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A modified, local sweat collector for warm and humid conditions

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Summary. The purpose of this study was to modify a previously described local sweat collector to facilitate the investigation of sweat rate and composition in a warm (30° C) and humid (relative humidity 80%) environment. The adherence of the collector to the skin was improved and a pouch was appended at the lower end of the collector. The limitations of the closed collector were examined by comparing the local sweat rate and the quantity of electrolyte excreted in sweat with those obtained using a second collector with a wide opening (to permit free evaporation) and by changes in the body mass. Eight subjects performed exercise on a cycle ergometer consisting of four equal periods of 15 min each, at 60% maximal oxygen consumption, with a rest of 5 min between each period. The sweat produced on a local skin area (85 cm^2, upper posterior thorax region) was collected at the end of each period, before measuring the body mass on a sensitive (±1 g) platform balance. The mean local sweat rate [2.61 (SEM 0.19) $mg \cdot cm^{-2} \cdot min^{-1}$] was 2.4 times greater than the pro-rated whole body mass loss but the two were strongly correlated ($r=0.82$, $P<0.01$). Compared to the open collector, the greater quantity of electrolyte excreted into the closed collector would suggest that the conditions which prevailed in the closed collector, such as a higher local skin temperature, may have affected the function of the sweat gland. This method enabled the efficiency of local sweat evaporation to be assessed by measuring the difference between sweat volume collected in the open and in the closed collectors. Recovery of water volumes at rest indicated that no contamination and no apparent leakage occurred. This improved sweat collector is suitable for obtaining clean local sweat samples of up to 6 ml, and for measuring the sweat composition and also sweat rate during exercise in warm and humid conditions.

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Introduction

A local sweat collection technique, as described recently by Brisson et al. (1991), allows the serial measurement of both sweat rate and composition using a disposable, flexible capsule stuck on to the skin. Repeated trials using this method have revealed some limitations including occasional leakage during prolonged exercise and apparent hidromeiosis occurring after 45 min of exercise due to direct skin exposure to rapidly accumulating sweat in severe conditions (intense exercise or a warm humid environment). The present study was designed to amend the former technique for local sweat collection thus reducing the above-mentioned drawbacks.

Methods

Subjects. Eight healthy, Japanese, male adults participated in the study after having given their written, informed consent. During the first session, the subjects were made familiar with the experimental protocol, the maximal oxygen consumption [($\dot{V}O_{2max}$) 50 (SEM 1) $ml \cdot kg^{-1} \cdot min^{-1}$] was measured, and the usual anthropometric characteristics were determined [age, 20 (SEM 0.7) years; body mass, 63.0 (SEM 2.8) kg; height, 1.73 (SEM 0.04) m; body surface area, 1.76 (SEM 0.05) m^2]. Their clothing consisted of a swim suit, socks and sports shoes.

Experimental protocol. Seated on a cycle ergometer each subject undertook 75-min of intermittent exercise consisting of four 15-min exercise periods at 60% $\dot{V}O_{2max}$ with a 5-min pause which allowed the subject to be thoroughly wiped with a hand towel and then weighed. The exercise tests were carried out in an air-conditioned chamber (30° C, 80% ±5% relative humidity). Humidity, produced by a vaporiser, was monitored with a quartz precision thermohygrograph (Isuzu, model 3-1122) which was calibrated using a ventilated psychrometer (Sibata). Ventilation was provided by a 30-cm commercial fan. Velocity, measured by a digital anemometer (Rion AM03), was 0.5 $m \cdot s^{-1}$ around the

trunk, and 0.2 $m \cdot s^{-1}$ around the posterior thorax region. So that they were well hydrated, the subjects were asked to drink at home 570 ml of iso-osmolar water (290 $mmol \cdot l^{-1}$) on the morning of the exercise test, and fresh, cool water (15 $g \cdot kg^{-1}$ of body mass) was given 30 min before exercise. Exercise tests were carried out during June and July 1991.

Sweat collection. In the method of Brisson et al. (1991) a V-shaped piece of Parafilm (American Can Co.) was positioned on a large and adhesive wound dressing (OpSite, Smith and Nephew) which, in turn, was made into a capsule by sticking the adhesive part of the wound dressing surrounding the Parafilm on to the skin. The sweat produced by the skin area delineated by the Parafilm accumulated in the lower part of the capsule between the skin and the Parafilm. A fluid-tight window, positioned in the upper part of the capsule provided access to the sweat. Through this window, complete emptying of the collection capsule was carried out repeatedly by suction, using a sterile syringe or a vacutainer tube inserted in a tube holder, and fitted with a long dull needle.

