



Short Communication

The mathematical relationship between dishware size and portion size[☆]Iain Stephen Pratt^{a,b,*}, Emma Jane Croager^a, Michael Rosenberg^c^a Education and Research Division, Cancer Council Western Australia, 15 Bedbrook Place, Shenton Park, WA 6008, Australia^b Centre for Behavioural Research in Cancer Control, Curtin University of Technology, GPO Box U1987, Perth, WA 6845, Australia^c School of Sport Science, Exercise and Health, The University of Western Australia, 35 Stirling Highway, Crawley, WA 6009, Australia

ARTICLE INFO

Article history:

Received 15 March 2011
 Received in revised form 12 October 2011
 Accepted 19 October 2011
 Available online 25 October 2011

Keywords:

Portion size
 Energy density
 Over-consumption
 Food intake
 Overweight
 Obesity

ABSTRACT

Portion size has increased considerably over the past few decades and one influencing factor is dishware size. Using mathematical models we investigated how dish size affects the potential energy available in a meal. Two types of plate filling – flat and conical – were modelled for a range of plate sizes and energy densities, then compared to recommended daily energy requirements from Australian guidelines. Bowl filling was also modelled. Results indicate that a small increase in dishware size can lead to a substantial increase in energy available to be consumed, particularly if food is energy dense. This reinforces the need to consider dishware size when developing strategies to prevent over-consumption.

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Introduction

Over time, modest changes in energy intake – without a complementary increase in energy expenditure – across the population can lead to an increase in the prevalence of overweight and obesity. Swinburn et al. calculated that an increase in total energy intake of ~5.5% every decade since the 1970s was sufficient to drive the increase in body weight that has resulted in the current obesity crisis in the United States (Swinburn et al., 2009).

Overweight and obesity are established risk factors for chronic diseases including cardiovascular disease, type 2 diabetes and some cancers. In Australia in 2007–2008, 61.4% of Australian adults were overweight or obese, representing an increase of 4.9 percentage points compared with 15 years ago (Australian Bureau of Statistics, 2009). The prevalence of overweight and obesity also increased throughout the life-course, peaking at more than 75% of people aged 65–74 years.

In 2003, the World Health Organization proposed an association between increased portion size and overweight and obesity (World Health Organization, 2003). Portion size has increased considerably over the past few decades, to the point where consumers are no longer able to determine what an appropriate amount to

eat at one serving is – a phenomenon described as ‘portion distortion’ by nutrition experts (Young & Nestle, 2003). Not surprisingly, the increased prevalence of obesity has coincided with the increasing portion sizes of meals eaten both in and out of the home (Matthiessen, Fagt, Biloft-Jensen, Beck, & Ovesen, 2003; Nielsen & Popkin, 2003; Smiciklas-Wright, Mitchell, Mickle, Goldman, & Cook, 2003; Young & Nestle, 2002, 2007).

One factor reported to influence portion size is the size of the dishware used to serve food (Steenhuis & Vermeer, 2009). Wansink and van Ittersum reported that larger dishware is a driver of larger portion size (Wansink & van Ittersum, 2007). Specifically, larger dishware increases appropriate perceived portion size and reduces the ability to monitor food intake, which ultimately increases the amount of food eaten during a single eating occasion. It is popularly reported that since the 1960s average plate size used in both domestic and commercial settings has increased from approximately 10 in. (25.4 cm) in diameter to approximately 12 in. (30.5 cm) in diameter (Klara, 2004). People serve themselves more food if using a larger bowl (Wansink & Cheney, 2005; Wansink, van Ittersum, & Painter, 2006), and although this finding was not replicated in the one reported study investigating plate size (Rolls, Roe, Halverson, & Meengs, 2007), it is clear that the size of dishware may have an impact on over-consumption, particularly as people use the vertical (but not horizontal) dimension to estimate portion size (van Ittersum & Wansink, 2007).

With no previously identified published information, we undertook a mathematical exercise to investigate empirically how the size of the dish relates to the potential energy available in a meal.

[☆] Acknowledgements: I.S.P. and E.J.C. are employed by Cancer Council Western Australia. M.R. is employed by The University of Western Australia.

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Methods

Dishware modelling

A range of plate sizes were selected, ranging from 6 in. (12.7 cm) to 12 in. (35.6 cm) in diameter. Plates had a 1.5 cm ($\frac{5}{8}$ in.) rim, resulting in a 1 $\frac{1}{4}$ in. (3 cm) reduction in diameter. Surface area (πr^2) was then calculated.

