FEATURE

CHRISTMAS 2014: GASTROENTEROLOGICAL TRACTS

When somebody loses weight, where does the fat go?

Ruben Meerman *researcher*, Andrew J Brown *professor*

School of Biotechnology and Biomolecular Sciences, University of New South Wales, Sydney, 2052, Australia

Abstract

Ruben Meerman and **Andrew Brown** explain why the answer might not be what you expect

Considering the soaring overweight and obesity rates and strong interest in this topic, there is surprising ignorance and confusion about the metabolic process of weight loss among the general public and health professionals alike. We encountered widespread misconceptions about how humans lose weight among general practitioners, dietitians, and personal trainers (fig 1⇓). Most people believed that fat is converted to energy or heat, which violates the law of conservation of mass. We suspect this misconception is caused by the "energy in/energy out" mantra and the focus on energy production in university biochemistry courses. Other misconceptions were that the metabolites of fat are excreted in the faeces or converted to muscle. We present a novel calculation to show how we "lose weight."

Weight we want to "lose"

Excess carbohydrate or protein in the diet is converted to triglyceride and stored in the lipid droplets of adipocytes. Excess dietary fat needs no conversion other than lipolysis and re-esterification. People who wish to lose weight while maintaining their fat-free mass are, biochemically speaking, attempting to metabolise the triglycerides stored in their adipocytes.

The chemical formula for an average triglyceride molecule can be deduced from fatty acid composition studies. In 1960, Hirsch and colleagues published data that yield an "average fatty acid" with the formula $C_{17.4}H_{33.1}O_2$.[1] This 50 year old result is in remarkable agreement with more recent data.[2] Three "average fatty acids" esterified to the glycerol backbone (+3C, +6H) give an "average triglyceride" with the formula $C_{54.8}H_{104.4}O_6$. The three most common fatty acids stored in human adipose tissues are oleate ($C_{18}H_{34}O_2$), palmitate ($C_{16}H_{32}O_2$), and linoleate ($C_{18}H_{32}O_2$),[1 2] which all esterify to form $C_{55}H_{104}O_6$.

The complete oxidation of a single triglyceride molecule involves many enzymes and biochemical steps, but the entire process can be summarised as:

$$C_{55}H_{104}O_6+78O_2 \rightarrow 55CO_2+52H_2O+\text{energy}$$

Stoichiometry shows that complete oxidation of 10 kg of human fat requires 29 kg of inhaled oxygen producing 28 kg of CO_2 and 11 kg of H_2O. This tells us the metabolic fate of fat but remains silent about the proportions of the mass stored in those 10 kg of fat that depart as carbon dioxide or water during weight loss.

To calculate these values, we traced every atom's pathway out of the body. The carbon and hydrogen atoms obviously depart as CO_2 and H_2O, respectively. The fate of a triglyceride molecule's six oxygen atoms is a conundrum solved in 1949 by Lifson and colleagues.[3] They used labelled heavy oxygen (O^{18}) to show that the oxygen atoms of body water and respiratory carbon dioxide are rapidly exchanged through the formation of carbonic acid (H_2CO_3). A triglyceride's six oxygen atoms will therefore be shared by CO_2 and H_2O in the same 2:1 ratio in which oxygen exists in each substance. In other words, four will be exhaled and two will form water.

Novel calculation

The proportion of a triglyceride molecule's mass exhaled in CO_2 is the proportion of its molecular weight (daltons) contributed by its 55 carbon atoms plus four of its oxygen atoms:

$$(661\ \text{Da}\ (C_{55})+64\ \text{Da}\ (O_4))/(861\ \text{Da}\ (C_{55}H_{104}O_6))\times 100=84\%$$

The proportion of mass that becomes water is:

$$(105\ \text{Da}\ (H_{104})+32\ \text{Da}\ (O_2))/(861\ \text{Da}\ (C_{55}H_{104}O_6))\times 100=16\%$$

These results show that the lungs are the primary excretory organ for weight loss (fig 2⇓). The water formed may be excreted in the urine, faeces, sweat, breath, tears, or other bodily fluids.

