

Pax7 identifies neural crest, chromatophore lineages and pigment stem cells during zebrafish development

ANA M^a LACOSTA*, JESÚS CANUDAS, CRISTINA GONZÁLEZ, PEDRO MUNIESA, MANUEL SARASA
and LUIS DOMÍNGUEZ†

Laboratory of Neurobiology, Department of Anatomy, Embryology and Animal Genetics, Faculty of Veterinary,
University of Zaragoza, Spain

ABSTRACT Using immunostaining during early zebrafish embryogenesis, we report that the cranial and trunk neural crest expresses the paired box protein Pax7, thus revealing a novel neural crest marker in zebrafish. In the head, we show that Pax7 is broadly expressed in the cranial crest cells, which indicates that duplication of the paralogous group Pax3/7 at the origin of vertebrates included the conserved expression of Pax7 in the head neural crest of all of the vertebrates species studied so far. In the trunk, Pax7 recognizes both premigratory and migratory neural crest cells. Notably, we observed the expression of Pax7 during the development of melanophore, xanthophore and iridophore precursor cells. In contrast to the case of melanocyte precursors in birds, Pax7 showed overlapping expression with early melanin pigment. Finally, during the larva to adult transition, we show that pigment stem cells recapitulate the expression of Pax7.

KEY WORDS: Pax7, neural crest, chromatophore precursor, pigment stem cell

To examine the cellular and molecular mechanisms of neural crest (NC) development, the zebrafish *Danio rerio* offers many advantages as an embryological and genetic model system (Kelsh and Raible, 2002; Quigley and Parichy, 2002).

Pax3 and *Pax7*, which are members of one of the four *Pax* subfamilies, are required to specify the NC in amniotes (Basch *et al.*, 2006; Relaix *et al.*, 2004). In a seminal paper by Seo *et al.* (1998), zebrafish *Pax3* and *Pax7* genes were analyzed and reported multiplicity of isoforms encoded by the paralogous *Pax7*. Since no expression of *Pax7* was detected in NC cells, they suggested the need for further study to reveal NC expression at the protein and RNA level.

Pax7 expression occurs in a large number of scattered cells throughout the body (Fig. 1A). With development, its expression progresses in an anterior-to-posterior wave. The large size of these *Pax7* cells and its dynamic pattern of spatiotemporal distribution are consistent with a NC cell identity. Notably, *Pax7* recognizes both trunk (Fig. 1) and cranial (Fig. 2) NC cells. Therefore, *Pax7* is an evolutionary conserved NC marker, either of the head crest in mammals (Mansouri *et al.*, 1996) or throughout the crest in chick (Kawakami *et al.*, 1997; Lacosta *et al.*, 2005) and zebrafish.

Both in toto (Fig. 1A,B) and in sections (Fig. 1D), we found

Pax7 expression in cells in a position dorsal and dorsolateral to the neural tube, which characterizes the premigratory phase of zebrafish NC development. To provide additional confirmation for the NC identity of these *Pax7* positive cells, we compared the *Pax7* staining pattern with that of several premigratory NC markers. As shown in Fig. 1C, *crestin* (see Luo *et al.*, 2001) seems to precede *Pax7* in the premigratory crest.

We also compared the immunostaining patterns of the Rohon-Beard (R-B) sensory neuron marker, HNK-1 (Metcalfe *et al.*, 1990) and that of *Pax7*. *Pax7* expression in the premigratory NC cells took place later than HNK-1 in the R-B (Fig. 1E). Therefore, these findings confirm the sequential steps of R-B neurogenesis and neurocristogenesis in the zebrafish (see Cornell and Eisen, 2000). In turn, this study identifies *Pax7* as a suitable marker to study the specification of individual crest cells. Zebrafish *Pax3*, however, is the earliest identified marker of the NC domain and thus used to study the initial induction of NC (Lewis *et al.*, 2004). Hence, both *Pax3* and *Pax7* paralogs may help to dissect how NC cells become specified and differentiated.

Before the onset of ventral migration, the longitudinal migration of some NC cells occurs along the dorsal neural keel-tube (Raible *et al.*, 1992; Vaglia and Hall, 2000). Here, we confirm that pattern of migration through the trunk and tail of the zebrafish (Fig. 1B).

*Address correspondence to: Ana M^a Lacosta. Laboratory of Neurobiology, Department of Anatomy, Embryology and Animal Genetics, Faculty of Veterinary, Miguel Servet 177, E-50013, University of Zaragoza, Zaragoza, Spain. Fax: +34-976-761-605. e-mail: alacosta@unizar.es

† Note: Dedicated to the memory of Dr. Luis Dominguez who passed away recently.

