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Nutrient intake and protein metabolism: responses to feeding

Nährstoffaufnahme und Proteinstoffwechsel: Reaktionen auf die Nahrungsaufnahme

Summary Lean tissue growth occurs when the rate of protein synthesis exceeds the rate of protein breakdown. Although *absolute* rates of protein synthesis and breakdown rise during growth from birth to maturity *fractional* rates fall. Both these processes are sensitive to nutrient intake but responses to feeding vary greatly amongst different tissues. Protein, carbohydrate and fat can all stimulate body protein accretion in immature animals and in children but the mechanisms by which they do so, and the energy expenditures involved, seem to be different.

Zusammenfassung Eine Zunahme von fettfreiem Gewebe tritt auf, wenn die Proteinsynthese größer ist als der Proteinabbau. Obwohl während des Wachstums von der Geburt bis zur Reife die absoluten Proteinsynthese- und -abbauraten ansteigen, nehmen dagegen die fraktionellen Raten ab. Beide Prozesse reagieren auf die Nährstoffaufnahme. Es gibt aber deutliche Unterschiede zwischen den verschiedenen Geweben. Protein, Kohlenhydrate und Fett können den Proteinansatz bei unreifen Tieren und Kindern stimulieren. Die zugrundeliegenden Mechanismen und die Energieaufwendungen scheinen jedoch unterschiedlich zu sein.

Key words Nutrient intake – protein metabolism – protein synthesis – growth – energy expenditures

Schlüsselwörter Nährstoffaufnahme – Proteinstoffwechsel – Proteinsynthese – Wachstum – Energieaufwand

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The accretion of body protein during growth requires that protein synthesis exceeds protein breakdown. The effects of nutrient intake on body protein accretion may act by increasing protein synthesis, reducing protein breakdown, or by any combination of changes which increases the difference between them.

In young, growing animals protein synthesis is sensitive to food intake. Thus, Baillie and Garlick (3, 4), using the flooding dose technique, reported substantial increases in muscle protein synthesis in young rats after feeding, whereas in adult rats these responses were slight or non-existent (Fig. 1).

In addition to these short term responses to diurnal rhythms of feeding and fasting, protein synthesis in growing animals responds in the long term to the chronic plane of nutrition. Reeds *et al.* (10) fed growing pigs increasing amounts of the same balanced diet and showed that whole-body protein synthesis, measured with a constant infusion of labeled leucine, increased with the increase in intake. Protein breakdown, calculated as the difference between protein synthesis and body protein accretion (estimated from nitrogen balance), also increased with intake, but to a lesser extent (Fig. 2). These responses to increasing amounts of food can also be considered as the sum of the responses to the individual nutrients given as a whole diet. In growing pigs supplements of protein, carbohydrate and fat increased body protein accretion to a similar extent but whole-body protein turnover was increased more by the protein than by the non-protein energy sources (12; Fig. 3).

These whole-body responses are of course the summation of the responses in individual tissues and organs. Sève *et al.* (15) examined the effect of increasing dietary protein on the rate of protein synthesis in various tissues

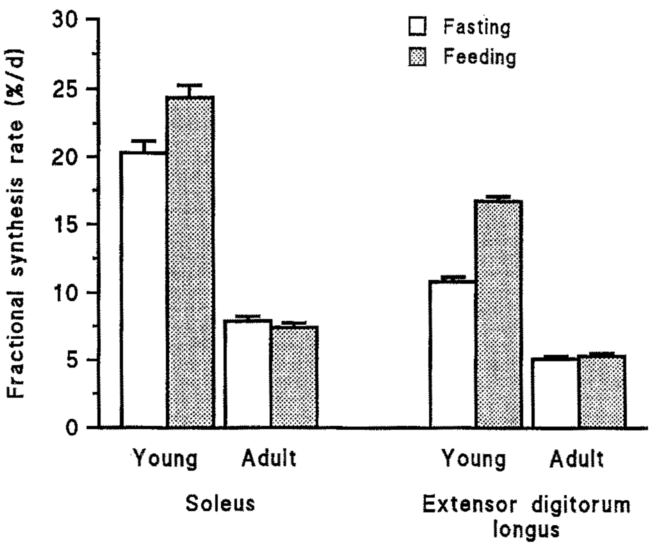

Fig. 1 Fractional rates of protein synthesis (± SEM) in muscles of young and adult rats and their responses to feeding after a 12 h fasting. Data of Baillie and Garlick (3, 4).

