News of chews: the optimization of mastication

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In chewing food, we break it into small fragments that are mixed with saliva to form a soft ball, or 'bolus'. A new study reveals that the number of chews is optimized for particular foods — too few, and the bolus doesn't stick together; too many, and it begins to fall apart.

Chewing breaks food down into small fragments, increasing the surface area that is exposed to digestive enzymes. A current view is that we should continue to chew each mouthful until the fragments are small enough (however small that may be), and until they are well mixed with the saliva that will lubricate their passage down the gullet[1]. But in *Proceedings of the Royal Society*, Prinz and Lucas[2] emphasize another function of chewing. They conclude that we should continue to chew until the food fragments bind together as a coherent bolus that can be swallowed safely, without the danger of stray particles entering the windpipe — but we should not chew for too long because, if we do, excess saliva will weaken the cohesive forces and allow the bolus to fall apart.

Prinz and Lucas predict an optimum number of chews for any particular food. To find this optimum, we have to understand both how the teeth break the food up, and how the saliva makes the fragments stick together. A piece of food in the mouth may or may not be broken into smaller fragments during a particular chewing cycle. The probability depends on its size — smaller fragments are less likely to be broken. If the piece of food does break, it may cleave into two pieces or shatter into many tiny fragments, depending on its toughness (the energy needed to produce unit surface area of crack) and Young's modulus (a measure of stiffness). The same group has already predicted[3] that fragmentation depends on the ratio of toughness to Young's modulus, and they confirmed this by experiments with foods ranging from soft cheese to Brazil nuts. Stiff foods of low toughness, such as nuts, are most likely to break into many fragments.

The food is formed into a bolus by tongue movements, which have been shown by X-ray cinematography of people with disks of lead foil glued to their tongues[4]. The cohesion of the bolus is expected to depend on viscous forces — the forces that make it so difficult to separate two sheets of wet glass. The thinner the layer of liquid between the solid particles, the more strongly they will cohere. Large particles cannot, in general, be packed close together (Fig. 1a), but smaller particles pack more tightly. It is not necessary for all of the particles to be small, because small particles can fill the spaces between large ones (Fig. 1b). Thus, the bolus is expected to cohere more firmly as chewing proceeds. But later in the chewing process there is too much saliva in the bolus to allow the particles to pack as tightly as they otherwise could, and cohesion falls.

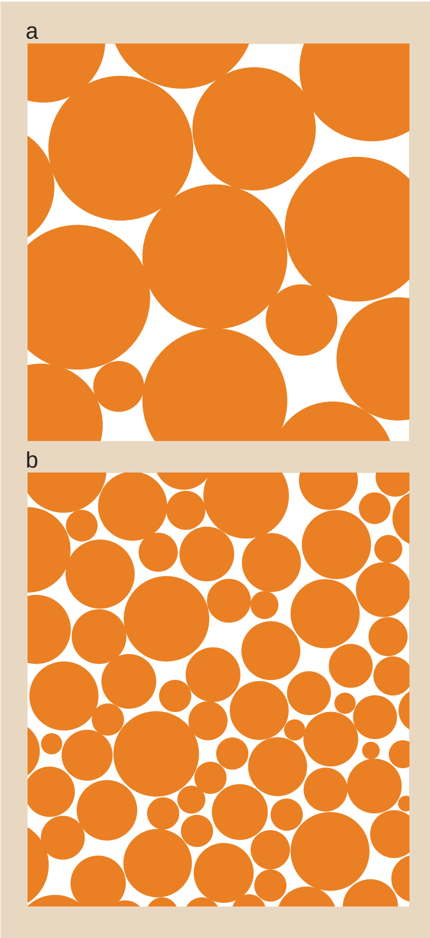

Figure 1 **Packing of raw carrot fragments at** (a) **an early, and** (b) **a later, stage in a computer simulation of chewing. Prinz and Lucas[2] studied the distribution of particle sizes after each chew, and they predicted that cohesion of the food fragments would peak after 20–25 chews. In fact, people tested chose to swallow raw carrot after a mean of 31 chews — in reasonable agreement with the predictions. (Adapted from ref. 2.)**

Prinz and Lucas[2] applied their theory to raw carrot and Brazil nuts. The fragmentation properties of both foods had been measured by previous experiments in which subjects spat the fragments out for analysis after different numbers of chews. The viscosity of saliva was measured, and a typical rate of secretion was assumed. A computer program predicted the distribution of particle sizes after each chew, then generated diagrams like those shown in Fig. 1 to estimate how closely the particles would pack. Although carrots and nuts have very different properties, the program predicted that cohesion would peak after 20–25 chews in each case. Subjects chose to swallow raw carrot after a mean of 31 chews, and Brazil nuts after 25, in reasonable agreement with the theory. When I was a child, my mother used to tell me to chew everything 30 times.

A different optimization criterion has been formulated for herbivorous mammals, whose food intake is limited by the time available for eating[5]. The longer they chew, the more finely the food is ground and the faster it can be digested or fermented in the gut — but prolonged chewing leaves less time for eating. Unlike the work of Prinz and Lucas, this theory takes into account the rates of digestion and fermentation in the gut. It treats the gut as a chain of chemical reactors, and it predicts that optimal chewing times will be longer for foods that can be eaten quickly, that break down only slowly when chewed, and that contain a lot of cellulose. We should not be surprised that cattle chew for about eight hours each day.

For humans, however, food intake is not seriously limited by the time available for eating, and the new model[2] seems the more relevant. We used to think that we should chew until our food was thoroughly broken up. Now we know that we should chew until it sticks together again. □

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