measured at unloaded tissue.

The results of the six repeated measurements of sweat metabolite concentrations and amounts at the loaded sacrum of subject 11 are presented in **Figure 2.** The median interface pressure across the collection site was 2.6 kPa (20 mmHg) for the six sessions, and the sweat rates ranged from 0.2 to 0.3 ml/m$^2$/min. It can be seen that for all metabolites the amounts secreted closely followed their concentrations in sweat.

The data provide a means of assessing the reproducibility of metabolite concentrations and amounts for one patient over an extended period. For example, lactate concentrations varied from 48 mmol/L to 73 mmol/L with a corresponding mean of 58.5 mmol/L and a coefficient of variation of 14 percent. By comparison, urate values varied considerably about a mean of 27.6 mmol/L and a coefficient of variation of 36 percent, due in part to the greater analytical imprecision of the urate method (5). There were some clear trends in the data, for example, all

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**Table 1.**
Summary of subjects included in the study.

| Subj. | Sex | Age | Clinical Diagnosis | Cushion Used | Sleeping Position |
|---|---|---|---|---|---|
| 1 SM | M | 20 | Duchenne muscular dystrophy | N/A | Lateral |
| 2 MW | M | 23 | Motor neurone disease | Roho | Lateral |
| 3 MP | F | 51 | Brain haematoma | None | Lateral |
| 4 MN | F | 71 | Amputation/leg ulcers | Sheepskin on foam | Lateral |
| 5 BW | M | 25 | Multiple sclerosis | Roho | Lateral |
| 6 MC | M | 55 | Motor neurone disease | Foam | Lateral |
| 7 GP | M | 43 | Motor neurone disease | Foam | Lateral |
| 8 MG | F | 35 | Multiple sclerosis | Roho | Lateral |
| 9 CC | M | 38 | Spinal stenosis | NHS bed | Supine |
| 10 DM | F | 43 | Multiple sclerosis* | Wedged Foam | Supine |
| 11 TT | M | 35 | Cerebral palsy* | Chair | Lateral |

*Subject had a history of pressure sores.

**Table 2.**
Comparative results of sweat analysis from the unloaded and loaded sacrum.

| STUDY Test conditions-time, temperature, subject group | | SWEAT METABOLITE CONCENTRATIONS (mmol/L) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Lactate | Urea | Urate* | Sodium | Potassium | Chloride |
| UNLOADED SACRUM | | | | | | | |
| TAYLOR ET AL. (5) | | | | | | | |
| 8-14 hours, ambient | Median | 32.9 | 17.9 | 27.0 | 28.2 | 10.7 | 31.8 |
| Able-Bodied | Range | 20.6-57.2 | 9.3-38.8 | 9.0-42.9 | 15.0-64.2 | 6.0-29.0 | 20.6-57.8 |
| PRESENT STUDY | | | | | | | |
| 9-16 hours, ambient | Median | 38.1 | 25.1 | 30.0 | 30.0 | 11.4 | 24.4 |
| Debilitated | Range | 20.0-87.0 | 2.4-49.9 | 6.0-91.0 | 12.0-60.0 | 1.8-21.0 | 13.1-69.0 |
| LOADED SACRUM | | | | | | | |
| PRESENT STUDY | | | | | | | |
| 8-16 hours, ambient | Median | 53.0 | 32.0 | 37.0 | 16.9 | 13.8 | 22.3 |
| Debilitated | Range | 41.9-72.9 | 30.8-51.8 | 15.0-90.0 | 6.0-27.0 | 10.8-23.4 | 14.8-44.9 |

*Urate concentration in μmol/L

the metabolite concentrations were at a maximum on measurement session 5 (**Figure 2**).

## DISCUSSION

This study discusses a technique of sweat collection and analysis as a means of assessing the status of unloaded and loaded tissues in a group of subjects undergoing rehabilitation. It provides strong evidence to support the feasibility of employing this simple and inexpensive method in a clinical setting. The method only requires one aide to assist in the attachment and removal of the sweat pad, the combined procedures taking less than 5 min to perform. In addition, the sweat pads were acceptable to each subject, causing no discomfort or distortion of the subject support interface.

The basal levels of the sweat metabolites measured in the rehabilitation subjects could be compared to those reported by the authors in nondisabled subjects (**Table 2**). The median lactate and urea concentrations were 16 and 40 percent higher, respectively, and chloride 30 percent lower in the rehabilitation subjects. The sweat rate and concentrations of the other metabolites were very similar.

