Eur J Appl Physiol (1994) 68:435–440

European Journal of Applied Physiology
and Occupational Physiology

Hydrogen breath test as a simple noninvasive method for evaluation of carbohydrate malabsorption during exercise

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Accepted: 14 January 1994

Abstract. The aim of this study was to examine hydrogen (H_2) production with the hydrogen breath test (HBT) after ingesting primarily digestible carbohydrate (CHO) during 3 h of 75% maximal oxygen consumption exercise. This was done to indicate CHO overflow in the colon which may occur when gastric emptying, intestinal transit and CHO absorption are not matched and CHO accumulates in the colon where it is subject to bacterial degradation. Further, this study was designed to assess breath H_2 production as a function of the type of CHO ingested and the type of exercise. A group of 32 male triathletes performed three exercise trials at 1-week intervals with either a semi-solid (S) intake, an equal energy fluid intake (F) or a fluid placebo (P). Each trial consisted of cycling (sessions 1 and 3) and running (sessions 2 and 4). The mixed-expired H_2 concentrations in the resting and "recovery" periods (5 min after each session) did not change significantly in time and did not differ among intakes. There were also no significant differences in H_2 concentrations between resting and "recovery" conditions. During exercise, H_2 concentrations decreased three to six-fold in comparison to resting and recovery levels and differed among intakes (ANOVA; $P<0.05$). The H_2 concentrations were almost continuously lower with P than with F and S. The H_2 concentrations were significantly higher during running than during cycling. During exercise, we found that CHO overflow could be compared among intakes and between exercise types by using the HBT, provided the influence of other factors on H_2 excretion – ventilation and intestinal blood flow – was similar for each condition.

Key words: Hydrogen breath test – Carbohydrate malabsorption – Endurance exercise

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Introduction

Exercise has been shown to result in an enhanced blood flow to the exercising muscles and a reduced blood flow to the gastro-intestinal (GI) tract (Wade and Bishop 1962). Studies on dogs have shown that a reduced blood flow to the GI tract results in a diminished carbohydrate (CHO) absorption (Varro et al. 1965). Fordtran and Saltin (1967), however, have found no change in small intestine absorption of glucose, water, and some electrolytes in humans [60 min at 71% maximal oxygen consumption ($\dot{V}O_{2max}$)] but recent work has suggested that exercise may affect the absorption of glucose, water and electrolytes (Barclay and Turnberg 1988; Lefèbvre et al. 1986).

If CHO absorption in the small intestine is impaired, some CHO could pass into the colon and bacterial fermentation would then increase (Kneepkens 1988). The products of bacterial CHO metabolism are mainly short chain fatty acids, carbon dioxide, methane and hydrogen (H_2).

The H_2 production has been shown to be completely dependent on bacterial action (Levitt and Engel 1975) and in healthy individuals more than 99% of the H_2 production to occur in the colon (Levitt 1969). The H_2 can leave the body as a flatus or as expired gas after diffusion and transport into the blood. Under rest conditions, it has been found that about 21% of the intestinal H_2 production appears in expired gas (Levitt 1969). Since H_2 excretion in expired gas shows a high correlation with the H_2 production in the intestinal lumen, it has been found that breath H_2 measurement can be used as an indication of CHO malabsorption (Levitt 1969).

While this correlation is high at rest, the relationship may be different during exercise. Increased ventilation and decreased intestinal blood flow, which are associated with exercise of high intensity, have been suggested to decrease H_2 concentration in expired gas (Perman et al. 1981, 1985). It has been considered that a change in GI processes such as gastric emptying and colonic motility may also influence H_2 production

(Perman 1991). Thus, it is impossible to assess which of the GI processes may cause a change in H_2 excretion, if these processes have not been directly measured. Therefore, we consider an elevated H_2 excretion to be an indication of CHO "overflow".

One purpose of this study was to examine H_2 production using the hydrogen breath test (HBT) during prolonged heavy exercise. The H_2 excretion was measured at rest, during different kinds of exercise, and also 5 min after each exercise period, when ventilation and intestinal blood flow should have returned to near resting values. These "recovery" samples of H_2 were regarded as an additional indication of CHO overflow of the preceding exercise. A second purpose of this study was to assess breath H_2 production as a function of the type of CHO ingested and type of exercise. The CHO intake consisted of a specific semi-solid and an equal energy fluid CHO intake. The effect of the fluid CHO intake on H_2 excretion was compared with intake of a placebo. The exercise types consisted of cycling and running.