Two types of plate filling were modelled: flat and conical. Firstly, plates were filled flat to a consistent depth of $\sim\frac{3}{4}$ in. (2 cm), and food volume was calculated (surface area [πr^2] \times depth [h] = $\pi r^2 \times h$). Secondly, plates were filled conically, with the height of the cone being half of the plate radius, and food volume was calculated ($\frac{1}{3} \times$ surface area [πr^2] \times depth [h] = $\frac{1}{3} \pi r^2 \times h$). Bowl volume was also calculated for comparison. For ease of calculation, bowls were assumed to be hemispheres ($\frac{2}{3} \pi r^3$), 85% filled (fill [0.85] \times volume [$\frac{2}{3} \pi r^3$] = $0.85 \times \frac{2}{3} \pi r^3$).

Energy density

Total energy density varies considerably between meals, depending on the foods selected. Three energy densities were used, based on population measurements: low (525 kJ/100 g), average (670 kJ/100 g), and high (1100 kJ/100 g) (Poppitt & Prentice, 1996; Prentice & Jebb, 2003). Similarly, food packing density varies dependent on the composition (liquid content, coarseness of the components) of the meal. A conservative packing density estimate of 0.4 g of food per cm^3 was adopted.

Energy requirements

Daily energy requirements were set at 10,000 kJ/day for males and 8000 kJ/day for females, the lower estimates for adults aged 19–50 (National Health and Medical Research Council (Australia), 2006).

Energy content

Finally, total energy content was calculated (portion size [volume] \times packing density [0.4 g/cm^3] \times energy density [525 kJ/100 g, 670 kJ/100 g, 1100 kJ/100 g]).

Results

Total plate capacity (portion size) by dishware diameter was plotted to compare the two stacking methods: flat and conical (Fig. 1). As seen in Fig. 1, the relationship between plate diameter and portion is not linear. That is, portion size changes exponentially with any change in diameter. Flat stacking results in a larger portion for plates smaller than 8 $\frac{1}{2}$ in. For larger plates, conical stacking results in larger portions.

Energy content by dishware diameter was plotted for three energy densities: low, average and high, by energy density (Figs. 2–4) and by filling method (Figs. 5 and 6). These figures show that, like plate capacity, energy available for consumption also increases exponentially with dishware size. The mathematical relationship differs by dishware, being strongest for bowls, then conically-filled plates and finally flat-filled plates. The effect of larger dishware is magnified when foods higher in energy density are selected as the energy available for consumption is markedly increased.

Energy requirement for males and females is included in each figure. At the highest energy density, a 10 in. plate holds more than one third of an adult's daily energy requirement whether it is filled flat (33.6%, male; 42.0%, female) or conically (35.0%, male; 43.8%,

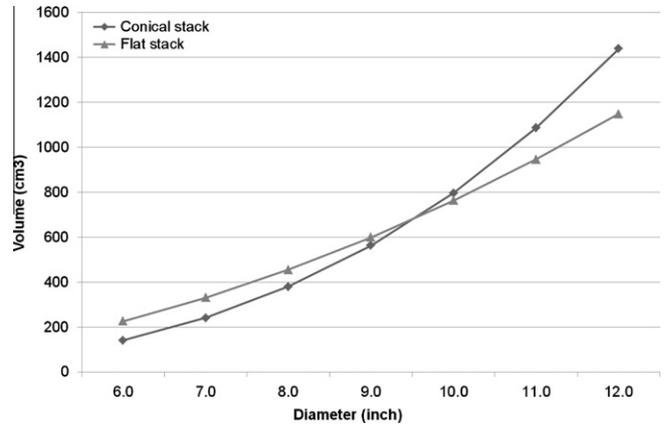


Fig. 1. Comparison of food volumes for flat and conical filled plates. Flat plate stacking food volume was calculated using the formula: $\pi r^2 \times h$, where πr^2 = plate surface area and h = food depth, set at $\sim\frac{3}{4}$ in. (2 cm). Conical plate stacking food volume was calculated using the formula: $\frac{1}{3} \pi r^2 \times h$, where πr^2 = plate surface area and h = food depth, with cone height set at half of the plate radius.

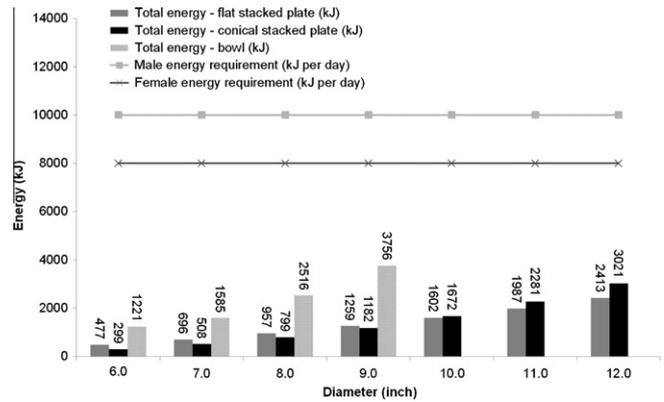


Fig. 2. Comparison of plate and bowl energy content for a low energy-dense meal. Energy density was based on population measurements and food packing density was set at 0.4 g of food per cm^3 . Daily energy requirements were set at 10,000 kJ/day for males and 8000 kJ/day for females, the lower estimates for adults aged 19–50 years.