Correspondence to: R Meerman rubenmeerman@me.com

Lifting the veil on weight loss

At rest, an average 70 kg person consuming a mixed diet (respiratory quotient 0.8) exhales about 200 ml of CO_2 in 12 breaths per minute.[4] Each of those breaths therefore excretes 33 mg of CO_2, of which 8.9 mg is carbon. In a day spent asleep, at rest, and performing light activities that double the resting metabolic rate, each for 8 hours, this person exhales 0.74 kg of CO_2 so that 203 g of carbon are lost from the body. For comparison, 500 g of sucrose ($C_{12}H_{22}O_{11}$) provides 8400 kJ (2000 kcal) and contains 210 g of carbon. Replacing one hour of rest with exercise that raises the metabolic rate to seven times that of resting by, for example, jogging, removes an additional 39 g of carbon from the body, raising the total by about 20% to 240 g. For comparison, a single 100 g muffin represents about 20% of an average person's total daily energy requirement. Physical activity as a weight loss strategy is, therefore, easily foiled by relatively small quantities of excess food.

Our calculations show that the lungs are the primary excretory organ for fat. Losing weight requires unlocking the carbon stored in fat cells, thus reinforcing that often heard refrain of "eat less, move more." We recommend these concepts be included in secondary school science curriculums and university biochemistry courses to correct widespread misconceptions about weight loss.

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Figures

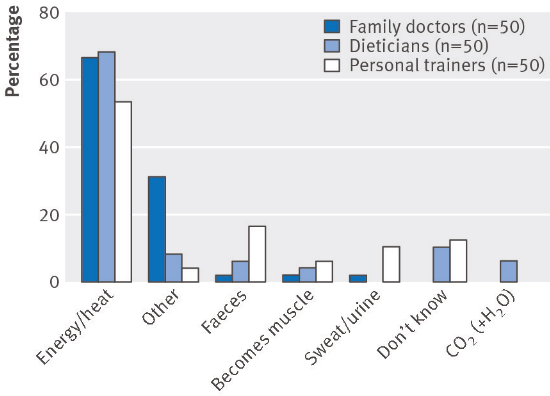

Fig 1 Responses of a sample of doctors, dieticians, and personal trainers to the question "When somebody loses weight, where does it go?" (Correct answer CO_2)

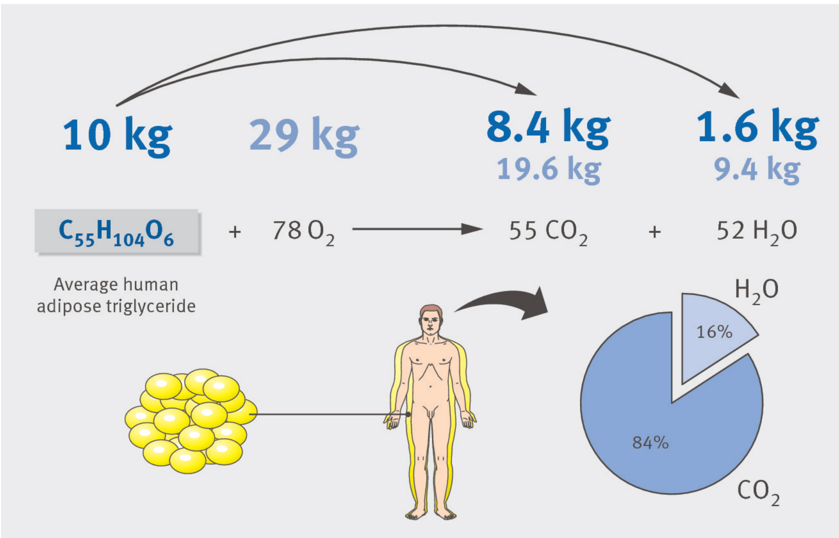

Fig 2 When somebody loses 10 kg of fat (triglyceride), 8.4 kg is exhaled as CO_2. The remainder of the 28 kg total of CO_2 produced is contributed by inhaled oxygen. Lungs are therefore the primary excretory organ for weight loss. (This calculation ignores fat that may be excreted as ketone bodies under particular (patho)physiological conditions or minor amounts of lean body mass, the nitrogen in which may be excreted as urea)