Methods

Subjects. After being informed about the nature and possible risks involved in the study, 32 healthy male triathletes, who were in training for at least a ¼-triathlon, gave their voluntary written consent to participate. Their mean values were age 27.5 (SEM 0.8) years, body mass (BM) 77.7 (SEM 1.2) kg, height 184.8 (SEM 1.1) cm. Their $\dot{V}O_{2max}$ during cycling and running were 61.9 (SEM 1.0) $ml \cdot kg^{-1} \cdot min^{-1}$ and 62.6 (SEM 1.0) $ml \cdot kg^{-1} \cdot min^{-1}$, respectively.

During the week prior to the first trial, $\dot{V}O_{2max}$ during cycling and running were determined using an incremental cycle ergometer test and an incremental treadmill test. The subjects rested for at least 90 min between exercise tests.

Standardization of dietary intake and training schedule prior to each trial. Since it has been shown that H_2 excretion is influenced by physical activity (Payne et al. 1983) and daily dietary intake (Levitt et al. 1987), training time and diet were standardized as follows: the subjects were asked to refrain from vigorous training during the 3 days preceding the trials and to refrain completely from training the day before a trial. The subjects were instructed to maintain the same diet and training schedule each 3-day period prior to a trial. The subjects consumed a breakfast at least 3 h before the exercise started on the morning of each trial. The composition of the breakfast was constant from week to week. All dietary instructions were given by a dietician.

Food intake was measured by using the 3-day dietary record method. Energy and nutrient intakes were calculated from the dietary records using a computerized version of the Netherlands NEVO nutrient data bank (NEVO 1989). To establish the training schedule, total training time was recorded for the 3 days prior to each trial.

Exercise protocol. The complete exercise protocol consisted of 3 h of exercise, three supramaximal tests and several periods of rest (Fig. 1). The supramaximal tests were used as a parameter for performance (to be published separately).

Exercise consisted of two cycling sessions at 75% $\dot{V}O_{2max}$ (sessions 1 and 3) of 51 and 43 min, respectively, and of two running sessions at 75% $\dot{V}O_{2max}$ (sessions 2 and 4) of 43 min. Directly after each cycling session the subjects cycled for 1 min at $1\ W \cdot kg\ BM^{-1}$. Directly after each running session they ran for 1 min at $8\ km \cdot h^{-1}$.

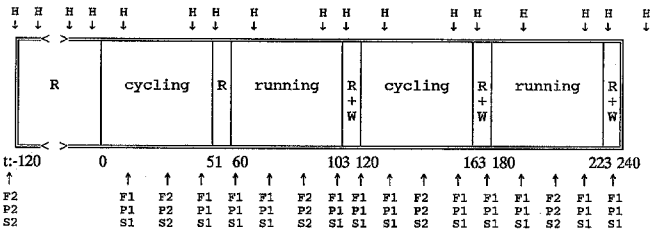

Fig. 1. Experimental protocol: *F1*, Fluid thirst quencher; *F2*, fluid energy drink; *P1*, placebo thirst quencher; *P2*, placebo energy drink; *S1*, semi-solid: orange juice with an equal amount of water; *S2*, semi-solid: white bread, marmalade, banana, water; *W*, supramaximal test; *R*, period of rest; *H*, sample expired hydrogen

After session 1 the subjects rested for 8 min. After sessions 2, 3, and 4 they rested for 6 min followed by a supramaximal cycling test, which lasted exactly 9 min. A supramaximal test consisted of 3-min warm-up, 3 min all-out performance and 3-min cool-down. The next exercise session was started 1 min later.

Feeding administration. Each subject performed three trials in the laboratory on three different intakes at weekly intervals. The starting time of a subject's test was kept constant from week to week. The intakes were administered in counterbalanced order with subjects as their own controls.

The intakes were: the fluid energy (F), the semi-solid (S), or the placebo (P). The F and P were administered in a double blind fashion.

The fluid energy intake consisted of a hypotonic (250 $mosmol \cdot l^{-1}$) thirst quencher (F1) ($8\ ml \cdot kg\ BM^{-1} \cdot h^{-1}$) and a hypertonic ($590\ mosmol \cdot l^{-1}$) energy drink (F2) ($2.5\ ml \cdot kg\ BM^{-1} \cdot h^{-1}$). The thirst quencher was a 4% CHO solution (3.6% fructose). The energy drink was a 40% CHO solution (33.3% maltodextrin).