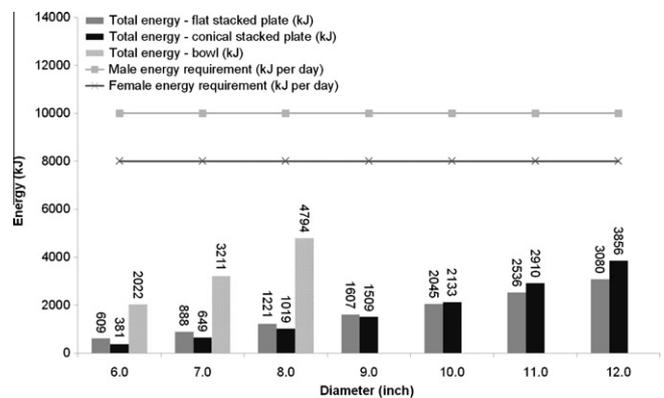


Fig. 3. Comparison of plate and bowl energy content for an average energy-dense meal. Energy density was based on population measurements and food packing density was set at 0.4 g food per cm^3 . Daily energy requirements were set at 10,000 kJ/day for males and 8000 kJ/day for females, the lower estimates for adults aged 19–50 years.

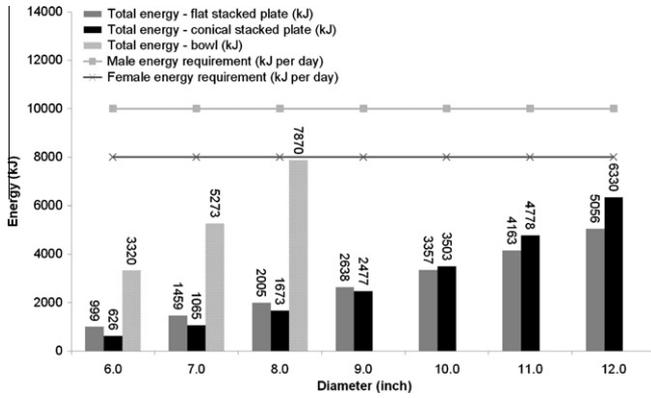


Fig. 4. Comparison of plate and bowl energy content for a high energy-dense meal. Energy density was based on population measurements and food packing density was set at 0.4 g of food per cm³. Daily energy requirements were set at 10,000 kJ/day for males and 8000 kJ/day for females, the lower estimates for adults aged 19–50 years.

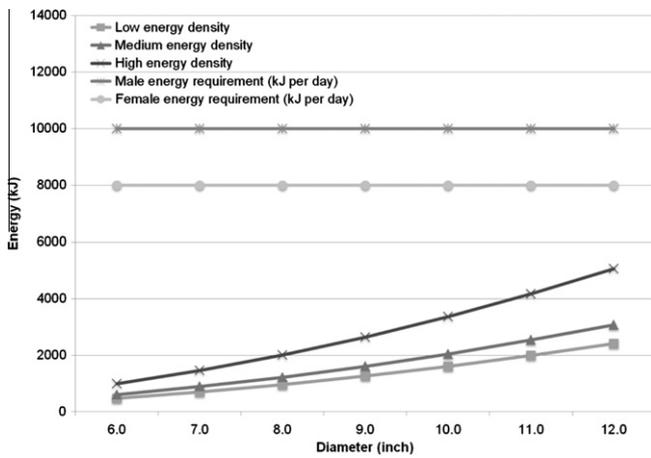


Fig. 5. Comparison of energy content of a low, medium and high energy-dense meal served on a plate using the flat filling method. Energy density was based on population measurements and food packing density was set at 0.4 g of food per cm³. Daily energy requirements were set at 10,000 kJ/day for males and 8000 kJ/day for females, the lower estimates for adults aged 19–50 years.

