The migration of neural crest cells to the wall of the digestive tract in avian embryo

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SUMMARY

Isotopic and isochronic grafts of quail neural primordium in chick embryos have been made. Due to the particular structure of their nuclei, quail cells can be distinguished from chick cells and so be used as natural markers to study the migration of neural crest cells. We have been able to demonstrate by this technique that the parasympathetic enteric ganglion cells arise from two different levels of the embryonic neural axis which correspond to the vagal and lumbo-sacral parasympathetic centres. The main source of the enteric neuroblasts is located at the level of the somites 1–7. It gives rise to ganglion cells which migrate in the whole gut including the large intestine and rectum. The other region from which enteric neuroblasts originate is situated behind the level of the 28th somite and gives rise only to some post-umbilical gut ganglion cells. In this region of the intestine the ganglia are made up of a mixture of cells arising from the vagal and the lumbo-sacral levels of the neural axis. The part of the neural primordium between the 8th and the 28th somite does not participate in the formation of the enteric ganglia. The chronology of the enteric neuroblast migration has been studied. Most cells of vagal origin leave the neural crest before the 13-somite stage but the migration lasts sometimes until after the 16-somite stage. Those cells which have to reach the hind-gut level accomplish a long-term migration which can be evaluated at 6 days or more. The presumptive neuroblasts of lumbo-sacral origin are not found in the hind-gut before the 7th day of incubation. In our experiments we have never observed the migration of any quail cells into the endoderm of the chick host embryo. Therefore we consider that enterochromaffin cells of the digestive epithelium are not derived from the levels of the neural crest concerned in these experiments (i.e. rhombencephalic and medullary *Anlagen*).

INTRODUCTION

The origin of enteric ganglion cells is not yet clearly established. Possible sources originally suggested were endoderm (Masson, 1923; Schack, 1932) and local gut mesoderm (Camus, 1913; Tello, 1924, 1925; Keuning, 1944, 1948). These points of view are now considered ill-founded and it is recognized that the primitive neural *Anlage* (neural crest and/or neural tube) gives rise to the intestinal wall ganglion cells. However, authors do not agree on the level of the neural axis from which they derive. Some consider the trunk neural *Anlage* as a source of enteric ganglia (Abel, 1909, 1912; Uchida, 1927; Van Campenhout, 1930, 1931, 1932; Dereymaeker, 1943; Kuntz, 1953); others think they arise exclusively from the vagal levels (Yntema & Hammond, 1945, 1947,

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1952, 1954, 1955). Finally some workers admit a double source for these cells: vagal for the anterior part of the digestive tract and lumbo-sacral for the ganglion of Remak (Jones, 1942). Andrew, in a series of papers (1964, 1969, 1970) describing the results of transplanting embryonic fragments to the chorio-allantois, finds that the whole trunk as well as the vagal neural crest participates in the production of enteric ganglion cells. In view of these discrepancies, we thought that the cell labelling technique which one of us devised (Le Douarin, 1969) might contribute to enlighten this question, if applied to the problem. This technique, which has already been used to study neural crest cell migration (Le Douarin & Teillet, 1970, 1971 *a*, *b*; Teillet & Le Douarin, 1970; Teillet, 1971; Le Douarin & Le Lièvre, 1970, 1971; Le Lièvre, 1971) is founded on the structural differences in the interphase nuclei of the chick (*Gallus gallus*) and the quail (*Coturnix coturnix japonica*), which constitute stable, natural markers in experimental associations of tissues from both species: in the chick, the inter-phase chromatin is evenly dispersed in the nucleoplasm with only a few small chromocentres, in the quail a large amount of DNA is condensed in one or several strongly Feulgen-positive heterochromatic masses (Fig. 1*a*, *b*). More-over the two species are related intimately enough to permit a perfect integra-tion of tissues grafted from one to the other.