The semi-solid intake consisted of orange juice with an equal amount of water (S1), banana, white bread, marmalade and water (S2). The subjects consumed 1.5-g banana, 0.875-g white bread, 0.313-g marmalade and 3.14-ml orange $juice \cdot kg\ BM^{-1} \cdot h^{-1}$.

The placebo consisted of a coloured, sweetened water placebo thirst quencher (P1), and a thickened (xanthum gum), sweetened water placebo energy drink (P2). Small amounts of citric acid were used as a flavouring ($0.4\ mg \cdot 100\ ml^{-1}$).

The energy contents of the three intakes were 22.4, 21.7 and $0\ kJ \cdot kg\ BM^{-1} \cdot h^{-1}$ for F, S and P, respectively. The CHO content was 1.3, 1.2 and $0\ g \cdot kg\ BM^{-1} \cdot h^{-1}$ for F, S and P, respectively; S also contained 0.1-g $protein \cdot kg\ BM^{-1} \cdot h^{-1}$.

At 2 h before each trial and at $t=30$ min of each hour during the trial, the subjects consumed the energy drink (F2) or the energy placebo (P2). The subjects consumed the semi-solid intake (S2) 2 h prior to each trial and between $t=25$ min and $t=35$ min at each hour. The F1, S1 and P1 beverages were consumed each hour at $t=15$, 45, 60 min (see Fig. 1).

Mixed-expired H_2 concentrations. The mixed expiratory air technique was used for H_2 sampling (Douwes et al. 1978; van der Klei-Moorsel et al. 1984). After a normal inspiration, the subject expired through a 60-ml plastic syringe with a hole at the side until functional residual capacity was reached. Next, the air volume of the syringe was compressed to a volume of 20-ml and placed in a H_2-analyser (Lactoscreen, Hoekloos, The Netherlands). A gas-sensitive semi-conductor, which transmitted an electrical signal to a microprocessor whenever the sample contained H_2, was used as detector. The detector was only sensitive to H_2. More details may be found in van der Klei-Moorsel et al. (1984). Since the H_2 concentration showed slight breath-to-breath fluctuations, sampling was in duplicate and the higher value was used (Douwes et al. 1978).

Comparison of the mixed-expired air technique with a gas chromatographic assay was satisfactory ($r=0.995$), though less precise in concentrations higher than 100 ppm (van der Klei-Moorsel et al. 1984). A reproducibility experiment in the same study revealed a coefficient of variation of 3.1%–5.4% for H_2 reference gases of 29–92 ppm, respectively.

In studying overflow or transit time of CHO from mouth to caecum, expired air samples have conventionally been obtained before, and at 30-min intervals for 3 h following, administration of the test substrate (Perman 1991). To obtain a reference value and some information on the changes of H_2 concentrations at rest, we sampled at $t=-120$, -90, -60 and -5 min prior to the first exercise session. Samples were also obtained during the exercise sessions at $t=15$ and $t=40$ min in each hour. We further sampled mixed-expired H_2 concentrations 5 min after each exercise session to obtain "recovery" measurements as ventilation and intestinal blood flow returned to their resting values. These measurements were regarded as an additional indication of CHO overflow during the preceding exercise. A recovery sample was also obtained 30 min after the whole trial to obtain information on CHO overflow when a complete return to resting conditions should have occurred.

Cardiopulmonary data. To assess exercise intensity, heart rate was sampled for 15-s by a Sport-tester type PE 3000 (Polar Electro, Finland). Mean heart rate was calculated for $t=11$–13 and $t=38$–40 min in each exercise session.

Ventilation, oxygen uptake and carbon dioxide production were determined using an Oxycon Beta (Mijnhardt, Bunnik, The Netherlands) that employed a digital volume transducer, a paramagnetic oxygen analyser and an infrared carbon dioxide analyser. All data were collected over 3 min and the mean values were calculated at $t=12$–13 and $t=39$–40 min in each exercise session.