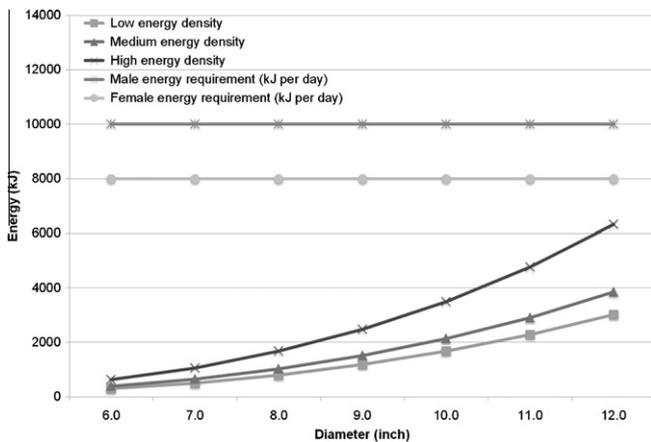


Fig. 6. Comparison of energy content of a low, medium and high energy-dense meal served on a plate using the conical filling method. Energy density was based on population measurements and food packing density was set at 0.4 g of food per cm³. Daily energy requirements were set at 10,000 kJ/day for males and 8000 kJ/day for females, the lower estimates for adults aged 19–50 years.

female). A 7 in. bowl holds around two-thirds an adult female’s daily energy requirement (66.0%) and more than half of an adult male’s (52.7%).

An increase from an 8 in. plate to a 10 in. plate results in a 67% increase in energy available to be consumed for a flat-filled plate across all energy densities (Table 1). The same increase in plate size for a conically-filled plate results in a 109% increase (more than double) in available energy across all energy densities (Table 2). For bowls, an increase of an inch, from 6 to 7 in., results in a 59% increase in energy available for consumption (Table 3).

Discussion

If, as reported, standard dishware has increased in size over the last few decades, there is a clear mathematical relationship with a corresponding increase in potential portion size, and consequently energy available for consumption. The increases in available energy for all types of dishware are much greater than those reported to result in weight gain, both for individuals and for the population (Swinburn et al., 2009).

This theoretical analysis of the relationship between dishware size and available energy demonstrates the consequence of even a small increase in the size of a plate or bowl. While the results support and underpin the association between portion size and energy intake (Steenhuis & Vermeer, 2009), they do not account for satiety, which may be achieved independently of plate size and result in people with smaller plates re-filling for a second helping. If smaller plate sizes are associated with second helpings, it is plausible that smaller plate sizes would result in greater energy intake per meal, as compared to larger plates that are only filled once. The results suggest that when larger plate sizes are used it is even more important to serve low energy-dense foods, or at least a mixture of low and high energy-dense foods to limit overall energy available.

Total energy available in any meal is influenced by a combination of choice of dishware (plate or bowl), dishware size, food

Table 1

Difference in available energy between a 8 and 10 in. flat-stacked plate for low, average and high energy densities.

Energy density	8 in. plate (kJ)	10 in. plate (kJ)	Difference (kJ)	Percentage difference (%)
Low	957	1602	645	67.4
Average	1221	2045	824	67.5
High	2005	3357	1352	67.4

Table 2

Difference in available energy between a 8 and 10 in. conical-stacked plate for low, average and high energy densities.

Energy density	8 in. plate (kJ)	10 in. plate (kJ)	Difference (kJ)	Percentage difference (%)
Low	799	1672	873	109.3
Average	1019	2133	1114	109.3
High	1673	3503	1830	109.4

Table 3

Difference in available energy between a 6 and 8 in. bowl for low, average and high energy densities.

Energy density	6 in. bowl (kJ)	7 in. bowl (kJ)	Difference (kJ)	Percentage difference (%)
Low	1585	2516	931	58.7
Average	2022	3211	1189	58.8
High	3320	5273	1953	58.8

energy density and how the dishware is filled. Increased dishware size, or multiple servings can be mitigated in part by reducing the energy density of foods that are offered or served. Conversely, smaller dishware minimises the effect of filling technique (flat or conical) on portion size.

This study has several limitations, most of which relate to the stated assumptions. Plate and bowl filling, both in terms of shape and density will differ – often considerably – between individuals and foods. Energy density will inevitably vary from meal to meal, and individuals have unique energy requirements. To mitigate against these variations, conservative assumptions were adopted and a number of conditions modelled.

Despite these limitations, the mathematical relationship is robust – a small increase in the size of dishware potentially results in a substantial increase in energy available to consume. The difference, in absolute terms, is exacerbated for bowls or if the food is high in energy density. The difference in practical terms is more complex and related to individual differences, available foods and possibly time required to reach satiety, which is a complex physiological and psychological interplay between food quantity, energy density, food quality, eating time and environmental stimuli. These results reinforce the need not only to offer low energy-dense foods – like vegetables – as part of every meal, but to serve high energy-dense foods on the smallest plates possible and avoid using bowls. Low energy-dense foods served on small dishware, irrespective of filling technique (flat, conical or other), minimises the energy available for consumption at a meal provided only one helping is eaten.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

I.S.P. conceptualised the study. E.J.C. and I.S.P. analysed and interpreted the data. M.R. critically reviewed the study. All authors contributed to drafting of the manuscript, and approved the final version.

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