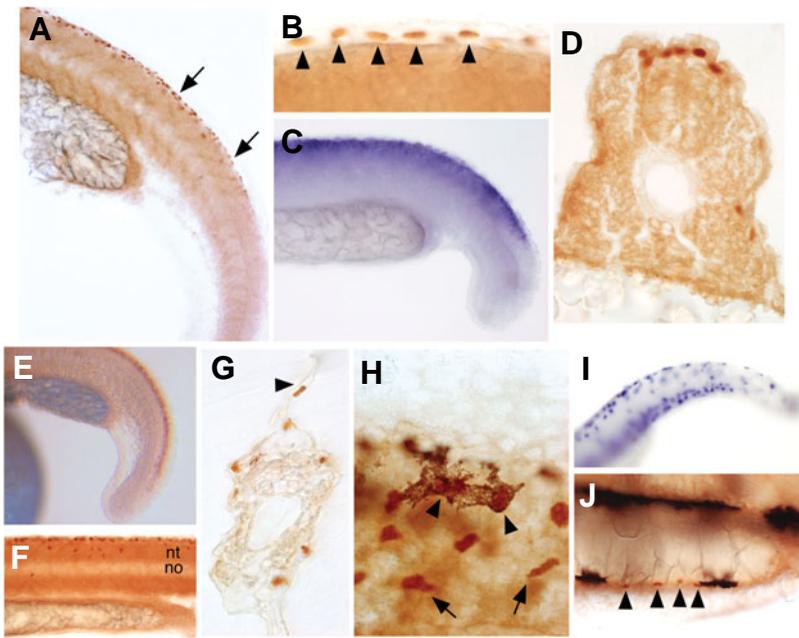


Fig. 1. Expression pattern of Pax7 in the trunk neural crest (NC). Whole-mounts of 24 hpf (A,B,F), 21 hpf (C,E) and 48 hpf (H-J) embryos. Transverse sections of whole-mount 21 hpf (D) and 48 hpf (G) embryos. (A) Trunk and tail level showing Pax7 expression within the premigratory NC (arrows) and migrating NC cells (out of focus). (B) Higher magnification showing several Pax7-positive crest cells along the top of the neural tube (arrowheads). (C) Crestin expression is shown for comparison. (D) Expression of Pax7 in several premigratory NC cells located dorsal to the neural tube. (E) Embryo showing HNK-1 expression in the Rohon-Beard neurons. (F) Note several Pax7+ cells migrating in the medial pathway. (G) Many Pax7 cells are evident at different dorso-ventral levels of the lateral migratory pathway. Note one Pax7+ NC cell in the dorsal median fin (arrowhead). Focus is on the dorsalmost NC cell. (H) Whole-mount showing lightly pigmented melanin granules surrounding Pax7 expressing nuclei (arrowheads) in some melanophores within the dorsal stripe. Note also some Pax7+ cells on the lateral pathway (arrows), which are devoid of melanin and are likely xanthophore precursors. (I) Dct in situ RNA hybridization reveals many dct-positive cells. Focus is on the dorsal and ventral stripes. PTU treated embryo. (J) Yolk sac stripe at the level of the yolk extension. Note several Pax7 iridophore precursors (arrowheads). Heavily pigmented melanophores can also be seen in the yolk sac and ventral stripes. no, notochord; nt, neural tube; PTU, 1-phenyl-2-thiourea. Anterior to the left and dorsal uppermost in (A-C), (E-F) and (H-J).

With development, Pax7 expression occurred in migrating trunk NC cells, which were located on the medial (Fig. 1F) and lateral migration routes (Fig. 1G). Additionally, because the NC frequently appears as streams of adjacent cells (Raible *et al.*, 1992; Vaglia and Hall, 2000), nuclear expression of the transcription factor Pax7 provides a reliable method for NC numbering. Cell counts of Pax7-positive early trunk NC cells are similar to other estimates of NC numbers (Raible *et al.*, 1992).

Comparison of Pax7 and the melanogenic enzyme dopachrome tautomerase (dct; Kelsh *et al.*, 2000) revealed coincident spatiotemporal distribution in some migrating cranial and trunk crest cells. In contrast to Pax7, however, premigratory NC cells lack *dct* (Fig. 1I; see also Kelsh *et al.*, 2000). Therefore, Pax7 precedes the expression of *dct* and thus may be involved in its regulation during zebrafish melanogenesis.

The spatial pattern of Pax7 downregulation closely follows the

wave of melanogenesis. Thus, Pax7 downregulation initiated in melanoblasts located behind the otic vesicle and progressed anteriorly and posteriorly in 30 and 48 hpf embryos.

In 48 hpf embryos, at the dorsal melanophore stripe level (Fig. 1H), we found melanophore progenitor cells (revealed by their characteristic stellate shape, mostly flattened, with lightly or more heavily pigmented melanin granules) with a Pax7-positive nucleus or not.