Statistical analysis. The analysis started with the transformation of all non-normal data, e.g. all H_2 data, to a normal distribution by using log-transformation (distribution positively skewed) or square transformation (distribution negatively skewed). Significance of differences in mixed-expired H_2 concentrations among the three feedings and among the exercise sessions was analysed using multivariate analysis of variance (MANOVA) for repeated measures with a P-value ≤ 0.05. Possible effects of disturbing variables such as changing laboratory conditions were evaluated by multiple regression analysis.

Results

Pretest and test conditions

Analysis of variance revealed no significant differences between feedings with respect to pretest feedings and physical activity during the 3-days prior to each trial. The subjects' breakfasts prior to each trial consisted, on average, of an energy intake of 2784 kJ, of which 12.6% was provided by protein, 23.8% by fat and 63.6% by CHO. Laboratory conditions during the tests were as follows: mean temperature of 23.9° C (range 20.0–27.5° C) and a mean relative humidity of 67.1% (range 55.0%–88.5%). Conditions differed slightly among subjects (10 subjects experienced a difference in temperature of 2–3.5° C, 12 subjects experienced a difference in relative humidity of 10%–20%). Statistical analysis revealed no significant influence of any of these factors on the expired H_2 concentrations.

During exercise, not all the subjects were able to ingest the food completely (session 2: F=2, S=2, P=4; session 3: F=4, S=4, P=1; session 4: F=0, S=2, P=1). As a result of this, and also due to the difference in feeding characteristics, actual food intake differed among intakes during exercise. The mass of the intake (in grams or millilitres) per minute of exercise (including the resting and supra-maximal-test periods) was, on average, 14.0 (SD 1.6) g for F, 16.1 (SD 1.7) g for S and 13.8 (SD 1.5) g for P. The CHO intake per minute was 1.8 (SD 0.3) g for F, 1.6 (SD 0.3) g for S and 0 g for P. Water intake per minute was 13.1 (SD 1.5) ml for F, 14.3 (SD 1.5) ml for S and 13.8 (SD 1.5) ml for P. On average, the subjects consumed 315 g CHO and a total mass of 2.45 kg with F and 284 g CHO and a total mass of 2.82 kg with S.

Table 1. Values ($n=30$) for ventilation during exercise, measured twice in session 1 (measurements 1, 2), twice in session 2 (measurements 3, 4), beginning of session 3 (measurement 5) and at the end of exercise (measurement 9) as a function of equal energy fluid intake (F), semi-solid fluid intake (S), and fluid placebo (P)

Measurement	F		S		P	
	Mean	SEM	Mean	SEM	Mean	SEM
	($l \cdot min^{-1}$ BTPS)					
1	79.1[a]	1.7	78.3[a]	1.7	78.1[a]	1.6
2	84.2	2.0	82.6	1.7	82.3	1.7
3	87.2	1.8	85.6	1.6	84.1[b]	1.6
4	89.3	2.0	89.0	1.8	86.8[b]	1.9
5	93.6	2.8	91.6	2.3	91.8	2.4
9	94.8	2.5	92.3	2.0	93.7	2.2

BTPS, Body temperature and pressure, saturated with water vapour

[a] Significant increase over the whole exercise period ($P<0.0001$)

[b] P significantly ($P<0.05$) different from F and S

Heart rate increased on average from 144 to 167 beats·min^{-1}. The mean values of the ventilation rate are shown in Table 1. Ventilation and heart rate increased during exercise ($P<0.0001$) for all intakes. Over the whole period there were no significant differences among intakes.

Pulmonary H_2 excretion

The mixed-expired H_2 concentrations during the resting and the "recovery" periods are shown in Fig. 2, and the mixed-expired H_2 values during the exercise periods are shown in Fig. 3. The H_2 sampling was not complete for 2 subjects and their H_2 data were not used in the analysis.

Mean H_2 concentrations measured at *rest* (Fig. 2) were not significantly different among intakes.

During *exercise* (Fig. 3), H_2 concentrations were three to sixfold lower than during rest or recovery. During exercise, expired H_2 concentration increased significantly from session 1 (samples 1, 2) to session 2 (samples 3, 4). The increase in H_2 from sample 2 to 3 and from 2 to 4 was higher with F and S than with P. Within a single session, H_2 concentration did not change significantly, irrespective of the type of feeding.