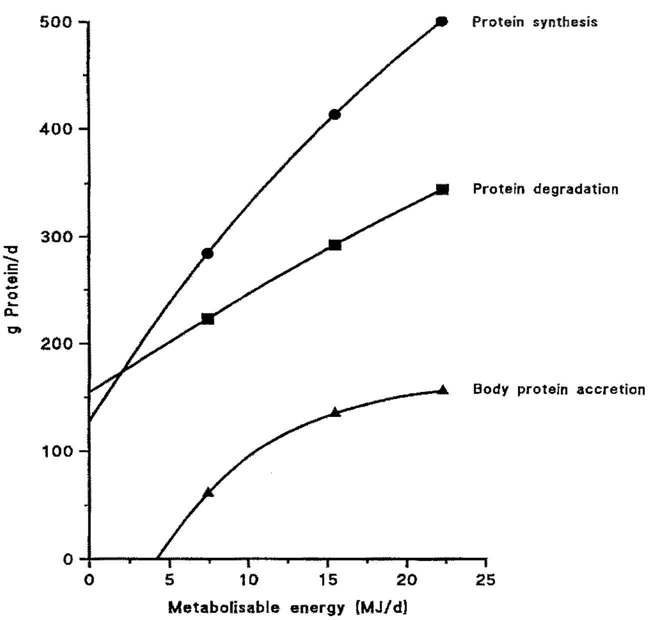

Fig. 2 Protein synthesis, protein degradation and body protein accretion in 30 kg pigs given a standard diet at twice daily rates. Data of Reeds *et al.* (10).

of young pigs. Although the fractional rate of protein synthesis in muscle was much lower than in liver or intestine, it increased proportionately much more with the increased protein supply (Fig. 4) and this, coupled with its greater contribution to body protein mass, made it the major site of the increased protein deposition.

As well as the amount of protein in the diet, body protein accretion is affected by protein quality. In sub-

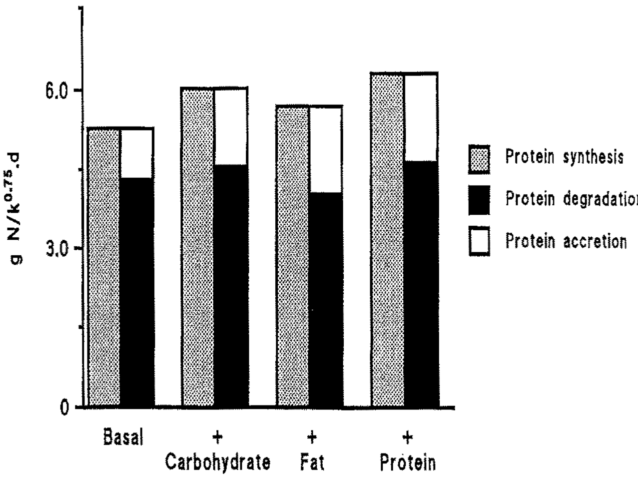

Fig. 3 The effect of supplementary protein, fat and carbohydrate on the rates of protein synthesis, protein degradation and body protein accretion in pigs. Data of Reeds *et al.* (12).

sequent experiments (7, 8) supplementation of a deficient diet with the single limiting amino acid, lysine, substantially increased the body protein accretion of growing pigs, as would be expected. Whole-body protein synthesis, measured simultaneously with a constant infusion of tritiated leucine and by the ^{15}N end product method, did not change significantly with the lysine supplementation change in whole-body protein synthesis, rather suggesting that the additional protein accretion was brought about by reduced protein breakdown (Fig. 5). In contrast, Salter *et al.* (13), also using the end product method, suggested that protein synthesis was increased. It is not clear what might have caused this different result.

The experiments with growing chicks by Tesseraud *et al.* (16) are difficult to interpret because the birds given a lysine-deficient diet were less than half the weight of those given an adequate diet and it is not clear to what extent the differences observed in protein synthesis were due to the different body weights; as seen above, as animals approach maturity, fractional rates of protein synthesis decline.

Although the protein-sparing effects of dietary carbohydrate and fat have been recognised for many years (9), the mechanisms of these effects are still poorly understood. Although, in the adapted animal, carbohydrate and fat increase body protein accretion to a similar extent, per kJ added, there is a delay in the response to fat. In experiments with rats Chen and Fuller (6) reported that fat was more effective than carbohydrate in inhibiting the postabsorptive fall in protein synthesis.