Two modifications have been made to this technique. Firstly, adherence of the collector to the skin has been improved by the prior application of a hypo-allergic glue made of benzoin simple tincture (Ono Co., Osaka, Japan; Luvabec, Montréal, Québec) over the surface delineated around the skin area to be studied and on to which the OpSite anchoring membrane is stuck. In our experiments, such an application has been shown to prevent sweat leaks when collection is extended over a long period (over 1 h) or performed in very humid environments. A recovery test of deionised water injected inside the closed collector at rest indicated that no changes in electrolyte concentrations occurred inside the collector (glue, plastic, skin, etc.). Secondly, the excreted sweat was then diverted into a pouch chamber attached at the lower end of the collector. The chamber was constructed from a thin plastic bag used for stomatized patients (Lapack-G 100 10×10 cm, Tokyo Ezai Lab. Co.). After having stuck the collector on to the skin below the shoulder blade, it was carefully dissected out along the Parafilm contour lines. A hole, that reproduced the shape of the parafilm paper was also cut out of the plastic bag. Then, both apertures were fitted and glued together. The chamber permitted the sweat to migrate away from the skin and to accumulate away from the production area, thus minimizing potential hidromeiosis. The pouch, so formed, allowed sweat collection from an extended space which minimized increases in skin temperature due to skin contact with the plastic.

A second sweat collector, mounted in parallel with the first one, had a wide opening at the upper part of the attached chamber, in forming a pouch at its lower part for collecting sweat drippage (sw_o). Such a modification ensured normal evaporation of the sweat produced by this skin area. Undesired evaporation during sw_o can be prevented by the continuous collection of sweat accumulating in the pouch. Assuming that the sweat collected in the closed collector (sw_c) was an accurate representation of the total sweat excreted by the delineated skin area, with negligible sweat evaporation, it was possible to calculate the efficiency of sweat evaporation from the following equation:

$$\text{Efficiency of sweat evaporation} = 100(sw_c - sw_o)/sw_c$$

Measurements. The sweat was collected at the end of each 15-min exercise period by a sterile syringe fitted with a cut-end needle which was weighed before and after sweat sampling. A correction of 0.2 g was made after the first collection for sweat volume lost in the needle and inside the collector. Mean local sweat rate was calculated as milligrams per centimetre squared per minute from the actual local skin area (85 cm^2) under investigation. Every 20 min, the whole body sweat rate was estimated from changes in the body mass of subjects on a sensitive (±1 g) platform balance (Metler, model 103), and adjusted for respiratory water loss (Mitchell et al. 1972), and metabolic mass loss (Kerslake 1972). The Na^+, K^+ and Cl^- concentrations in sweat were measured with an automated biochemical analyser (Olympus EU-550) fitted with ion-specific electrodes. Osmolality was assessed in sweat by the freezing point depression method (Auto and Stat OM-6010; Kyoto Daihichi Sci. Corp.).

Skin temperatures were measured inside and outside the sweat collector with sensitive (±0.01° C) thermistors (Takara SZL-64), and recorded each minute.

Statistical analysis. Data were analysed using a two-way analysis of variance (ANOVA) procedure for repeated measures, performed by SAS software (SAS Institute, Cary, NC). A P value less than 0.05 was considered to be significant.

Results

The local sweat rate increased slightly during exercise if the first 15-min sweat collection, which corresponded to the onset of sweating, is not taken into consideration (Fig. 1). The local sw_o, as measured by the open collector, was significantly lower than that measured by the closed collector, but significantly greater than the change in body mass. Moreover, the body mass loss correlated positively and significantly with the local sweat collected ($r=0.82$, Fig. 2). The efficiency of sweat evaporation was 65% after 15 min of exercise and ranged from 36% to 42% thereafter.

The Na^+ and Cl^- concentrations and the osmolality in sweat significantly increased with time during exercise, while the K^+ concentrations decreased over the same time period (Table 1). Moreover, electrolyte concentrations were significantly greater in the sweat collected with the open collector than with the closed one, but the quantity of electrolyte excreted (electrolyte concentration times sweat rate) was significantly greater in the sweat collected using the closed than using the open collector, for all the periods and electrolytes examined (Table 2).

