NUTRITION AND ENDURANCE PERFORMANCE – A REVIEW

J. D. BROOKE, DLC, MSc, PhD & G. J. DAVIES, DLC, BSc

Human Performance Laboratory, University of Salford

A sufficient normal diet is defined by Keele and Neil (1961) as follows:—

“An adequate diet must have a caloric value sufficient to provide for the requirements of basal metabolism . . . and the needs of varying degrees of muscular work. It must have adequate amounts of proteins (essential amino acids), fat, carbohydrate, water and salts (ions) in suitable proportions and an ample vitamin content.”

The present paper will deal with that part of the diet which provides fuel for the support of muscular work, namely, fats and carbohydrates, with a brief review of the role of protein.

First, let us consider protein. Over 100 years ago von Leibig (1851) suggested protein might be the fuel for muscular work. However, Pettenkofer and Voit (1866) showed that urinary excretion of nitrogen was not affected by prolonged strenuous exercise. The utilization of protein as a source of energy, in such work, does not take place. This early work has been confirmed repeatedly, Chaveau (1896), Zuntz (1901), Cathcart (1925), Cathcart and Burnett (1926) and Margaria and Foa (1939). Hedman (1957), working with cross country skiers racing between 38 and 85 km in one day, demonstrated no noticeable change in the nitrogen output compared with resting controls. Yamaji (1951) suggested that an increased protein intake was required during training to prevent utilization of protein reserves, shown by a decrease in blood haemoglobin and serum albumin. However, the normal balanced diet will be stimulated by physical activity so that a greater expenditure of energy [possibly up to 20.93 MJ (5,000 kcal)/day, Ruffels (1962)] is met by a greater energy intake. The increased protein intake, as part of this diet, is sufficient for any increase that takes place in muscle mass. As protein can normally be excluded as a source of energy for exercise, this role must be fulfilled by fats and/or carbohydrates.

In 1901, Zuntz demonstrated that the R.Q. could be altered by changes in diet and that for moderate work, after a high fat diet, fat was essentially the only source of energy. Krogh and Lindhard (1920) confirmed the importance of fat for energy during exercise and Christensen and Hansen (1939b) showed that after a high fat, low carbohydrate diet, some 70% of the energy was derived from fat during aerobic work. Carlson and Froberg (1967) showed that, during a 10 day fast and

exercise period (50 km walk daily), the energy contribution from glycogen stores is negligible. Most of these experiments were based upon R.Q. measurements showing that muscles utilize both fat and carbohydrate for combustion during exercise. The proportion of fat and carbohydrate used depends upon the intensity of work, — Bock et al (1928). The greater the intensity, the greater is the contribution from carbohydrate. Christensen and Hansen (op. cit.) also showed that the duration of work affected the contribution of fat and carbohydrate. During exercise at a constant work load there was a pronounced drop in R.Q. later in work indicating an increasing contribution of fat. Thus, intensity and duration of work affect the proportion of fat and carbohydrate used as energy sources. Another factor involved is the type of diet and again Christensen and Hansen (1939a) showed that different diets affected work times. On a high fat diet, working at a constant load, subjects were exhausted after 90 minutes, while on a high carbohydrate diet the same work could be maintained for 240 minutes. Most of these experiments were carried out to exhaustion but, when 200 gm of carbohydrate were administered, work could be continued for another hour. This confirmed the earlier work of Dill, Edwards and Talbot (1932) who fed carbohydrate (candy) to their dog Joe and obtained a work time of 17 hours (covering a distance of 82 miles). Without carbohydrate, work could be continued for just over 4 hours.