The responses of protein metabolism to additions of carbohydrate and fat seem to be due in part to the provision of the substrates and in part to hormonal changes which are themselves triggered by the influx of nutrients. Insulin and cortisol are both implicated. In experiments

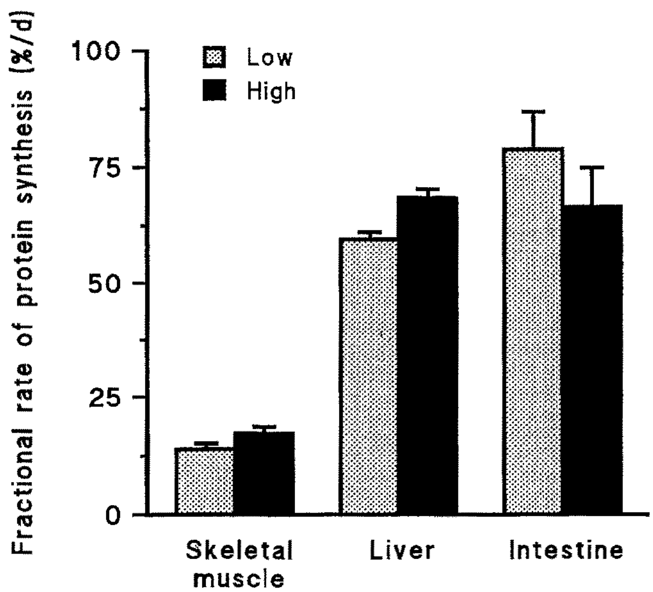

Fig. 4 Protein synthesis in the tissues of piglets given diets low (160 g/kg diet) or high (300 g/kg diet) in protein. Data of Sève *et al.* (15).

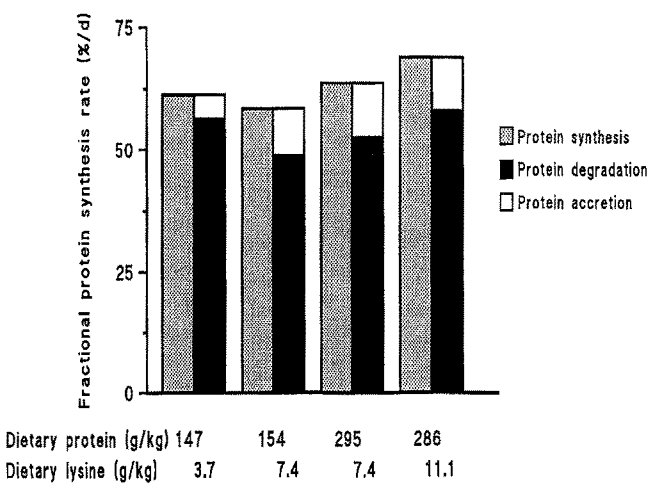

Fig. 5 Effect of doubling dietary lysine, protein or both on whole body protein synthesis, degradation and accretion in pigs. Data of Fuller *et al.* (8).

with growing pigs the time course of changes in urea entry was observed by the continuous infusion of ^{14}C urea in pigs given a basal diet to which either carbohydrate or fat was then added (11). Urea entry fell within two hours of the start of carbohydrate supplementation whereas with fat there was a delay of 12-24 h (Fig. 6). By 48 h after the start of supplementation however urea entry rate had fallen to a similar extent with both supplements. The accompanying changes in hormone

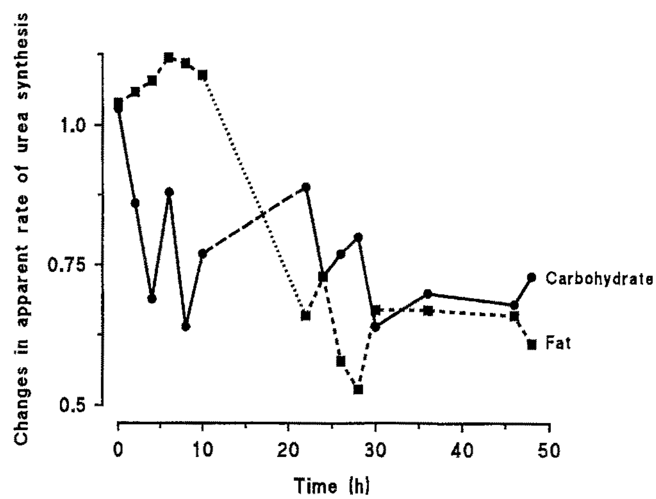

Fig. 6 Changes in the apparent rate of urea synthesis in growing pigs over 2 d following the addition of carbohydrate and fat to the diet. Data of Reeds *et al.* (11).