Only iridophores and melanophores contribute to the yolk sac stripe (Kelsh, 2004; Kimmel *et al.*, 1995). Here, iridophores differentiate *in situ*, whereas melanophores become pigmented while migrating (Rawls *et al.*, 2001). As in the dorsal stripe, Pax7 positive cells, which are devoid of melanin, were also identified in the iridophore precursors (Fig. 1J). Pax7 was downregulated in the iridophore lineage at around 3 days post-fertilization.

In *albino* embryos (Kelsh *et al.*, 2000), with reduced and delayed melanin synthesis, distribution of Pax7 expressing cells was apparently similar (data not shown). This suggests that Pax7 acts upstream of *albino* during melanogenesis.

In contrast to trunk crest, there are no published reports of cranial NC cell counts. Here, immunocytochemical observations in toto and in sections permitted easy identification and counting of head NC cells by revealing the Pax7 transcription factor. That procedure even permitted the counting of overlapping NC nuclei. Crest cell counts made from the level of the first somite to the most rostral end in embryos aged between 24 hpf and 30 hpf showed an average of $182,10 \pm 20,13$ ($n = 11$) head NC cells.

Expression of Pax7 occurred in head NC cells located at every level of the embryonic brain, except at the most rostral telencephalic level (Fig. 2A), which supports their lack of specification in regions rostral to the diencephalon (Aybar and Mayor, 2002). To analyze whether Pax7 in the brain and the NC are correlated, we also studied younger embryos. As shown in Fig. 2B, Pax7 positive crest cells only segregate from a previous Pax7-expressing dorsal progenitor domain.

Pax7 immunostaining show positive cells with patterns of distribution that correspond to melanophore and xanthophore precursors (Fig. 2A). Strikingly, Pax7 displays a differential temporal expression in both pigment cell lineages (Fig. 2C,D). Thus, Pax7 is first downregulated in the melanophore lineage, while persisted longer in the xanthophore lineage, until about the 3dpf.

Dct and melanin as melanophore markers and xanthine dehydrogenase (xdh), GTP-cyclohydrolase I (gch) and the receptor fms as xanthophore markers (but see Parichy *et al.*, 2000) were also used to verify melanophore and xanthophore precursors identity (Fig. 2C-F).

From stage 20 hpf, we first noted some Pax7 cells over the optic cup (Fig. 2B). With development, their number increases, become located over the dorsal eye and later spread through the entire eye (Fig. 2G). At 3 dpf, Pax7 downregulate coinciding with the appear-

ance of the reflective platelets of the iridophores. Therefore, as in the trunk, the paired box protein Pax7 also identifies iridophore precursors in the head.

No NC cells occur at the level of the otic vesicle and, hence, Pax7-expressing cells were only located around the vesicle, within the second and third cranial NC streams (Fig. 2A).

Next, we examined whether Pax7 is also expressed by the pigment stem cells at metamorphosis. As previously reported (Mellgren and Johnson, 2006), an initial pigment pattern of scattered melanophores and xanthophores develops throughout the caudal fin at early-middle metamorphosis (Fig. 3). Interestingly, we noted a distribution pattern of Pax7+ unpigmented precursors, mainly in the proximal area of the caudal (Fig. 3A,B,D,E) and anal (Fig. 3C) fins. In the caudal peduncle, we observed many Pax7+ cells adjacent to the hypurals (Fig. 3E). Together, these findings suggest a proximo-distal gradient of pigment cells development during caudal fin metamorphosis.

Here, we have observed a close association between Pax7 and the melanophore lineage that is similar to that noted between

Pax7/Pax3 and the analogous melanocyte precursors of amniotes (Lacosta *et al.*, 2005; Lang *et al.*, 2005). In birds, however, Pax7 downregulation precedes the appearance of melanin pigment (Lacosta *et al.*, 2005), while in zebrafish it takes place after melanin deposition begins. Hence, there is a notable difference between Pax7 regulation and deposition of melanin pigment in both vertebrate pigmentation models. Together, these findings in zebrafish Pax7 open up new avenues to understand how different vertebrate pigmentation models orchestrate Pax3/Pax7 and other factors (see Hou *et al.*, 2006; Lang *et al.*, 2005) in controlling melanin formation at the proper time and place.

In contrast to melanophores, little is known of the mechanisms regulating the differentiation of the xanthophore and iridophore

