

colonists of a sexually reproducing damselfly (*Ischnura hastata*), for example, that became exclusively parthenogenetic⁹. Parthenogenesis can also bias the sex ratio: in *Varanus* species, females have dissimilar chromosomes (Z and W), whereas the combination ZZ produces males¹⁰, so the parthenogenetic mechanism can produce only homozygous (ZZ or WW) individuals and therefore no females.

Parthenogenesis in wild Komodo dragons could be adaptive, given that viable offspring are always male and that sexual reproduction can resume, albeit between related individuals, in a colony founded by a single unfertilized female. Fewer than 4,000 Komodo dragons remain in the wild, of which perhaps fewer than 1,000 are mature females (T. Jessop, personal communication). Our discovery of the potential for asexual reproduction in this species, and possibly in other reptiles presumed

until now to be exclusively sexual, calls for further investigation into the genetic load experienced by the parthenogens, the frequency with which asexual offspring occur in captive and in wild populations, and the fitness consequences associated with facultative parthenogenesis.

Phillip C. Watts*, **Kevin R. Buley†**,
Stephanie Sanderson‡, **Wayne Boardman‡**,
Claudio Ciofi§, **Richard Gibson‡**

*School of Biological Sciences, University of Liverpool, Liverpool L69 7ZB, UK
e-mail: p.c.watts@liv.ac.uk

†North of England Zoological Society, Chester Zoo, Upton-by-Chester CH2 1LH, UK

‡Zoological Society of London, Regents Park, London NW1 4RY, UK

§Department of Animal Biology and Genetics, University of Florence, 50125 Florence, Italy

1. Ciofi, C. & De Boer, M. *Herpetol. J.* **14**, 99–107 (2004).

2. Ciofi, C. & Bruford, M. W. *Mol. Ecol.* **7**, 134–136 (1998).
3. White, M. J. D. *Animal Cytology and Evolution* (Cambridge University Press, Cambridge, UK, 1973).
4. Avise, J. C., Quattro, J. M. & Vrijenhoek, R. C. in *Evolutionary Biology* (eds Hecht, M. K., Wallace, B. & MacIntyre, R. J.) 225–246 (Plenum, New York, 1992).
5. Groot, T. V. M., Bruins, E. & Breeuwer, J. A. *Hereditas* **90**, 130–135 (2003).
6. Lenk, P., Eidenmueller, B., Staudter, H., Wicker, R. & Wink, M. *Amphibia-Reptilia* **26**, 507–514 (2005).
7. Saccheri, I. J. et al. *Nature* **392**, 491–494 (1998).
8. Spielman, D., Brook, B. W. & Frankham, R. *Proc. Natl Acad. Sci. USA* **101**, 15261–15264 (2004).
9. Sherratt, T. N. & Beatty, C. D. *Nature* **435**, 1039–1040 (2005).
10. Halverson, J. & Spelman, L. H. in *Biology and Conservation of Komodo Dragons* (eds Murphy, J. B., Ciofi, C., de La Panouse, C. & Walsh, T.) 165–177 (Smithsonian Institution, Washington DC, 2002).

Supplementary information accompanies this communication on Nature's website.

Received 4 October; accepted 16 November 2006.

Competing financial interests: declared none.

doi:10.1038/nature4441021a

MICROBIAL ECOLOGY

Human gut microbes associated with obesity

Two groups of beneficial bacteria are dominant in the human gut, the Bacteroidetes and the Firmicutes. Here we show that the relative proportion of Bacteroidetes is decreased in obese people by comparison with lean people, and that this proportion increases with weight loss on two types of low-calorie diet. Our findings indicate that obesity has a microbial component, which might have potential therapeutic implications.

Trillions of microbes live in the human gut, helping to break down otherwise indigestible foods¹. Transplanting the gut microbiota from normal mice into germ-free recipients increases their body fat without any increase in food consumption², raising the possibility that the composition of the microbial community in the gut affects the amount of energy extracted from the diet².

The relative abundance of the two predominant bacterial divisions (deep evolutionary lineages or superkingdoms) in mice differs between lean and obese animals: mice that are genetically obese (*ob/ob*) have 50% fewer Bacteroidetes, and correspondingly more Firmicutes, than their lean (+/+) siblings³. In an accompanying Article⁴, we show that the gut microbiota in these *ob/ob* mice are more effective at releasing calories from food during digestion than are the +/+ microbiota: this trait is transmissible to germ-free recipients, resulting in greater adiposity.