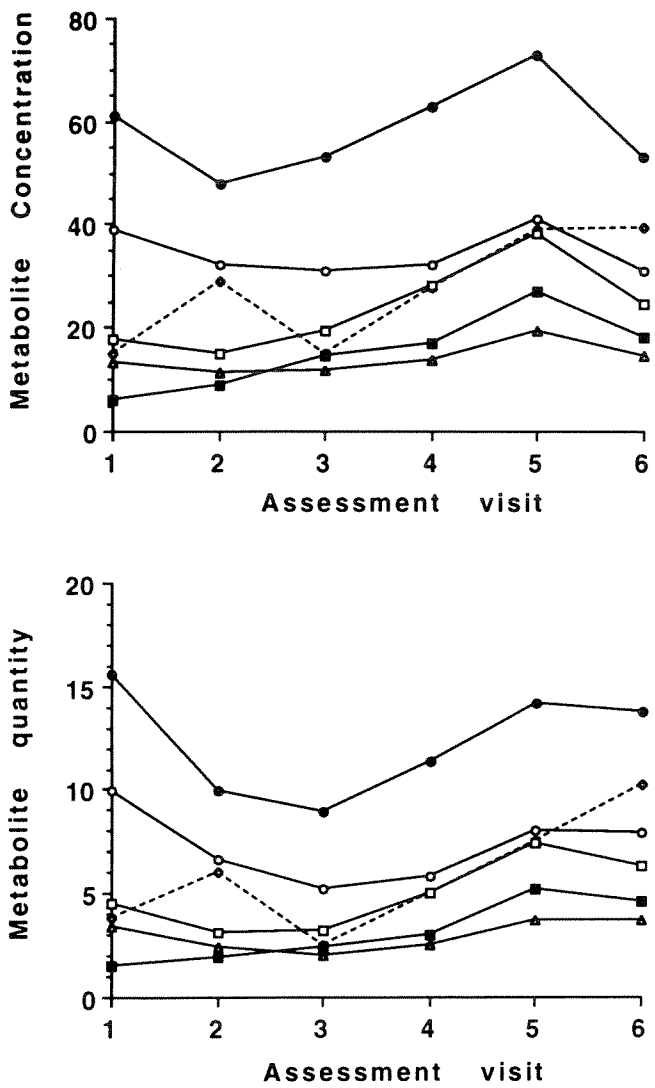


**Figure 2.**
A series of metabolite concentrations (top) and metabolite amounts (bottom) from sweat collected at the sacrum of one subject (male age 35 years). Numbers on the abscissa refer to the separate measurement sessions; *=concentration in μmol/L; **=amount in nmol.

This table also shows that the median lactate and urea concentrations increased further in the rehabilitation subjects during periods of sacral loading.

Similar ranges of metabolite concentrations were observed in the unloaded tissues of the rehabilitation subjects as in the nondisabled (**Table 2**). The ranges of metabolites observed in this heterogeneous group were slightly greater than for the nondisabled subjects. The ranges represent the natural variation between individuals, with evidence for possible further changes in the rehabilitation group as a consequence of susceptibility to tissue breakdown. Indeed, it is well established that there is a range of disposition to tissue breakdown even within a group of subjects with the same condition, for example a spinal cord lesion, as has been demonstrated by objective measures of tissue viability (6).

Variation within an individual over a period of time is illustrated for subject 11 under conditions of loading in **Figure 2.** This may indicate variations in the true clinical condition of the subject at the time of the measurement, in addition to analytical variation. It is worth noting that the ranges of metabolite concentration in this person were less than for the groups of nondisabled or rehabilitation subjects. This illustrates the importance of considering the relative changes within an individual when attempting to assess the effects of tissue loading on metabolite concentrations.

Significantly elevated levels of lactate have been observed in subjects with peripheral occlusive arterial disease (2) and in nondisabled subjects where externally applied pressure caused ischaemia at the site of sweat collection (3,4). Lactate is a product of anaerobic glycolysis in ischaemic or hypoxic tissues. Its elevation indicates that oxidative metabolism is insufficient to meet local energy requirements and may indicate local compromise of tissue viability. The greater median lactate concentration for unloaded tissues in the rehabilitation subjects compared to that for nondisabled subjects, and its further elevation with prolonged loading (**Table 2**), suggests that a degree of pressure ischaemia was produced. The interface pressure was applied at relatively low levels, not exceeding 6.5 kPa (49 mmHg) for any measurement, for prolonged periods of about 10 hours, a condition implicated in tissue damage (7). The observation of a rise in lactate in the absence of a marked reduction in sweat rate (**Table 3**), generally observed when the energy supply is reduced (8), suggests that lactate may be a sensitive marker of tissue compromise.

Sweat urea concentrations in unloaded tissues were several fold greater than plasma urea and increased further with loading. The mechanism for such increases is unclear. However, sweat/plasma urea ratios greater than unity have been widely reported in sweat collected from an enclosed skin surface, with water reabsorption a proposed mechanism under these conditions (9,10).

The combined effect of pressure and time on tissue response is of critical importance for subjects in a clinical setting, who commonly sit or recline in one position for many hours. The results from this group of subjects may reflect possible differences in metabolic state of the soft

**Table 3.**
Summary of sweat volumes and sweat rates at the ischium.

| | Sweat Volume (ml) | | Sweat Rate (ml/m²/min) | |
|---|---|---|---|---|
| | Unloaded | Loaded | Unloaded | Loaded |
| Median | 172 | 208 | 0.179 | 0.225 |
| Range | 94-726 | 149-433 | 0.082-0.840 | 0.118-0.300 |
| n | 13 | 9 | 13 | 9 |

tissues when compared to nondisabled subjects (4). Indeed, the increase in the lactate concentrations at relatively low levels of pressure, sustained for a long duration, suggests that the soft tissues are susceptible to cellular damage. However, during this study no subjects developed pressure sores.

Further work is in progress to ascertain the relative importance of pressure and time in terms of the metabolic products in sweat collected from soft tissues in nondisabled subjects. The study to date demonstrates the application of the technique for the measurement of a range of potential markers of tissue status in debilitated subjects. It has been applied to repeated measurements in an individual person. Variability among individuals, either nondisabled or debilitated, was greater than in one debilitated subject. The technique is likely to be of most value in individual subjects irrespective of the underlying condition predisposing to tissue injury, whereby the susceptibility to tissue compromise can be monitored over time. The nature of clinical condition leading to tissue compromise may be less important than the changes observed within an individual.

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