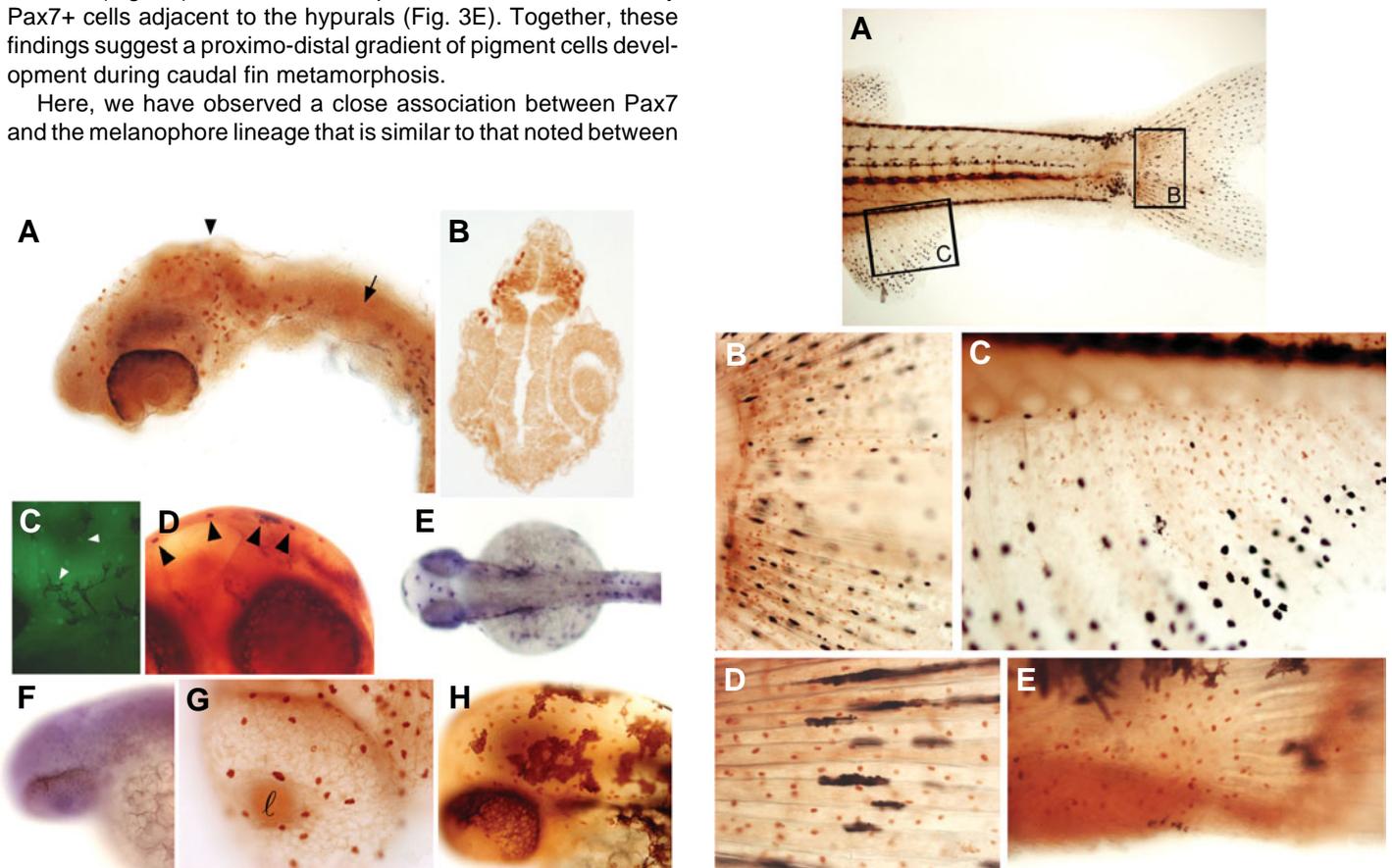


Fig. 2 (Left). Expression pattern of Pax7 in the developing head. (A) Whole-mount of a 24 hpf embryo. Pax7 is expressed by head neural crest (NC) cells, except at its most rostral end and at the level of the otic vesicles (arrow). Note many Pax7-positive cells (arrowhead) at the mid-hindbrain. (B) Section through a 21 hpf embryo. Note that Pax7 positive NC cells of the first cranial stream are only generated caudal to the telencephalon. (C) Several dendritic melanophores and Pax7+ xanthophore precursors (arrowheads) showing close heterotypic interactions in the dorsal head of a stage 33 hpf embryo. (D) Whole-mount showing Pax7+ xanthophore precursors (arrowheads) and one melanophore at the rostral end of a stage 48 hpf embryo. (E) Typical distribution pattern of melanophores in the head is revealed by *in situ* RNA hybridisation. Stage 48 hpf. PTU treated embryo. (F) Broad distribution pattern of xanthophore precursors in the head is revealed by the xanthophore lineage marker *xdh*. Stage 48 hpf. PTU treated embryo. (G) Lateral view of a 48hpf embryo displaying Pax7+ iridophore precursors over the eye. Pax7 staining is also observed in adjacent xanthophore precursors. PTU treated embryo. (H) Pax3 immunolabeling reveals a similar spatio-temporal expression pattern in the three pigment cell precursors. Anterior to the left in (A) and (E-H). I, lens; PTU, 1-phenyl-2-thiourea.

