The Chick Embryo Model System

Guest Editor

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Preface

The chick model system: a distinguished past and a great future

When I was asked by the Chief Editor of the *Int. J. Dev. Biol.* to consider editing a Special Issue about "the chick", I was first hesitant, because I had already edited such an issue for another journal in 2004 (*Mech. Dev.* volume 121), when the sequence of the chick genome was first released (Stern, 2004, 2005). But at the same time I was surprised that this journal, well known for its Special Issues of which many have become important historical and literary landmarks to the developmental biology literature, had not yet produced a volume on what is probably the oldest developmental model system. Despite this, it is often forgotten that much of what we know (or think we know) about human developmental events is due to extrapolation from chick embryological studies. This even includes the current legislation setting a limit on human experimentation to the period from fertilization to the 14th day, when the primitive streak forms. This is due to the fact that the early chick embryo displays "regulative" behaviour (that is, the ability to form twins when cut into fragments) right until the formation of the primitive streak (Lutz, 1949; Spratt and Haas, 1960; Streit *et al.*, 1998; Streit and Stern, 1999; Bertocchini *et al.*, 2004; Torlopp *et al.*, 2014). Rodent embryos, of which the mouse is the dominant mammalian developmental model, have quite a distinctive topology at early stages of development, i.e. a cylinder, whereas avian and most other mammalian embryos share a flat disc-like arrangement of the germ layers. Probably partly for this reason, mouse embryos seem unable to generate monozygotic twins that develop beyond the primitive streak or early neural tube stages. Many other morphological similarities between chick and non-rodent mammalian embryos continue to be found until much later stages of development. Together with the large size and accessibility of the chick embryo, the fact that it does not require killing the mother to study it, and the ease with which cells and tissues can be manipulated, as well as the huge number of anatomical studies to which it has been subjected (at least since Fabricius in the XVI century, and detailed histological and other studies in the 200 years since Pander and von Baer in the early XIX), observations in the chick embryo account for many of the often dogmatic statements about human development found in most textbooks to this day. It is true that there are many important differences, but the similarities are also very striking, and certainly more than with most other current "model systems" used in modern developmental biology.

This long history led to many fundamental discoveries about developmental mechanisms and "descriptive" embryology, as well as in immunology, virology and many other fundamental areas of biology (see Stern, 2005). Crucial concepts in cell biology, such as Contact Inhibition of Locomotion which is now seeing a resurgence of interest (see Roycroft and Mayor, 2018, in this issue) also emerged from the extensive use of chick embryonic cells. Neuroscience also owes many fundamental discoveries to the chick, including many of the studies of Santiago Ramón y Cajal, the pioneering work of Thomas Jessell and his group on spinal cord patterning, and numerous studies on axonal pathfinding and the specificity of innervation (for example see Landmesser, 2018; Placzek and Briscoe, 2018, in this issue).

The main advantages of the chick as a model system for experimental embryology have been, and remain, the ease with which cells and tissues can be labelled, transplanted and cultured, along with its similarity to mammalian systems. In the last two decades, the introduction of the technique of *in vivo* electroporation, the brain child of T. Muramatsu and Hirokazu Nakamura (Sakamoto *et al.*, 1998) has moved the chick system to a new level. This allows not only mis-expression of genes, but also knockdowns using morpholinos, siRNAs and most recently, gene editing using TALEN and CRISPR/Cas9 to specific cells at particular times in development (Veron *et al.*, 2015). This opens the door to true somatic cell genetics as powerful as that of *Drosophila*. The main advantage of this is that by targeting specific cells, tissues and times, and especially by combining this with the more classical advantages of ease of transplantation and cell labelling, one can ask questions about gene function in a context-specific (cell-specific) way, which avoids problems due to multiple, diverse gene functions in different tissues at different types which cannot as easily be studied in most other model vertebrate species. This also allows, and even encourages, the design of elegant experiments to discriminate cleanly between different possible underlying mechanisms (see Stern, 2017).

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It is impossible even in a whole issue of a journal to cover all the wonderful aspects of the chick as an experimental system for studying development. I have therefore chosen a subset of examples, to illustrate first some aspects of its rich historical past, including some papers written by some of the key individuals who have contributed to making the system so powerful in the last century. This section also includes a short review of the history of stage tables; such tables are also a particularly important feature of the chick system, because having a very precise and fine-grained staging system encourages a much greater appreciation of the changes that occur in time in the embryo, and therefore the importance of cellular context in understanding not only embryological, but also molecular events. Second, a set of papers reviewing some key developmental events that have been illuminated particularly well by studies done on chick embryos, such as neurulation, segmentation, left-right asymmetry and limb development. Then, a few examples of how the chick embryo has contributed to crucial concepts of cell biology such as epithelial-mesenchymal transitions, sex determination, muscle development and neurogenesis. A set of papers focuses on how studies done in the chick have led to understanding major principles in neuroscience. Finally, there is a small selection of papers touching on advances offered by new technologies, including genetic modification of the germ line and somatic cells, pluripotent cells (including both embryonic stem cells and cultured germ cells) and recent progress made in mapping and annotating the chicken genome. It would have been easy to make this a two-volume selection and I apologise to the many authors and topics that had to be left out.

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