Thus, it can be seen that carbohydrate is of decisive significance for muscular work. Most of these studies mentioned earlier have used indirect methods to measure the carbohydrate metabolism, that is, the non-protein R.Q. An estimate is made of the carbohydrate metabolism by measuring oxygen intake and carbon dioxide production. This needs very careful experimentation to ensure accurate results. More recent studies involving needle biopsy techniques, Hultman (1967), have been able to measure directly the changes in glycogen content in working muscle. Bergström and Hultman (1967) have shown that during work the muscle glycogen falls to values approaching zero and the working capacity decreases when the store is depleted. Ahlborg et al (1967) related the ability to perform prolonged heavy work to the initial glycogen store and this store can be varied with different treatments of diet. It is relevant, therefore, to consider briefly methods of increasing the carbohydrate stores.

1. Diet prior to work

Christensen and Hansen (1939b) in a study on diet and work capacity found that 3-7 days on a high carbohydrate diet resulted in a work time of 210 minutes compared to 80 minutes after an equal time on a fat diet. More recently, Karlson and Saltin (1971) found that a high carbohydrate diet produced higher (double) muscle glycogen stores and better performances in a 30 km race compared with a normal mixed diet.

2. Diet during work

The work of Dill, Edwards and Talbot (1932) established the importance of feeding carbohydrate during work and its effects on increasing work times. Brooke, Davies and Green (1972) have investigated the effects of nutrition during severe prolonged exercise in racing cyclists. Four diets were used, glucose syrup, normal racing diet (rice pudding with sucrose and fruit salad), the first two isocaloric, a low calorie feed and no feeding. The treatments were randomly arranged according to a Latin Square design. Eight racing cyclists worked to exhaustion on Ergowheel* ergometers set to approximate their racing load of 67% $\dot{V}O_2$ maximum. Mean work times for the four treatments as ordered were 216, 201, 180 and 148 minutes. Subjects on the glucose syrup drink worked significantly longer on this treatment ($P < .05$) than when they took any of the other treatments. The R.Q. was maintained at quite high levels indicating a high carbohydrate utilization and the efficiency, in terms of oxygen consumption, was greater. Thus, carbohydrate intake during work increases work capacity. Care must be taken not to feed too large a quantity of carbohydrate as this prevents gastric emptying and the subject becomes bloated and uncomfortable. In this context the high energy/volume ratio and satisfactory palatability of the glucose syrup drink were beneficial.

3. Post exercise diet: following exercise, especially if it is so strenuous as to exhaust the muscle glycogen store, a high carbohydrate diet can cause dramatic increases in these stores. Bergström and Hultman (1966) demonstrated this in an experiment based on one leg working while the other rested. After work to exhaustion a high carbohydrate diet produced drastic changes. In the exercised leg the glycogen content rose from almost zero to higher levels than the resting leg on the first day. By the third day the stores in the exercise leg had doubled those in the resting leg which had risen only slightly. Brooke and Green (1973) worked two groups of subjects at 60% and 70% of their maximum $\dot{V}O_2$ to exhaustion and then during a 40 minute rest period fed a high carbohydrate, a normal isocaloric mixed, and a low calorie feed. The subjects were then worked again at the same loads to exhaustion a second time, the mean 2nd work times being 80.0, 58.0 and

29.0 minutes respectively. Thus, a high carbohydrate intake following exhausting work markedly increased the rate of recovery to perform.

4. Combinations of exercise and diet

Saltin and Hermansen (1967) and Bergström et al (1966) found that not only did a high carbohydrate diet replenish exhausted muscle glycogen stores but, if after exhaustion the stores were kept low by a high fat and protein diet and then followed by the high carbohydrate intake, considerable increases were seen in muscle glycogen. Following the same procedure as Hermansen and Saltin, Brooke and Green (1972) discovered what they called an exercise adaptation. When trained racing cyclists every 3 days, after a 20 hour fast carry out prolonged severe work to exhaustion, on the second trial total carbohydrate available is reduced, and work time to exhaustion is reduced approximately 60%. On the third trial 3 days later the work time increases to over 200% of the first trial, in conjunction with markedly increased carbohydrate stores. Between trials the subjects were on a normal mixed diet. This confirms the work of Bergström and Hultman (1966) who found that exercise with glycogen depletion enhanced the resynthesis of glycogen through some factor operating locally in exercised muscle.