Fig. 3 (Right). Pax7 is expressed during pigment pattern metamorphosis. Whole-mount staining for Pax7 of the caudal (A,B,D,E) and anal (C) fins. (A) A 7 mm stage showing many Pax7+ cells in the proximal end of the caudal and anal fins. Boxed areas are depicted in (B,C). (B) Detail showing numerous Pax7+ cells distributed throughout the proximal region of the caudal fin. (C) Detail of the anal fin. Most Pax7+ cells appear in the proximal area of the fin. (D) Detail of the caudal fin of a 10 mm larva. Numerous unpigmented Pax7+ cells are interspersed with mature pigment cells. (E) Higher magnification showing Pax7+ cells adjacent to the hypurals in the caudal peduncle. 10 mm larva. Anterior to the left.

lineages (Quigley and Parichy, 2002). Here we present evidence that Pax7 is a common transcription factor of the zebrafish cromathophore lineages. Of note, temporal control of Pax7 is closely related to the timing of differentiation of the three pigment cell precursors. Therefore, these findings are consistent with the tight association between downregulation of Pax genes and differentiation (Chen *et al.*, 2006).

In zebrafish, several studies have demonstrated that metamorphic and also regenerative pigment cells differentiate de novo from latent stem cells (Rawls *et al.*, 2001). It has been claimed the lack of molecular markers for pigment stem cells (Kelsh, 2004; Quigley and Parichy, 2002). Recent studies showed that Pax7 is a reliable skeletal muscle stem (satellite) cell marker across vertebrates (see Chen *et al.*, 2006 and references therein). Therefore, we evidence that the evolutionary conserved stem cell transcription factor Pax7 is also expressed in zebrafish pigment stem cells at metamorphic stages. Taken together, this study will provide the basis for future analysis of Pax7 gene function during zebrafish development

Experimental Procedures

Zebrafish embryos and larvae were raised at 28.5°C and staged according to the number of hours or days post-fertilization (Kimmel *et al.*, 1995). Adult *albino* D. rerio were purchased at a local pet store. To reduce melanin formation, some embryos were treated with 0.003 % 1-Phenyl-2-thiourea (PTU, Sigma) in embryo medium beginning at 20-22 hpf. For whole-mount antibody staining, embryos or metamorphic larvae were anesthetized with MS222, fixed in 4% paraformaldehyde at 4°C for 5-24 h and incubated in primary antibodies overnight at 4°C. Embryos and larvae were incubated in horseradish peroxidase-conjugated goat anti-mouse or goat anti-rabbit secondary antibodies (Jackson Immuno Research) overnight at 4°C. To develop the peroxidase reaction product, embryos were incubated in 1.86 mg/ml DAB (Sigma) with 0.033% H₂O₂ in phosphate buffer. After the yolk cell was removed, some embryos were mounted on slides and photographed using an Olympus Microscope BX60. For sectioning, whole-mount Pax7 immunoreacted embryos were embedded in paraffin. Sections (10 µm) were mounted on slides and photographed as above.

For fluorescent detection, we used a biotin-conjugated anti-mouse antibody (1/200, Sigma) followed by AlexaFluor 488-conjugated Streptavidin (1/200, Molecular Probes) and viewed with epifluorescence optics.

We obtained the anti-Pax7 (used undiluted) (Kawakami, A.) and Zn-12/HNK-1 (1/20) (Trevarrow, B.) supernatant mAbs from the Developmental Studies Hybridoma Bank, which was developed under the auspices of the NICHD and is maintained by the Department of Biological Sciences, University of Iowa. Pax3 (1/100) polyclonal Ab was a generous gift from Dr. Gerard C. Grosveld.

Whole-mount RNA *in situ* hybridization was performed essentially by the method of Thisse *et al.* (1993). Probes containing digoxigenin (Roche Biochemicals) were prepared for *crestin*, Pax3 (Seo *et al.*, 1998), *dct* (Kelsh *et al.*, 2000), *fms*, *gch* and *xdh* (Parichy *et al.*, 2000). Detection of labeled antisense probes was performed by using alkaline phosphatase-conjugated anti-digoxigenin Fab fragments (Roche) and with BM Purple AP Substrate (Roche).

Acknowledgements

We are very grateful to Dr. E.M. González for helpful comments; Dr. M. Halpern for *crestin*, Dr. A. Fjose and Dr. H.C. Seo for Pax3 and Dr. R. Cornell for *dct*, *xdh*, *gch* and *fms* probes. We thank Dr. A. Kawakami for useful comments on Pax7 antibody; R. Puyo, S. Serrano and V. Melgarejo for technical assistance; and Dr. G.C. Grosveld for Pax3 antibody. We

also thank Mr. K. Dobbie for the kind correction of the English manuscript and Dr. M.V. Robinson and Dr. B. McWhirter for editing a previous draft. This work was supported by grants from the Spanish Ministry of Science and Technology (PM99-0086) and from the Government of Aragón (PO68/2000).