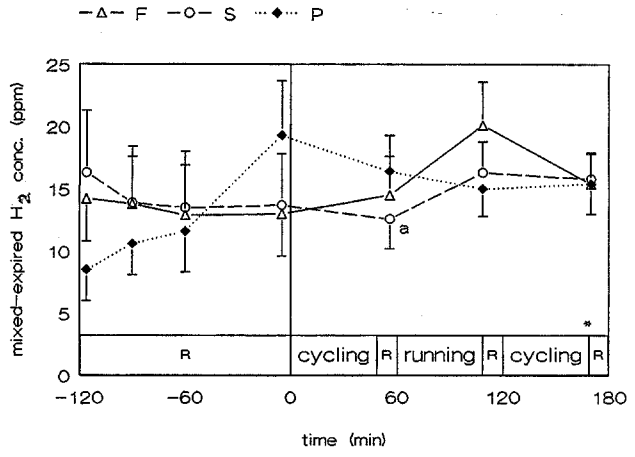

Fig. 2. Mean values (and SEM; $n=30$) of the mixed-expired H_2 concentrations during *rest and recovery.* [a] Significant increase from after session 1 to after session 2 ($P<0.05$); * in 51 out of 96 times subjects did not complete second cycling session

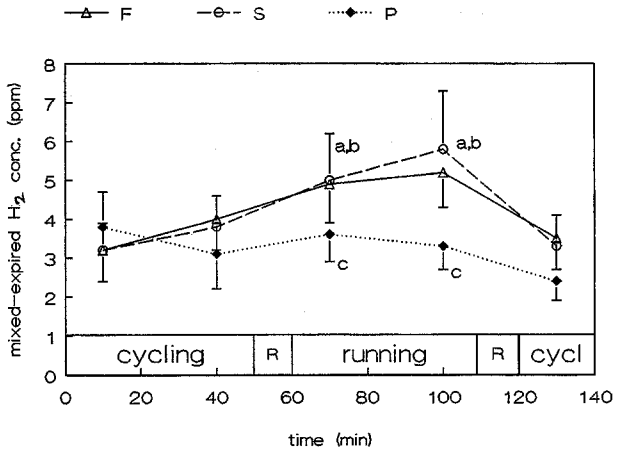

Fig. 3. Mean values (and SEM; $n=30$) of the mixed-expired H_2 concentrations during *exercise,* sampled twice in session 1 (samples 1, 2), twice in session 2 (samples 3, 4) and beginning of session 3 (sample 5). [a] Significant increase from session 1 (samples 1, 2) to session 2 (samples 3, 4) ($P<0.05$); [b] significant increase from sample 2 to 3 and from 2 to 4 significantly higher with F and S than with P ($P<0.05$); [c] F and S significantly different from P ($P<0.05$)

As we will show later, breath H_2 concentrations were higher during running than during cycling. Furthermore, on 51 out of 96 occasions, the subjects reached exhaustion during the second cycling session, while the other 45 times the subjects ended their exercise during or after the second running session. Therefore we decided to use only data obtained for each session from all 30 subjects and disregard all data obtained during or after session 4.

While the H_2 concentrations showed a trend towards lower values with P as compared to F and S, the difference was only statistically significant during session 2 (samples 3, 4). Furthermore, the statistical analysis showed that the increase in H_2 from sample 2 to 3 and from sample 2 to 4 was significantly greater with F and S than with P.

The H_2 *recovery* values as shown in Fig. 2 did not differ significantly from resting values and did not differ significantly among intakes.

To compare H_2 values during *cycling* and *running* irrespective of the intake, H_2 concentrations were averaged for all intakes. We found that H_2 concentration increased significantly from after session 1 (5 min after session 1, Fig. 2) to after session 2.

Discussion

Pretest and test conditions

No differences among intakes could be found in pretest dietary intake and physical activity. Also climatic conditions, ventilation and heart rate were similar. Therefore, we concluded that each subject started and performed the three exercise trials under comparable conditions.

During exercise, however, the supplement of CHO and the total mass of the nutrition differed among intakes due to differences in feeding content and actual intake. Although these differences were statistically significant, it remains questionable whether the differences of +31 g CHO (9.9%) and −0.37 kg (15.1%) total mass between F and S are physiologically significant for any differences in CHO overflow. Furthermore, the largest difference in CHO intake per minute between F and S was observed during sessions 3 and 4, and since it would have taken time for the ingested CHO to reach the colon, we expected that the effects of the difference in CHO intake on CHO overflow would not be great. If any influence of the difference in CHO intake was present, it was likely that this would have been effective during or after sessions 3 and 4 only. Our data, however, gave no indication of such an influence.