To investigate the relation between gut microbial ecology and body fat in humans, we studied 12 obese people, who were randomly assigned to either a fat-restricted (FAT-R) or to a carbohydrate-restricted (CARB-R) low-

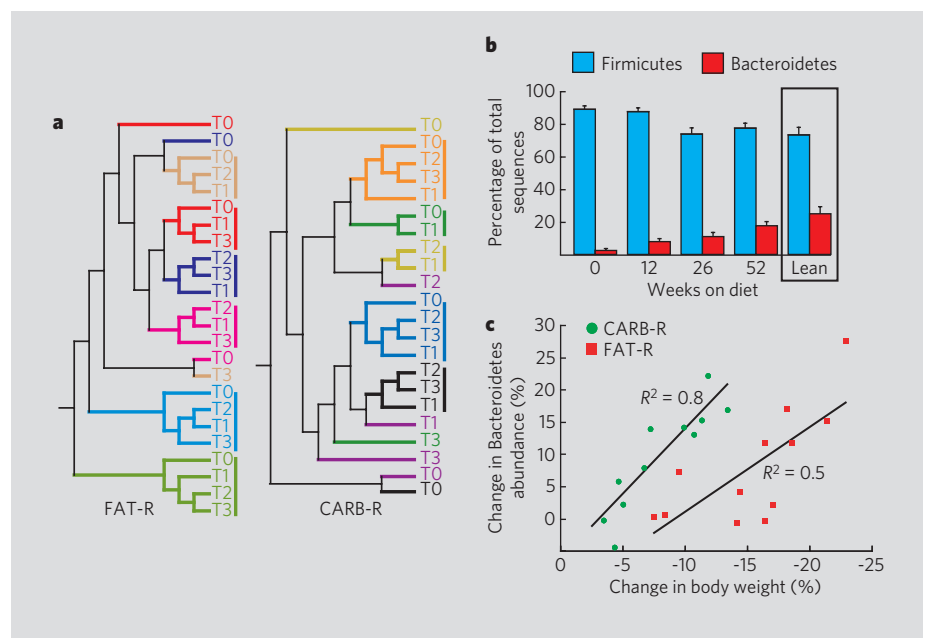


Figure 1 | Correlation between body-weight loss and gut microbial ecology. **a**, Clustering of 16S ribosomal RNA gene sequence libraries of faecal microbiota for each person (in different colours) and time point in diet therapy (T0, baseline; T1, 12 weeks; T2, 26 weeks; T3, 52 weeks) in the two diet-treatment groups (fat restricted, FAT-R; carbohydrate restricted, CARB-R), based on UniFrac analysis of the 18,348-sequence phylogenetic tree. **b**, Relative abundance of Bacteroidetes and Firmicutes. For each time point, values from all available samples were averaged (n was 11 or 12 per time point). Lean-subject controls include four stool samples from two people taken 1 year apart, plus three other stool samples⁶. Mean values \pm s.e. are plotted. **c**, Change in relative abundance of Bacteroidetes in subjects with weight loss above a threshold of 2% weight loss for the CARB-R diet and 6% for the FAT-R diet.

calorie diet. The composition of their gut microbiota was monitored over the course of 1 year by sequencing 16S ribosomal RNA genes from stool samples (for details, see supplementary information).

The resulting data set of 18,348 bacterial 16S rRNA sequences revealed that most (70%) of the 4,074 identified species-level phylogenetic types (phylotypes) were unique to each person (see supplementary information). Despite the

marked interpersonal differences in species-level diversity, members of the Bacteroidetes and Firmicutes divisions dominated the microbiota (92.6% of all 16S rRNA sequences).

Bacterial lineages were remarkably constant within people over time: communities from the same person were generally more similar to one another than to those from other people (Fig. 1a). Before diet therapy, obese people had fewer Bacteroidetes ($P < 0.001$) and more Firmicutes ($P = 0.002$) than did lean controls (Fig. 1b). Over time, the relative abundance of Bacteroidetes increased ($P < 0.001$) and the abundance of Firmicutes decreased ($P = 0.002$), irrespective of diet type (Fig. 1b).

This change was division-wide and not due to blooms or extinctions of specific bacterial species: bacterial diversity remained constant over time. Increased abundance of Bacteroidetes correlated with percentage loss of body weight (R^2 was 0.8 for the CARB-R diet and 0.5 for the FAT-R diet, $P < 0.05$; Fig. 1c), and not with changes in dietary calorie content

over time (R^2 was 0.06 for the CARB-R diet and 0.09 for the FAT-R diet). This correlation held only after the person had lost at least 6% of their body weight on the FAT-R diet and at least 2% on the CARB-R diet.

Obesity is, to our knowledge, the only condition in which a pronounced, division-wide change in microbial ecology is associated with host pathology. The factors that drive shifts in representation at such broad taxonomic levels must operate on highly conserved bacterial traits as they are shared by a great variety of phylotypes within the divisions. The gut habitat itself selects for specific ratios of divisions: microbiota transplanted to germ-free recipients of a different species reconfigure to match the community structure usually present in the recipient⁵. The coexistence of Bacteroidetes and Firmicutes in the gut implies minimized competition for resources through cooperation or specialization: the obese gut has as-yet uncharacterized properties that tip the balance towards the Firmicutes.

The dynamic linkage between adiposity and gut microbial ecology described here, together with our results from mice⁴, indicates that manipulation of gut microbial communities could be another approach in the treatment of obesity.

