Dynamic colloidal transformations of human milk during infant in vitro digestion

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Human milk (HM) is a dynamic, naturally optimized colloidal system, in which the structural organization of lipids, proteins, and carbohydrates ensures efficient nutrient delivery to the infant. Over recent years, our research group has extensively investigated how variations in HM composition and microstructure influence its colloidal transformations during in vitro infant gastric digestion. These transformations determine the bioaccessibility and subsequent intestinal hydrolysis of nutrients. The studied variations reflected the impact of gestation length and lactation stage in colostrum and mature HM, and highlighted differences relative to cow's milk and selected commercial formulas.

A custom-made miniaturised semi-dynamic in vitro digestion model was developed and applied to mimic the physicochemical and enzymatic environment of the infant stomach. Such experiments remain a methodological challenge, given the complexity of the digestion processes and the limited availability of certain HM samples, particularly colostrum. The colloidal behaviour of HM emulsion systems during digestion was monitored by laser light scattering and laser diffraction combined with qualitative methods, enabling real-time observation of phase transitions, aggregation phenomena, and structural rearrangements within the complex digestion mixture. Gastric emptying was simulated through sequential sampling of digesta.

The digestion kinetics of HM were strongly governed by its evolving colloidal microstructure over a course of gastric hydrolysis. Under physiologically relevant acidification, the protein–lipid matrix underwent extensive rearrangements, dominated by fat droplet flocculation and coalescence, protein aggregation and gelation, and progressive enzymatic breakdown. These transitions led to pronounced phase separation, with creaming of lipid-rich fractions and sedimentation of protein aggregates. Such dynamic restructuring influenced the partitioning and release rates of macronutrients from the stomach, shaping their subsequent small intestinal hydrolysis.

Our findings reveal that the digestive fate of HM is fundamentally linked to its colloidal transformations under gastric conditions. Understanding these processes is crucial for designing infant formulas (IFs) that reliably reproduce the multiscale colloidal structure and digestive behaviour of HM. In this context, IFs should not be viewed merely as concentration-adjusted mixtures of selected HM components, e.g. macronutrients. Since they only constitute a subset of milk constituents, particular attention must also be paid to ensuring that the colloidal organization and interfacial dynamics in IF formulations closely resemble those of HM to achieve comparable structural and functional performance during digestion.

Keywords:
human milk, colloidal transformations, microstructure dynamics, in vitro digestion, infant model

References:

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