Discussion

In theory, if the evaporation of sweat is the sole physiological difference that distinguishes the open from the

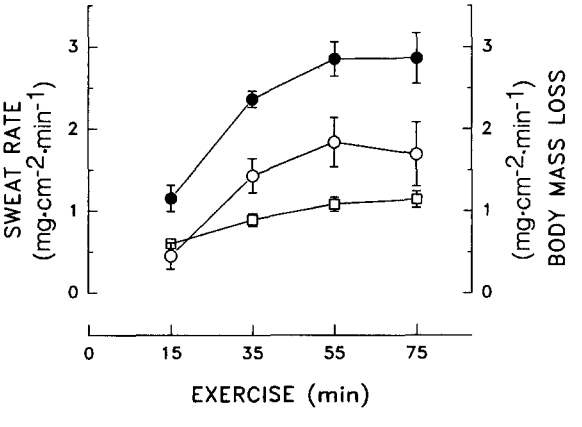

Fig. 1. Local sweat rate measured with the closed and open collectors, and whole body mass loss ($mg \cdot cm^{-2} \cdot min^{-1}$) during exercise. ● Closed collector; ○ Open collector; □ Body mass loss

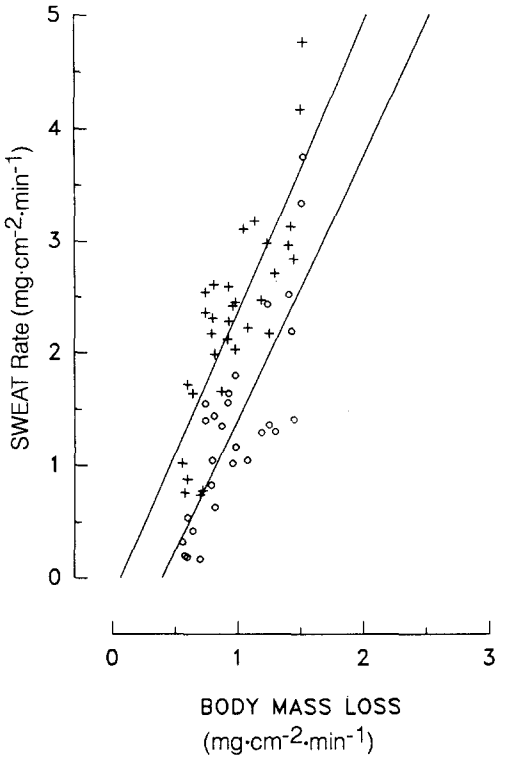

Fig. 2. Correlation between local sweat rate and whole body mass loss during exercise. + Closed collector; O Open collector

closed collectors, and if the total sweat rates (evaporated or not) are equivalent in both collectors, the electrolytes should have been excreted in the same quantity in both collectors. Therfore, a high drippage of unevaporated sweat should contain a low concentration of electrolyte. The sweat collected by the closed collector was compared with the sweat collected by the open collector, and a greater quantity of electrolyte was found in the closed collector. These results would indicate that the function of the sweat gland may be modified by the characteristics per se of the closed sweat collector. The differences found in the quantity of electrolyte excreted in sweat can most probably be explained by the higher sweat rate and/or the larger concentration of electrolyte observed using the closed collector. Firstly, since the concentration of electrolyte in sweat has been found to vary proportionately with the rate of excretion (Quinton 1987), the higher excretion of electrolytes cannot be explained solely by an increase in sweat rate. Secondly, the skin temperatures measured with the closed collector were greater than with the open collector, reaching a mean difference of +0.7° C during exercise. The higher skin temperature could possibly have acted as an additional local heat stimulus that led to an overestimation of the sweat rate. Using the original closed sweat collector, the difference in skin temperature reached +1.4° C (unpub-

Table 1. Electrolyte concentrations and osmolality in sweat collected using a closed and an open collector during exercise

Electrolyte concentration		Closed collector					Open collector				
		Time (min)					Time (min)				
		15	35	55	75	mean overall	15	35	55	75	mean overall
$[Na^+]$	mean	46	53	59	61	55	54	62	63	68	63
$(mmol \cdot l^{-1})$	SEM	4.4	5.4	5.7	7.1		9.3	7.6	8.6	7.3	
$[K^+]$	mean	6.8	5.3	5.1	5.1	5.6	8.7	7.0	6.0	6.0	6.9
$(mmol \cdot l^{-1})$	SEM	0.4	0.2	0.1	0.1		0.7	0.5	0.4	0.5	
$[Cl^-]$	mean	40	51	58	61	53	46	60	69	69	61
$(mmol \cdot l^{-1})$	SEM	5.1	6.7	7.1	8.3		10	9.2	11	8.8	
Osmolality	mean	119	124	133	138	129	123	150	157	158	147
$(mmol \cdot kg^{-1})$	SEM	8.8	12	12	16		25	16	17	16	

Table 2. Quantity of electrolyte (mean cumulative values for the intervals given) in sweat collected using a closed and an open collector during exercise

