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Interfacial & colloidal aspects of lipid digestion

P.J. Wilde *, B.S. Chu

Food Structure & Health, Institute of Food Research, Norwich, NR4 7UA, UK

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ABSTRACT

Amongst the main issues challenging the food manufacturing sector, health and nutrition are becoming increasingly important. Global concerns such as obesity, the ageing population and food security will have to be addressed. Food security is not just about assuring food supply, but is also about optimising nutritional delivery from the food that is available [1]. Therefore one challenge is to optimise the health benefits from the lipids and lipid soluble nutrients.

Colloid scientists have an affinity for lipids because they are water insoluble, however this presents a challenge to the digestive system, which has to convert them to structures that are less insoluble so they are available for uptake. Despite this, the human digestive system is remarkably effective at digesting and absorbing most lipids. This is primarily driven through maximising energy intake, as lipids possess the highest calorific value, which was a survival trait to survive times of famine, but is now an underlying cause of obesity in developed countries with high food availability.

The critical region here is the lipid-water interface, where the key reactions take place to solubilise lipids and lipid soluble nutrients. Digestive lipases have to adsorb to the oil water interface in order to hydrolyse triacylglycerols into fatty acids and mono glycerides, which accumulate at the interface [2], and inhibit lipase activity. Pancreatic lipase, which is responsible for the majority of lipid hydrolysis, also requires the action of bile salts and colipase to function effectively. Bile salts both aid the adsorption of co-lipase and lipase, and help solubilise the lipolysis products which have accumulated at the interface, into mixed micelles composing bile salts and a range of other lipids, to facilitate transport to the gut mucosal surface prior to uptake and absorption.

The process can be affected by the lipid type, as shorter chain, fatty acids are more easily absorbed, whereas the uptake of longer chain fatty acids, particularly the very long chain n-3 fatty acids from fish oils are dependent on source and so may depend on food microstructure for optimal uptake [3]. The uptake of some poorly water soluble nutrients are enhanced by the presence of lipids, but the mechanisms are not clear. In addition, controlling the digestion of lipids can be beneficial as slower release of lipids into the bloodstream can reduce risk of cardiovascular disease, and can promote gut feedback processes that reduce appetite.

This presents an opportunity to colloid and interfacial science, as there are many unanswered questions regarding the specific physicochemical mechanisms underlying the process of lipid digestion and uptake. I will review our current knowledge of lipid digestion and present examples of how fundamental research in colloidal and interface science is beginning to address these issues. These include the adsorption behaviour of physiological surfactants such as bile salts; interfacial processes by which different polar lipids can influence lipolysis; and the effect of emulsion based delivery systems on cellular uptake of lipid soluble nutrients.

A fundamental understanding of these processes is required if we are to develop intelligent design strategies for foods that will deliver optimal nutrition and improved health benefits in order to address the global challenges facing the food sector in the future.

Contents

* Corresponding author. Tel.: +44 1603 255258; fax: +44 1603 507723.
E-mail address: peter.wilde@bbsrc.ac.uk (P.J. Wilde).

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1. Introduction

From a colloidal perspective, the human body relies largely on its aqueous phase for transporting vital nutrients around the circulatory system. Lipids are essential nutrients, contributing to energy intake, cellular organisation (membranes and organelles), and essential metabolic pathways. However, lipids are insoluble in the aqueous continuous phase, so have to form a variety of colloidal structures in order to be organised, processed, digested and utilised. Therefore there is a huge scope for colloid science to address key biological questions concerning how the human body handles lipids and lipid structures.