In summary, the ability to perform hard physical work depends upon the carbohydrate stores and it is possible to increase these stores in the following ways:— a) a high carbohydrate diet prior to activity, b) a high carbohydrate intake during work, c) exhaust carbohydrate stores by exercise and then feed a high carbohydrate diet. (c) would of course take place before the activity. A more detailed survey of food carbohydrates and human performance, which also encompasses mental aspects, is provided by Brooke (1973).

How can this research be applied to the field of team games? The total body stores of glycogen normally are approximately 300 g giving an energy value of approximately 5.023 MJ (1200 kcal). In an active games player, let us assume an energy expenditure of 41.86 kJ (10 kcal)/minute. This would mean a complete emptying of body stores in 120 minutes or at the end of an 80 minute game of rugby these stores would be reduced by 3.349 MJ (800 kcal). Thus, in particular circumstances, the fatigue towards the end of a game could be related to low carbohydrate stores. In present times, with the increasing number of games and training sessions, it is possible that, after a game, because of training, or a low carbohydrate intake, the glycogen stores are not allowed to refill. Hultman and Bergström (1967) have shown that, with a carbohydrate diet, resynthesis is complete in 24 hours; but with a carbohydrate free diet resynthesis may take 8-10 days. Thus, it is important that, during

*Worthwhile Designs Ltd., Grange Road, Eccles, Manchester.

such periods of intense activity, the carbohydrate intake must be increased, if fatigue from lack of muscle glycogen is not to ensue.

It is on tours that this situation is most likely to arise. With games twice per week and hard training sessions of 1½ hours, carbohydrate intake should be increased. It

may not be practical to follow a particular dietary regime (certainly not if it has detrimental psychological effects) but one can provide that the diet is supplemented with high energy carbohydrate nutrients such as glucose syrup drinks and that meals are rich in carbohydrates as well as the other essential constituents of the normal diet.

REFERENCES

- AHLBORG, B. et al Muscle glycogen and muscle electrolytes during prolonged physical exercise. *Acta Physiol.Scand.* **70**, 129, 1967.
- BERGSTRÖM, J., HERMANSEN, L., HULTMAN, E. & SALTIN, B. Diet, muscle glycogen and physical performance. *Acta Physiol.Scand.* **71**, 140, 1967.
- BERGSTRÖM, J. & HULTMAN, E. Muscle glycogen synthesis after exercise: an enhancing factor localized to the muscle cells in man. *Nature (Lond.)* **210**, 309, 1966.
- BERGSTRÖM, J. & HULTMAN, E. A study of the glycogen metabolism during exercise in man. *Scand.J.Clin.Lab.Invest.* **19**, 218, 1967.
- BROOKE, J. D. Food carbohydrates and human performance. In: G. G. Birch & L. F. Green (Eds.). *Molecular Structure and Function of Food Carbohydrates*. London: Elsevier, 1973.
- BROOKE, J. D., DAVIES, G. J. & GREEN, L. F. Nutrition during severe prolonged exercise in trained cyclists. *Proc.Nutr.Soc.* 1972.
- BROOKE, J. D., DAVIES, G. J. & GREEN, L. F., Nutrition and endurance performance. *Proc.Nutr.Soc.*, 1972, **31**, 93A.
- BROOKE, J. D. & GREEN, L. F. Carbohydrate availability in human recovery from physical work exhaustion. *Proc.Nutr.Soc.* 1972/73. (In Press).
- BROOKE, J. D. & GREEN, L. F. Variations in available carbohydrate and physical work ability with repeated prolonged severe exercise. *Proc.Nutr.Soc.* 1973, **32**, 11A.
- BOCK, A. V., VANCAULEART, C., DILL, D. B., FOLLING, A. & HURXTHAL, L. Studies in muscular activity: IV, Steady state and R.Q. during work. *J.Physiol.* **66**, 162, 1928.
- CARLSON, L. A. & FROBERG, S. O. *Metab.Clin.Exptl.* **16**, 624, 1967.
- CATHCART, E. P. The influence of muscle work on protein metabolism. *Physiol.Rev.* **5**, 225, 1925.
- CATHCART, E. P. & BURNETT, W. A. The influence of muscle work on metabolism in varying conditions of diet. *Proc.Roy.Soc.London.* **3**, 99, 405, 1926.
- CHAVEAU, A. Source et nature du potentiel directement utilisé dans le travail musculaire d'après les échanges respiratoires, chez l'homme en état d'abstinence. *C-R.Acad.Sci.Paris.* **122**, 1163, 1896.
- CHRISTENSEN, E. H. & HANSEN, O. Untersuchungen über die verbrennungsvorgänge bei langdauernder, schwerer Muskelarbeit. *Skand.Arch.Physiol.* **81**, 152, 1939a.
- CHRISTENSEN, E. H. & HANSEN, O. Arbeitsfähigkeit und Ernährung. *Scand.Arch.Physiol.* **81**, 160, 1939b.
- DILL, D. B., EDWARDS, H. T. & TALBOTT, J. H. Studies in muscular activity. *J.Physiol.(Lond.)* **77**, 49, 1932.
- HEDMAN, R. The available glycogen in man and the connection between rate of oxygen intake and carbohydrate usage. *Acta Physiol.Scand.* **40**, 305, 1957.