Ruth E. Ley, Peter J. Turnbaugh, Samuel Klein, Jeffrey I. Gordon

Washington University School of Medicine, St Louis, Missouri 63108, USA

e-mail: jgordon@wustl.edu

1. Gill, S. R. *et al. Science* **312**, 1355–1359 (2006).
2. Backhed, F. *et al. Proc. Natl Acad. Sci. USA* **101**, 15718–15723 (2004).
3. Ley, R. E. *et al. Proc. Natl Acad. Sci. USA* **102**, 11070–11075 (2005).
4. Turnbaugh, P. J. *et al. Nature* **444**, 1027–1031 (2006).
5. Rawls, J. F., Mahowald, M. A., Ley, R. E. & Gordon, J. I. *Cell* **127**, 423–433 (2006).
6. Eckburg, P. B. *et al. Science* **308**, 1635–1638 (2005).

Supplementary information accompanies this communication on Nature's website.

Received 8 October; accepted 10 November 2006.

Competing financial interests: declared none.

doi:10.1038/nature4441022a

BIOMECHANICS

Rubber bands reduce the cost of carrying loads

Vertical movement of the hip during locomotion causes a loaded backpack to be accelerated with each step¹, which imposes large peak forces on the wearer. Here we show that using bungee cords to suspend the load from a backpack frame reduces not only its vertical movement, and hence its vertical force on the carrier, but also the energetic cost of walking with the pack. This permits larger loads to be carried while moving rapidly, and at the same time reduces the risk of orthopaedic and muscular injury.

Backpacks have an inherent limitation: because the hips move up and down by 5–7 cm during walking², the mass of a backpack — which is usually attached tightly to the body — must undergo a similar vertical displacement^{1,3}. As a result, the peak vertical forces acting on the body increase by up to twice those imposed by the static weight, owing to the acceleration of the added mass.

If the load were to stay positioned at the same height during walking and running, it would not exert any accelerative force on each step — a strategy that has been exploited by Asian merchants running with springy bamboo poles¹. We designed a backpack in which the load is suspended from an external frame by a compliant coupling and is therefore largely uncoupled from the body's movements. A locking mechanism enables the coupling between the load and the body to be altered from 'suspended' to 'locked' (Fig. 1).

While walking at 5.6 km h⁻¹, the vertical oscillation of a 27-kg load is reduced from

68.5 mm in the locked backpack (Fig. 2a) to 26.5 mm in the suspended backpack ($P < 0.001$, paired t -test, $n = 6$; see table in supplementary information). The oscillation is reduced mainly because the amount of movement of the load relative to the frame is similar in magnitude and nearly 180° out of phase with the frame's displacement relative to the ground. The reduction causes an 82% decrease in peak accelerative vertical force (Fig. 2b), which declines from 185 to 30.5 N in the locked versus the suspended backpack ($P < 0.001$, paired t -test, $n = 6$; see table in supplementary information). The total peak vertical force drops by 33%.

The metabolic cost of walking with the load falls from 640 W for the locked backpack to 600 W ($P = 0.027$, paired t -test, $n = 6$; see table in supplementary information) for the suspended backpack, because the force exerted by the load is reduced during the energetically expensive 'double-support' phase of walking (when both feet are on the ground)^{4,5}. Although the average force (that is, weight or static force) from the load is the same for the locked and suspended backpack, the locked backpack concentrates the forces in the double-support phase (Fig. 2b), probably resulting in greater ground-reaction force and loss of mechanical energy. The consequent reduction in force during the energy-conserving inverted-pendulum phase (when only one foot is on the ground) yields little energetic benefit.

Although the reduction in metabolism is modest (6.2%) in terms of the total metabolic

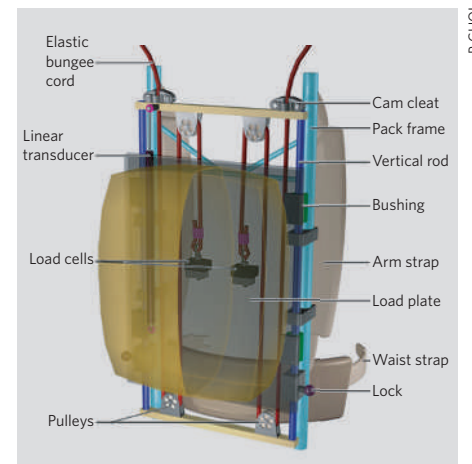


Figure 1 | Suspended-load ergonomic backpack. The pack frame is fixed to the body but the load, mounted on the load plate, is suspended by elastic bungee cord(s) from the frame (shown in light blue and gold). The tension in the elastic cord is set by cam cleats on the top of the frame. When the backpack's locking mechanism is disengaged, the suspended load is free to ride up and down on bushings constrained to vertical rods during walking or running; locking prevents movement and the backpack behaves like a normal rigid backpack. For movies, see supplementary information.

rate, it represents 23% of the extra metabolic power (176 W) that is required to walk with a 27-kg load rather than with an empty backpack. Walking with 27 kg in the suspended