Pulmonary H_2 excretion

There are very few investigations concerning mixed-expired H_2 excretion under exercise conditions (Cammack et al. 1982; Keeling and Martin 1987; Meshkinpour et al. 1989; Moses et al. 1988). These studies have concentrated mainly on the transit time of food from mouth to colon (intestinal transit time). We were interested in the net result of CHO intake on H_2 excretion. Furthermore, most studies have measured H_2 excretion after ingestion of a test meal at or before the start of an exercise. In contrast the subjects in the present study also consumed food during exercise.

We used mixed-expired H_2 samples to study CHO overflow before, during and after exercise as a function of diet and exercise type. This technique is based on the assumptions (Levitt et al. 1987) that:

a. H_2-producing bacteria are found in the colon only;
b. The activity of H_2-producing bacteria is predominantly nourished by ingested, malabsorbed CHO; and
c. There is a linear relationship between H_2 produced and H_2 excreted by the lungs.

As long as there is no bacterial overgrowth in the small intestine all assumptions should hold under conditions

of rest (Levitt 1969; Levitt et al. 1987). However, the technique may be faced with some problems.

One aspect of the technique is the difficulty in differentiating between the H_2 excretion from malabsorption following the ingestion of a test meal and the basal H_2 excretion. Levitt (1969) has found large interindividual differences in basal H_2 production, presumably due to differences in bacterial H_2 production or consumption (Bjørneklett and Jensen 1982). The capacity of the gut flora to produce an re-use H_2 may differ among subjects as a result of differences in the quantity and composition of colonic bacteria. Subjects showing no H_2 in the breath were called "nonproducers".

Furthermore, H_2 production in the gut has been shown to be influenced by other factors such as colonic pH (Perman et al. 1981), antimicrobial drugs, acute diarrhoea (Solomons et al. 1979), bacterial overgrowth in the small intestine and physical activity (Payne et al. 1983). In the present study, however, many of these problems would not have been of concern since all our subjects were their own controls. Furthermore, all the subjects were healthy and showed no signs of bacterial overgrowth, took no antimicrobial drugs, started each exercise trial after consumption of the same diet and were H_2 producers, since they showed a resting H_2 excretion greater than 2 ppm. Thus, quantification of CHO malabsorption was possible, but since we did not measure the subjects in the fasting state, it was not possible to calculate the additional H_2 excretion as a result of exercise. Nevertheless, a comparison of H_2 excretion among feedings and between exercise types was possible.

It has been shown that changes in GI processes, such as gastric emptying, intestinal transit and absorption of the substrate ingested, may also influence the H_2 excretion (Perman 1991). Therefore, as mentioned in the Introduction, CHO "overflow" is a more general and more appropriate term for the net result of those GI processes causing an elevated H_2 excretion.

At *rest*, we found no significant differences in H_2 values among intakes. One would expect some differences in H_2 values, based on the different CHO content of P as compared to F and S. Mixed-expired H_2 concentrations with P should reflect the influence of the breakfast, since P contains no CHO. The results would indicate that resting H_2 concentrations were not changed by the additional consumption of CHO (fluid or solid) prior to exercise.

So far, we have indicated that several factors may influence H_2 excretion at rest. After fermentation of the substrate in the colon, H_2 has been shown to be produced and transferred into the portal circulation, transported to the lungs and excreted via the alveoli (Perman et al. 1981). During *exercise*, all these processes may be changed. In the present study, the high intensity exercise caused a considerable increase in ventilation and a decrease in intestinal blood flow. Both factors have been shown to contribute to a lower H_2 excretion rate (Perman et al. 1981, 1985). It is also possible that exercise may have altered the fractional loss of H_2 into the mucosal circulation (Keeling and Martin 1987). Levitt (1969) has found that a mean of 21% of the total H_2 production was excreted by the lungs. In the same study, pulmonary H_2 excretion correlated significantly ($r=0.94$) with H_2 production. It is possible that the relationship and the fractional loss found at rest may be different during exercise. These factors make it hazardous to compare quantitatively expired H_2 concentrations between rest and exercise. However, ventilation and heart rate (as an indicator of blood flow) were the same among intakes and there were no indications that the correlation between pulmonary H_2 excretion and the colonic H_2 production differed among intakes during exercise. Therefore, a reliable comparison of CHO overflow among intakes can be made. Since H_2 excretion with P must be considered as the basal H_2 excretion during exercise and excretion with F and S was higher than with P, we can conclude that there was CHO overflow with F and S.