The main subject of this article is lipid digestion, so we will focus on the main colloidal processes involved. The interface is critical, as the aim of the process is to hydrolyse lipid soluble triglyceride lipids into amphiphilic products such as fatty acids and monoglycerides, which can then be transported away from the oil phase into aqueous phase micelles ready for uptake by the epithelial cells. Most dietary fats are consumed in the form of triglycerides (TG) and are emulsified into droplets. In order for the lipase to access TG, the enzyme has to adsorb onto the surface of the fat droplets to hydrolyse TG (lipolysis) as shown in Fig. 1. Dietary fats consumed, if not in emulsified form already (e.g. milk etc.) the body can emulsify them into oil or fat droplets in the mouth, stomach or intestine to increase the surface area available for lipolysis.

Lipid digestion is important because lipids are essential nutrients, and they have a range of positive and negative health implications. Therefore it is important to understand the fundamental mechanisms involved in lipid digestion in order to be able to develop strategies that may have beneficial effects on health. The main impacts on health are Energy intake (Obesity) and bioavailability of lipid soluble nutrients.

Obesity levels are increasing worldwide which is mainly due to the increased rate of weight gain throughout life [4] that has grown steadily over the past 50 years as lifestyle patterns and eating habits have changed. The increase in obesity rates with age are thought to be due largely to small to moderate excess energy intakes, leading to a steady increase in Body Mass Index (BMI) over the lifecourse. A sustained, small decrease in our average energy intake could therefore prevent or reduce this long term weight gain in a large proportion of the population, and thus reduce the incidence of obesity and associated health problems. An obvious solution is to inhibit lipid digestion and uptake, and this is an approach used in certain drug therapies, and previous novel foods such as olestra. However, the human body has evolved highly efficient methods for extracting lipids from food to meet its metabolic requirements (energy, membrane lipids etc.). As a result, undigested lipid in the colon can cause physiological problems such as steatorrhea (fatty diarrhoea). Hence, approaches designed to inhibit lipid digestion will often cause these types of side effects, and so their use is often restricted. One aspect of lipid digestion is the physiological control mechanisms used to regulate digestion and uptake. Most nutrients are absorbed in the duodenum, the first part of the small intestine. However, at times of excessive consumption, or malabsorption, undigested nutrients may be able to travel further along towards the distal end of the small intestine (ileum). These nutrients are sensed by cells lining the gut wall, and in response, secrete hormones and peptides which slow

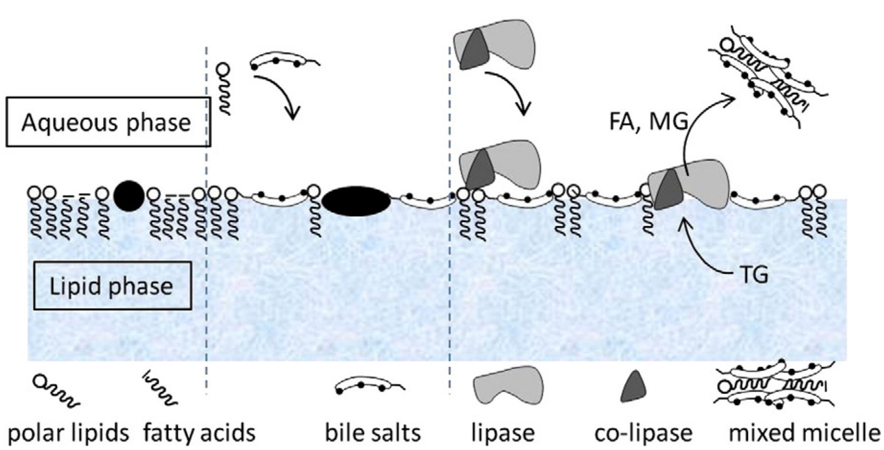

Fig. 1. Mechanism of duodenal lipolysis. Left: lipid phase is coated by surface active material surviving stomach such as polar lipids, fatty acids, emulsifiers etc. Centre: bile salts and phospholipids secreted into the duodenum adsorb onto lipid surface. Right: pancreatic lipase and colipase adsorb, aided by the interaction with bile salts and hydrolyse triglycerides, which are "solubilised" by bile salts into mixed micelles.