Quantity excreted	Closed collector					Open collector				
	Time (min)					Time (min)				
	15	35	55	75	Total	15	35	55	75	Total
Na^+ (nmol)	53	126	167	175	521	24	89	126	114	353
K^+ (nmol)	7.8	12.5	14.5	14.6	49.4	3.9	10.0	11.0	10.1	43.9
Cl^- (nmol)	46	121	164	176	507	21	86	127	116	350
Osmoles (nmol)	137	293	380	394	1204	55	214	289	266	824

lished observation). However, the influence of a small local skin temperature difference on local sweating is questionable, since central temperature has been estimated to have a ten times greater influence than skin temperature on sudomotor control (Wyss et al. 1974; Nadel 1979). Moreover, no difference in sweat rate output has been observed in two legs kept at different local skin temperatures during exercise (Bothorel et al. 1991). These results were consistent with those observed by Lemon et al. (1986); during exercise, electrolyte concentration obtained by various regional and closed sweat collection methods have usually been found to be greater than those obtained by whole-body washdown which is an open collection method (Verde et al. 1982). Further investigations are needed for a better understanding of the influence of local skin temperature on sweating.

Considering the high dripping rate and the relative small sweat evaporation observed using the open collector, it is unlikely that any electrolytes would have been lost. Any electrolytes which may have remained on the skin after evaporation would have been recovered by the subsequent dripped sweat excreted. Also, the recovery of different volumes of deionised water (1–4 ml) injected inside the closed collector at rest indicated negligible contamination coming from the collector (glue, instruments, plastic, skin), with no changes in electrolyte concentrations, and no apparent water leakage. Finally, the liquid (benzoin tincture) used to improve the collector adherence helped to prevent possible sweat leakage in a warm and humid condition. However, the slight increase in change of body mass was in contrast to the stabilisation in local sweat collections during the last period of exercise, although as the difference was small, the leakage, if any, was evidently negligible.

Although the local sweat rates observed inside the closed collector were, on average, over twice as high as those obtained by the rate of body mass loss, these variables were strongly correlated ($r=0.82$). These results would suggest that the posterior thorax region is a skin area that reflects the sweating of the body, but has a high rate of sweat excretion when compared to the average of the whole body calculated from body mass changes.

The hidromeiosis which has been found to occur in response to wet skin (Candas et al. 1980) induced inside the collector, or after 1 h of profuse sweating (Kerslake 1972), is another factor to be considered. The stability of the local sweat rate observed after 55 min of exercise cannot be associated with hidromeiosis over the whole body, since the rate of body mass loss increased linearly over the exercise period (Alber-Wallerstrom and Holmer 1985). Indeed, the stabilisation of the local sweat rate cannot result from the inherent characteristics of the closed collector (high humidity, high vapour pressure, higher skin temperature), since the stabilisation also occurred using the open collector.

On average, the efficiency of evaporation was greater for the first 15 min of exercise (65%) than after 1 h (41%). Since, as previously mentioned, the total sweat rate could have been overestimated in the closed collector, the efficiency of sweat evaporation has also probably been overestimated. However, the dripping sweat, which only had to cover an average distance of 8 cm before reaching the pouch of the collector, was prevented from completing its full evaporation potential which would in normal conditions, leading to an underestimation of evaporation compared to the whole body. The efficiencies of sweat evaporation in the present study were lower than the observations reported by Alber-Wallerstrom and Holmer (1985) during light exercise (100 W) where sweat evaporative efficiency ranged from 84% to 51% when relative humidity increased from 30% to 70%. Candas et al. (1979) have found that the sweat evaporative efficiency was 67% when resting subjects were exposed to a hot humid environment. Nevertheless, it is unwise to make a comparison between values of sweat evaporation induced by different methods. Considering the limits of local collectors, the efficiency of sweat evaporation observed in the present study can only be considered as an approximation.

The modified, closed sweat collector described in this paper offers additional advantages. For example, the flexible components of the collector are not restricted to specific planes or to small skin surface areas, allowing investigation of areas larger than 100 cm^2 depending on the size of wound dressing chosen. Also, the onset of dripping, defined here as the time elapsing from the beginning of exercise (or heat exposure) to the first sweat drop that ran into the pouch, could be estimated. In the present study, the rectal temperature at the onset of dripping was 37.1° C after 6 min of exercise. These data are lower than at the onset of sweating measured by the oesophageal temperature (37.4° C) which did not occur until after the 7th min of exercise (Mekjavić and Bligh 1989).

In conclusion, the modified sweat collector discussed here is simple and convenient to use, is appropriate for analysis of sweat composition, may be used for measuring the local sweat rate, and is suitable for obtaining clean local sweat samples over a 75-min humid heat exposure.

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