Perman et al. (1985) have found that exercise could suppress H_2 excretion to zero. Therefore, we also performed H_2 measurements in *recovery* conditions. We observed that exercise at 75% $\dot{V}O_{2\,max}$ considerably reduced H_2 excretion as compared to rest, but did not suppress mean pulmonary H_2 excretion to zero.

We believed that the measurements made 5 min after the end of exercise could be regarded as an indication of CHO overflow during the preceding exercise since, after 5-min recovery, ventilation would have returned to near rest values. However, 5-min may not have been sufficient for a nearly complete recovery of intestinal blood flow. Qamar and Read (1987) have found that 15 min of treadmill exercise (5 $km \cdot h^{-1}$ up a 20% gradient) reduced mesenteric blood flow by 43%; 5 min after exercise blood flow was still reduced by 29%. If the same is true in our studies, although most H_2 values returned to the levels obtained during the pretest rest period (Fig. 2), the H_2 values actually would have been higher when intestinal blood flow returned to normal (higher) resting values.

Expired H_2 concentrations were not different among intakes during recovery, in contrast to the results during exercise. This may indicate that the recovery of intestinal blood flow after exercise differed among intakes. Qamar and Read (1987) have found that the mesenteric blood flow was reduced during exercise. After ingestion of a liquid meal, this reduction became smaller. One may hypothesize that the reduction in intestinal blood flow could be different among intakes. In fact, intraluminal glucose has been found to stimulate mesenteric blood flow (Norryd et al. 1975). These findings would suggest that the use of recovery H_2 values as an indicator of CHO overflow in the preceding exercise is questionable.

Expired H_2 concentrations during *cycling* (session 1: samples 1, 2) were lower than during *running* (session 2: samples 3, 4). Furthermore, the significant increase in H_2 concentration from session 1 to session 2 was significantly higher with F and S than with P. This would indicate that CHO overflow was higher during running than during cycling. This cannot be explained in terms of ventilation, since ventilation during running was

even higher than during cycling and would have resulted in a lower H_2 excretion during running. Further, the higher CHO overflow during running cannot be explained in terms of the duration of the exercise: H_2 excretion during session 3 (second cycling session, sample 5) was lower than during session 2 (first running session).

Rehrer and Meijer (1991) have found that jostling of the internal organs was almost doubled in running versus cycling. This so-called vertical component of running may have affected the intestinal transit time and may have increased the rate of CHO delivery to the small intestine. This may also have affected the absorption per se. On the other hand, one can speculate that the removal of H_2 via the flatus is smaller during running than during cycling. As a consequence more H_2 can leave the body by expiration. Further studies are necessary to evaluate the pulmonary excretion of H_2 during cycling compared to running.

Conclusions

Mixed-expired H_2 concentration can serve as an indicator of CHO overflow during exercise as it measures the net result of gastric emptying, intestinal transit and absorption. Since all subjects were their own controls, CHO overflow could be compared among feedings and between exercise types. Since we did not measure the basal H_2 excretion in our subjects, exact quantification of CHO overflow was not possible.

Further research on HBT during exercise should take into account:

1. A larger CHO intake than was used in this study, resulting in a larger CHO overflow. This would facilitate the differentiation between the basal H_2 excretion and the intake and/or exercise-induced H_2 excretion;
2. Knowledge of the basal H_2 excretion; and
3. Knowledge of the effects of ventilation and intestinal blood flow on H_2 excretion.

The HBT could also be useful in other applications. For instance, H_2 measurements could be used to investigate GI complaints during exercise. We have found that H_2 concentrations could explain a significant proportion of the variance in the duration of the GI complaints of cramps and side ache (stitch) in triathletes during exercise (Peters et al. 1993).

Since HBT can indicate CHO overflow, comparison of the effect of different CHO types and different CHO quantities on CHO overflow during exercise is possible. In this way HBT can be used for investigating the most appropriate CHO source and quantity to be used by endurance athletes.

Acknowledgements. We are grateful to the subjects for their participation in this project.

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