References

- AYBAR, M.J. and MAYOR, R. (2002). Early induction of neural crest cells: lessons learned from frog, fish and chick. *Curr. Opin. Genet. Dev.* 12: 452-458.
- BASCH, M.L., BRONNER-FRASER, M. and GARCIA-CASTRO, M.I. (2006). Specification of the neural crest occurs during gastrulation and requires Pax7. *Nature* 441: 218-222.
- CORNELL, R.A. and EISEN, J.S. (2000). Delta signaling mediates segregation of neural crest and spinal sensory neurons from zebrafish lateral neural plate. *Development* 127: 2873-2882.
- CHEN, Y., LIN, G. and SLACK, J.M.W. (2006). Control of muscle regeneration in the *Xenopus* tadpole tail by Pax7. *Development* 133: 2303-2313.
- HOU, L., ARNHEITER, H. and PAVAN, W.J. (2006). Interspecies difference in the regulation of melanocyte development by SOX10 and MITF. *Proc. Natl. Acad. Sci. USA* 103: 9081-9085.
- KAWAKAMI, A., KIMURA-KAWAKAMI, M., NOMURA, T. and FUJISAWA, H. (1997). Distributions of PAX6 and PAX7 proteins suggest their involvement in both early and late phases of chick brain development. *Mech. Dev.* 66: 119-130.
- KELSH, R.N. (2004). Genetics and evolution of pigment patterns in fish. *Pigment Cell Res.* 17: 326-336.
- KELSH, R.N. and RAIBLE, D.W. (2002). Specification of zebrafish neural crest. *Results Probl. Cell Differ.* 40. In *Pattern Formation in Zebrafish*, L. Solnica-Krezel, ed. (Springer-Verlag). pp. 216-236.
- KELSH, R.N., SCHMID, B. and EISEN, J.S. (2000). Genetic analysis of melanophore development in zebrafish embryos. *Dev. Biol.* 225: 277-293.
- KIMMEL, C.B., BALLARD, W.W., KIMMEL, S.R., ULLMANN, B. and SCHILLING, T.F. (1995). Stages of embryonic development of the zebrafish. *Dev. Dyn.* 203: 253-310.
- LACOSTA, A.M., MUNIESA, P., RUBERTE, J., SARASA, M. and DOMÍNGUEZ, L. (2005). Novel expression patterns of Pax3/Pax7 in early trunk neural crest and its melanocyte and non-melanocyte lineages in amniote embryos. *Pigment Cell Res.* 18: 243-251.
- LANG, D., LU, M.M., HUANG, L., ENGLEKA, K.A., ZHANG, M., CHU, E.Y., LIPNER, S., SKOULTCHI, A., MILLER, S. and EPSTEIN, J.A. (2005). Pax3 functions at a nodal point in melanocyte stem cell differentiation. *Nature* 433: 884-887.
- LEWIS, J.L., BONNER, J., MODRELL, M., RAGLAND, J.W., MOON, R.T., DORSKY, R.I. and RAIBLE, D.W. (2004). Reiterated Wnt signaling during zebrafish neural crest development. *Development* 131: 1299-1308.
- LUO, R., AN, M., ARDUINI, B.L. and HENION, P.D. (2001). Specific pan-neural crest expression of zebrafish *Crestin* throughout embryonic development. *Dev. Dyn.* 220: 169-174.
- MANSOURI, A., STOYKOVA, A., TORRES, M. and GRUSS, P. (1996). Dysgenesis of cephalic neural crest derivatives in Pax7^{-/-} mutant mice. *Development* 122: 831-838.
- MELLGREN, E.M. and JOHNSON, S.L. (2006). *pyewacket*, a new zebrafish fin pigment pattern mutant. *Pigment Cell Res.* 19: 232-238.
- METCALFE, W.K., MYERS, P.Z., TREVARROW, B., BASS, M.B. and KIMMEL, C.B. (1990). Primary neurons that express the L2/HNK-1 carbohydrate during early development in the zebrafish. *Development* 110: 491-504.
- PARICHY, D.M., RANSOM, D.G., PAW, B., ZON, L.I. and JOHNSON, S.L. (2000). An orthologue of the kit-related gene *fms* is required for development of neural crest-derived xanthophores and a subpopulation of adult melanocytes in the zebrafish, *Danio rerio*. *Development* 127: 3031-3044.
- QUIGLEY, I.K. and PARICHY, D.M. (2002). Pigment pattern formation in zebrafish: a model for developmental genetics and the evolution of form. *Microsc. Res. Tech.* 58: 442-455.
- RAIBLE, D.W., WOOD, A., HODSDON, W., HENION, P., WESTON, J.A. and EISEN, J.S. (1992). Segregation and early dispersal of neural crest cells in the