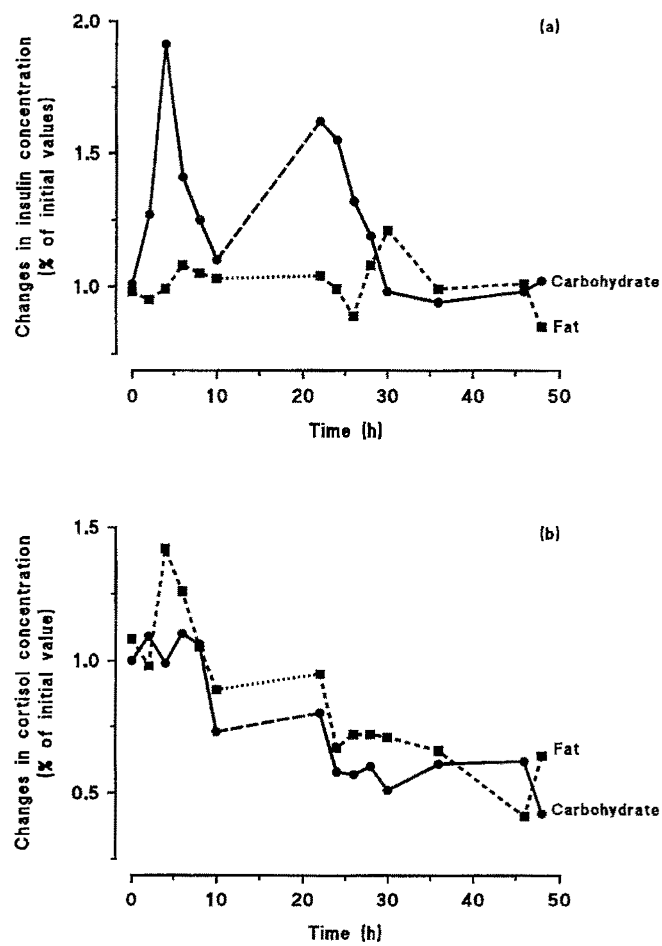

Fig. 7 Changes in insulin (a) and cortisol (b) concentrations in growing pigs over 2 d following the addition of carbohydrate and fat to the diet. Data of Reeds *et al.* (11).

concentrations (Fig. 7) show an increase in insulin in response to carbohydrate, which may be related to its immediate effect on protein metabolism but which disappeared after 24 h. In the longer term the common feature of the responses to both supplements was the fall in cortisol. In considering the long term regulation of these response to nutrients and the decline in those responses as maturity is approached, it would be valuable to know more of the role of IGF_1 in the mediation of the effects of nutrients on protein metabolism.

Because additional protein turnover involves additional energy expenditure the implication of the above is that diets with excess protein or a poor balance of amino acids would be used with a low energetic efficiency. We attempted (7, 8) to assess the energy cost of body protein accretion by measuring the heat production of pigs when their basal lysine deficient diet was given alone or supplemented with lysine. In this way body protein accretion was approximately doubled with only a trivial change in substrate supply. In the same experiment lysine intake was also increased by dietary addition. The associated changes in heat production were quite small. However, the increases in body protein accretion were accompanied by decreased rates of fat deposition. By assuming an energy cost of fat deposition of 54 kJ/g (14) we calculated that the energy cost of body protein accretion was, on average, 19 kJ/g, a value very close to the 20 kJ/g derived by the Agricultural Research Council (1) from a collation of the literature. The value was however much higher when dietary protein was increased than when only lysine was added. Since additional protein increased both protein synthesis and protein degradation more than the additional lysine, these results are consistent. Although there may be an energy requirement for protein degradation (2) there in as yet no information on its magnitude. A basic problem in these experiments is that, because only a small percentage change in protein synthesis or degradation can result in a large percentage change in body protein accretion, it proved difficult to measure either with sufficient precision to establish firmly their relationship to energy expenditure.

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