ELSEVIER

Mechanisms of Development 124 (2007) 253–278

MOD

www.elsevier.com/locate/modo

Review

Evolution of the mechanisms and molecular control of endoderm formation

Anne Grapin-Botton *, Daniel Constam

ISREC and Ecole Polytechnique Fédérale de Lausanne, Chemin des Boveresses 155, Case Postale, CH-1066 Epalinges s/Lausanne, Switzerland

Received 14 September 2006; received in revised form 24 December 2006; accepted 3 January 2007
Available online 11 January 2007

Abstract

Endoderm differentiation and movements are of fundamental importance not only for subsequent morphogenesis of the digestive tract but also to enable normal patterning and differentiation of mesoderm- and ectoderm-derived organs. This review defines the tissues that have been called endoderm in different species, their cellular origin and their movements. We take a comparative approach to ask how signaling pathways leading to embryonic and extraembryonic endoderm differentiation have emerged in different organisms, how they became integrated and point to specific gaps in our knowledge that would be worth filling. Lastly, we address whether the gastrulation movements that lead to endoderm internalization are coupled with its differentiation.

Keywords: Gastrulation; Movement; Nodal; Gata; β-Catenin; Wnt; Endoblast

Contents

* Corresponding author. Tel.: +41 21 692 5819/5820; fax: +41 21 652 6933.
E-mail addresses: anne.grapin@isrec.ch (A. Grapin-Botton), daniel.constam@isrec.ch (D. Constam).

0925-4773/$ - see front matter
doi:10.1016/j.mod.2007.01.001

1. Introduction

Endoderm differentiation and movements are of fundamental importance not only for subsequent morphogenesis of the digestive tract and other internal organs involved in nutrient, gas and waste exchange but also to enable normal patterning and differentiation of mesoderm- and ectoderm-derived organs. The molecular signaling pathways that specify and pattern the endoderm during gastrulation have not been investigated until relatively recently. In the present article, we ask how signaling pathways are integrated and lead to differentiation of endoderm lineages and their characteristic gastrulation movements in different species. Inevitably, the result of this endeavor must remain quite unsatisfactory since far too many pieces of the puzzle are still missing, and because the unifying principles probably remain to be discovered as to how various endodermal populations relate to each other in different species in terms of developmental fate and the partitioning of essential signaling functions. Nevertheless, we feel that such a comparative approach might be fruitful to develop new models that can be tested experimentally to identify molecular mechanisms of universal importance.

2. Definition of endoderm

The endoderm is classically defined as the inner germ layer of diplo- and triploblastic animals. Although it is internalized only during gastrulation, its differentiation in many species starts earlier. The main derivative is the epithelial outlining of the primitive gut, which during embryonic development contributes to a number of visceral organs including the digestive tract, and in the adult provides the interior of the body with a protective barrier against the environment. Of note, in all species a portion of the gut epithelium close to its orifices is of ectodermal origin. The fusion between endoderm and ectoderm is yet poorly understood (Dickinson and Sive, 2006). In contrast to invertebrates, where all endoderm contributes to the embryo, different types of cells have been called endoderm in vertebrates (Fig. 1). In yolk-rich eggs of vertebrates, the vegetal hemisphere cells will seed the future gut tube epithelium, and include yolk granules that serve as nutrients during development. The yolk remains extra-embryonic and uncleaved in birds and fish (Figs. 1 and 3).

In amniotes several endoderm-specific genes are expressed before gastrulation in extraembryonic lineages, which initially assume the position and nutritive function of the prospective inner layer. These extraembryonic tissues have also been termed "endoderm", even though they eventually do not contribute to embryonic structures, which leads to some confusion (Fig. 1). In birds, one of these extraembryonic lineages is derived from islands of polyingressing epiblast cells which assemble to form the pregastrulation stage hypoblast layer. The other, termed endoblast (previously known as secondary hypoblast), arises from deep cells in the posterior marginal zone that start moving in antero-lateral direction at the onset of gastrulation closely behind the hypoblast (Bachvarova et al., 1998; Eyal-Giladi et al., 1992). In mouse, primitive endoderm (PrE) segregates from the inner cell mass (ICM) at the blastocyst stage as a squamous epithelium. Whereas some PrE cells remain attached to the basement membrane of the ICM and differentiate into cuboidal visceral endoderm (VE), others undergo an epithelial–mesenchymal transition to become parietal endoderm (PE). PE cells migrate along the basement membrane of trophectoderm (TE) cells which gives rise to Reichert's membrane of the parietal yolk sac. Until placentation, PE and VE lineages together are responsible for nutrient and waste exchange between maternal tissue and the foetus, a function which in lower organisms is partly fulfilled by the yolk. While these extraembryonic tissues are clearly distinct from the definitive endoderm lineage, we find it appropriate, owing to the characteristics they share with definitive endoderm and to their influence on gastrulation events, to review their ontogeny and critical functions in the process of gastrulation. In rabbits, an interesting mammalian species which is apparently closer to human embryos (flat embryo), there is functional and molecular evidence for an AVE (Knoetgen et al., 1999). It also shares expression of Cerberus (Cer) and Dickkopf (Dkk) with the mouse AVE and chick hypoblast but the movements remain to be studied as well as its origin (Chapman et al., 2003; Idkowiak et al., 2004). We have used the mouse as the example of vertebrates as it is the most studied, especially at the molecular level but validation in rabbits regarding the specification of endoderm is still limited.

3. Endoderm origin and specification

Fate mapping experiments initiated in the first half of the 20th century allowed to locate endoderm precursors prior or during gastrulation. The resulting fate maps are detailed in Figs. 2–4. A few points of comparison can be extracted from the fate maps in different species. With the notable exception of sea urchin, most species spatially segregate ectoderm precursors early from progenitors that give rise to endoderm and mesoderm. Niewkoop's experiments associating vegetal and animal hemispheres of frogs