- embryonic zebrafish. *Dev. Dyn.* 195: 29-42.
- RAWLS, J.F., MELLGREN, E.M. and JOHNSON, S.L. (2001). How the zebrafish gets its stripes. *Dev. Biol.* 240: 301-314.
- RELAIX, F., ROCANCOURT, D., MANSOURI, A. and BUCKINGHAM, M. (2004). Divergent functions of murine Pax3 and Pax7 in limb muscle development. *Genes Dev.* 18: 1088-1105.
- SEO, H.C., SAETRE, B.O., HAVIK, B., ELLINGSEN, S. and FJOSE, A. (1998). The zebrafish Pax3 and Pax7 homologues are highly conserved, encode multiple isoforms and show dynamic segment-like expression in the developing brain. *Mech. Dev.* 70: 49-63.
- THISSE, C., THISSE, B., SCHILLING, T.F. and POSTLETHWAIT, J.H. (1993). Structure of the zebrafish *snail1* gene and its expression in wild-type, spadetail and no tail mutant embryos. *Development* 119: 1203-1215.
- VAGLIA, J.L. and HALL, B.K. (2000). Patterns of migration and regulation of trunk neural crest cells in zebrafish (*Danio rerio*). *Int. J. Dev. Biol.* 44: 867-881.

Received: 5th September 2006

Reviewed by Referees: 3rd October 2006

Modified by Authors and Accepted for Publication: 15th December 2006

Published Online: 16th May 2007

Previously published, related *Int. J. Dev. Biol.* articles

See our recent Special Issue on ***The Nogent Institute*** edited by Françoise Dieterlen at:
<http://www.ijdb.ehu.es/web/contents.php?vol=49&issue=2-3>

Fate of cranial neural crest cells during craniofacial development in endothelin-A receptor-deficient mice

Makoto Abe, Louis-Bruno Ruest and David E. Clouthier

Int. J. Dev. Biol. (2007) 51: 97-105

Comparative expression analysis of Pax3 and Pax7 during mouse myogenesis

David Horst, Svetlana Ustanina, Consolato Sergi, Gregor Mikuz, Herbert Juergens, Thomas Braun and Eugene Vorobyov

Int. J. Dev. Biol. (2006) 50: 47-54

Interplay of Pax6 and SOX2 in lens development as a paradigm of genetic switch mechanisms for cell differentiation

Hisato Kondoh, Masanori Uchikawa and Yusuke Kamachi

Int. J. Dev. Biol. (2004) 48: 819-827

Changes in the proportion and number of Pax(7+ve) and MF20(+ve) myoblasts during chick myogenesis in the head and limb.

Antonio S J Lee, Ming Zhang and Darrell J R Evans

Int. J. Dev. Biol. (2004) 48: 31-38

Origins and plasticity of neural crest cells and their roles in jaw and craniofacial evolution.

Paul A Trainor, Kristin R Melton and Miguel Manzanares

Int. J. Dev. Biol. (2003) 47: 541-553

Cell-intrinsic and cell-extrinsic cues regulating lineage decisions in multipotent neural crest-derived progenitor cells.

Christian Paratore, Lilian Hagedorn, Julien Floris, Lisette Hari, Maurice Kléber, Ueli Suter and Lukas Sommer

Int. J. Dev. Biol. (2002) 46: 193-200

PAX genes in development and disease: the role of PAX2 in urogenital tract development.

Michael R Eccles, Shujie He, Michael Legge, Rajiv Kumar, Jody Fox, Chaoming Zhou, Michelle French and Robert W S Tsai

Int. J. Dev. Biol. (2002) 46: 535-544

Limb muscle development.

Bodo Christ and Beate Brand-Saberi

Int. J. Dev. Biol. (2002) 46: 905-914

Patterns of migration and regulation of trunk neural crest cells in zebrafish (*Danio rerio*).

J L Vaglia and B K Hall

Int. J. Dev. Biol. (2000) 44: 867-881

IJDB Special Issue on

THE NOGENT INSTITUTE

Institut d'Embryologie Cellulaire et Moléculaire Nogent-sur-Marne

Edited by Françoise Dieterlen

Forward

by Nicole M. Le Douarin

Preface

by Françoise Dieterlen

INTRODUCTORY PAPERS

L'École de Nogent: the contributions of Etienne Wolff and Nicole Le Douarin

by Charles Galperin

The Nogent Institute - 50 Years of Embryology

by Nicole M. Le Douarin

CONTRIBUTIONS

Early stages of neural crest ontogeny: formation and regulation of cell delamination

by Chaya Kalcheim and Tal Burstyn-Cohen

Brain switching: studying evolutionary behavioral changes in the context of individual brain development

by Evan Balaban

Commitment of hematopoietic stem cells in avian and mammalian embryos: an ongoing story

by Françoise Dieterlen-Lièvre

The Le Douarin phenomenon: a shift in the paradigm of developmental self-tolerance

by António Coutinho

Regulatory T cells in the establishment and maintenance of self-tolerance: role of the thymic epithelium

by Josselyne Salaün, Catherine Corbel and Nicole M. Le Douarin

Migration of neural crest-derived enteric nervous system precursor cells to and within the gastrointestinal tract

by Alan J. Burns

The instability of the neural crest phenotypes: Schwann cells can differentiate into myofibroblasts

by Carla Real, Corinne Glavieux-Pardanaud, Pierre Vaigot, Nicole Le Douarin and Elisabeth Dupin