- HULTMAN, E. Muscle glycogen in man determined in needle biopsy specimens. *Scand.J.Clin.Lab.Invest.* 19, 209, 1967.
- HULTMAN, E. & BERGSTRÖM, J. Muscle glycogen synthesis in relation to diet studied in normal subjects. *Acta Med.Scand.* 182, 109, 1967.
- KARLSON, J. & SALTIN, B. Diet, muscle glycogen and work performance. *J.Appl.Physiol.* 31, 2, 1971.
- KEELE, C. A. & NEIL, E. In: *Samson Wright's Applied Physiology*. Oxford Univ. Press: London. 1971.
- KROGH, A. & LINDHARD, J. Relative value of fat and carbohydrate as a source of muscular energy. *Biochem.J.* 14, 290, 1920.
- LIEBIG, J. von. *Letters on Chemistry*. London. 361, 1851.
- PETTENKOFER, M. & VOIT, C. *Z.Biol.* 2, 537, 1866.
- RUFFELL, J. In: J. G. P. Williams (Ed.). *Sports Medicine*. Edward Arnold & Sons Ltd. London. 1961.
- SALTIN, B. & HERMANSEN, L. Glycogen stores and prolonged severe exercise. In: G. Blix (Ed.). *Nutrition and Physical Activity*. Uppsala: Almqvist & Wiksells. 1967.
- YAMAJI, R. Studies on protein metabolism during muscular exercise: 2, Changes of blood properties during training for heavy muscular work. *J.Physiol.Soc.Japan.* 13, 483, 1951.
- ZUNTZ, N. *Pflügers Arch.ges.Physiol.* 83, 557, 1901.

HONOURS BSc DEGREE IN HUMAN MOVEMENT STUDIES AND PHYSIOLOGY

The editor's attention has been drawn to a new university BSc degree being offered from October 1974 in Human Movement Studies and Physiology at the University of Salford. The degree will be taught in the Departments of Biology, Physical Education and Mathematics.

It is expected that, graduating after three years, students from the course will take professional qualifications that lead them to teaching physical education, to ergonomics, to sports guidance and coaching, to management of recreational and education facilities, and to research.

The course, for male and female students, is intended to provide an understanding of concepts and knowledge about physical movement, its determinants and its relevance for human beings.

Details of the course and of matriculation requirements are contained in the Undergraduate Prospectus which may be obtained from the Registrar, University of Salford, Salford, M5 4WT. Further information can be obtained from Dr. J. D. Brooke at the Physical Education Department of the University.