Neural crest derivatives in ocular and periocular structures

by Sophie Creuzet, Christine Vincent and Gérard Couly

Endothelin receptor B is required for the expansion of melanocyte precursors and malignant melanoma

by Ronit Lahav

Cellular dynamics and molecular control of the development of organizer-derived cells in quail-chick chimeras

by Jean-Baptiste Charrier, Martin Catala, Françoise Lapointe, Nicole Le Douarin and Marie-Aimée Teillet

Experimental study of early olfactory neuron differentiation and nerve formation using quail-chick chimeras

by Fabrice L. Lalloué and Christiane S. Ayer-Le Lièvre

Single-cell transcriptional profiles and spatial patterning of the mammalian olfactory epithelium

by Ian Tietjen, Jason Rihel and Catherine G. Dulac

Oligodendrocyte development in the embryonic brain: the contribution of the plp lineage

by Barbara Le Bras, Elli Chatzopoulou, Katharina Heydon, Salvador Martínez, Katzuhiko Ikenaka, Laetitia Prestoz, Nathalie Spassky, Bernard Zalc and Jean-Léon Thomas

Common mechanisms for boundary formation in somitogenesis and brain development: shaping the 'chic' chick

by Yoshiko Takahashi

Isthmus organizer and regionalization of the mesencephalon and metencephalon

by Harukazu Nakamura and Yuji Watanabe

Transfer of an avian genetic reflex epilepsy by embryonic brain graft: a tissue autonomous process?

by Marie-Aimée Teillet, Robert Naquet and Cesira Batini

Embryonic development of the human hematopoietic system

by Manuela Tavian and Bruno Péault

Of birds and mice: hematopoietic stem cell development

by Isabelle Godin and Ana Cumano

Vascular development: from precursor cells to branched arterial and venous networks

by Anne Eichmann, Li Yuan, Delphine Moyon, Ferdinand Lenoble, Luc Pardanaud and Christiane Bréant

Tracing the hemangioblast during embryogenesis: developmental relationships between endothelial and hematopoietic cells

by Thierry Jaffredo, Karine Bollerot, Daisuke Sugiyama, Rodolphe Gautier and Cécile Drevon

α 1b integrin, a novel marker for hemopoietic progenitor cells

by Catherine Corbel, Pierre Vaigot and Josselyne Salaün

The human T cell immune response to Epstein-Barr virus

by Elise Landais, Xavier Saulquin and Elisabeth Houssaint

Development and function of bombesin-like peptides and their receptors

by Hiroko Ohki-Hamazaki, Maiko Iwabuchi and Fumihiko Maekawa

Sclerotome development and morphogenesis: when experimental embryology meets genetics

by Anne-Hélène Monsoro-Burq

Synchronised cycling gene oscillations in presomitic mesoderm cells require cell-cell contact

by Miguel Maroto, J. Kim Dale, Mary-Lee Dequéant, Anne-Cécile Petit and Olivier Pourquié

Running after the clock

by Catarina Freitas, Sofia Rodrigues, Leonor Saúde and Isabel Palmeirim

Three developmental compartments involved in rib formation

by Hirohiko Aoyama, Yoko Mizutani-koseki and Haruhiko Koseki

Antero-posterior patterning of the vertebrate digestive tract: 40 years after

Nicole Le Douarin's PhD thesis

by Anne Grapin-Botton

Mouse-chick neural chimeras

by Josiane Fontaine-Pérus and Yvonnick Chéraud

Vasculogenesis and angiogenesis in the mouse embryo studied using quail/mouse chimeras

by Michel Pudliszewski and Luc Pardanaud

The cap 'n' collar family member NF-E2-related factor 3 (Nrf3) is expressed in mesodermal derivatives of the avian embryo

by Heather C. Etchevers

Notch in vertebrates - molecular aspects of the signal

by Ken-Ichi Katsube and Kei Sakamoto

ORDER BY

Web: <http://www.intjdevbiol.com>

E-mail: ijdb@ehu.es

FAX: +34-94-601-3266

POST: to the address shown to the right

Price: US\$ 90 or Euro €70 per copy (including post and packaging)

The International Journal of Developmental Biology

Editorial Office, Uni. of the Basque Country

Faculty of Medicine, E-48940 Leioa

Vizcaya, SPAIN