The experimental procedure consists in isotopic, isochronic grafting of frag-ments of quail neural *Anlage* at various levels of the chick embryo neural axis. The contribution of the grafted quail neural crest cells to the formation of intestinal wall ganglionic structures is thereafter studied in serial sections of the digestive tract stained by the Feulgen & Rossenbeck reaction (1924). The grafting technique, already used in the chick embryo by Weston (1963) with tritiated-thymidine-labelled cells, despite the excision of fragments of the neural primor-dium, reduces or even completely excludes the regulation processes which occur after deletion of an embryonic area at an early developmental stage. Previous experiments performed on neural-crest cell migration in the trunk region (Le Douarin & Teillet, 1971*a*) have shown that the quail crest cells migrate in the host by the same pathways as in normal developmental conditions. The histogenesis of the enteric ganglia is the main subject of this paper but our experiments also contribute to the problem of the origin of the enterochromaffin cells of the digestive epithelium – another controversial subject (see Andrew, 1963, for references). The possible origin of these cells from the neural crest has been suggested by various authors, and recently by Pearse (1969, 1971). This author pointed out that the gastro-intestinal enterochromaffin cells possess many cytochemical and ultrastructural characteristics in common with other endocrine cells known to produce polypeptide hormones and, in particular, with endocrine cells whose origin from the neural crest had been or has now been established. Among these are the adrenomedullary cells, and the calcitonin (C) cells of the ultimobranchial body (Le Douarin & Le Lièvre, 1970; Le Douarin, Le Lièvre & Fontaine, 1972) and thyroid gland (Pearse & Polak, 1971).
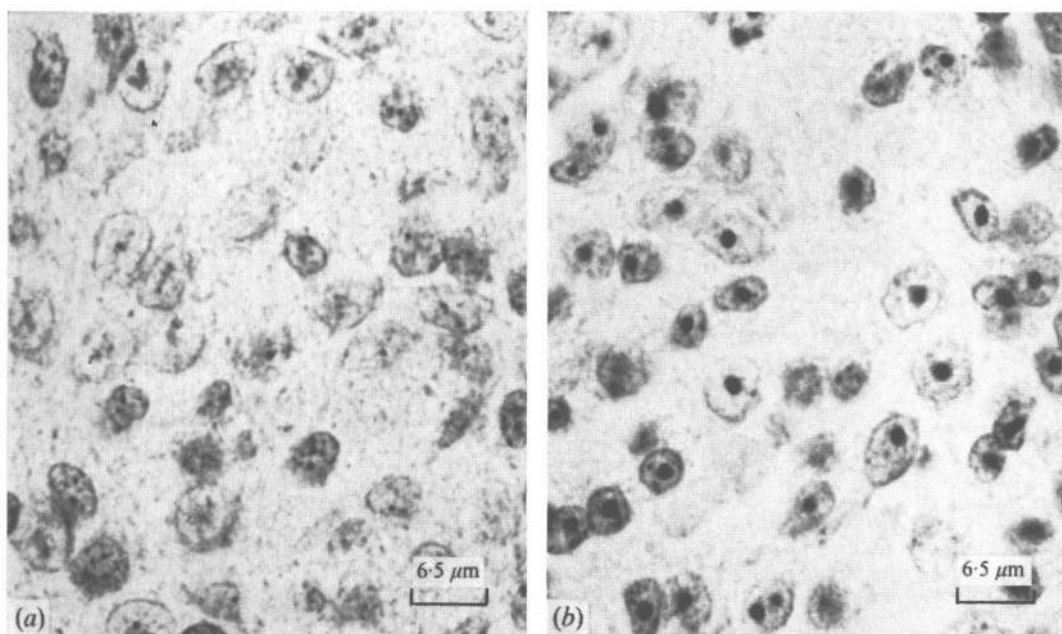
Fig. 1. (*a*) Enteric ganglion of an 11-day chick embryo in the gizzard. Feulgen and Rossenbeck staining. (*b*) Enteric ganglion of an 11-day quail embryo in the gizzard. Feulgen and Rossenbeck staining.

All these cells have the ability to take up the amino acid precursors of fluorogenic amines and they contain specific amino acid decarboxylases. For this reason they have been grouped together in the so-called 'APUD series' (Amine Precursor Uptake and Decarboxylation). It is possible to speculate that these common cytochemical and ultrastructural characteristics could indicate a common embryological origin.

MATERIAL AND METHODS

The experiments were performed on White Leghorn chick and Japanese quail embryos of 6- to 30-somite stages.

Microsurgical techniques

Fragments of neural *Anlage* are excised from chick embryos *in ovo* at various levels according to the experimental series. The neural tube is separated from the lateral mesoderm and the notochord by using a microscalpel. The result of the intervention can be seen on the Fig. 2(*a*). The older the embryos are, the more caudal is the level of intervention. The neural crest first appears in the head at the 6- to 7-somite stage and then forms progressively towards the tail shortly after the neural tube is established at each level. The neural crest cells very soon begin to migrate, so that excision of the neural *Anlage* must be done before or shortly after closure of the neural tube in order that all the crest cells
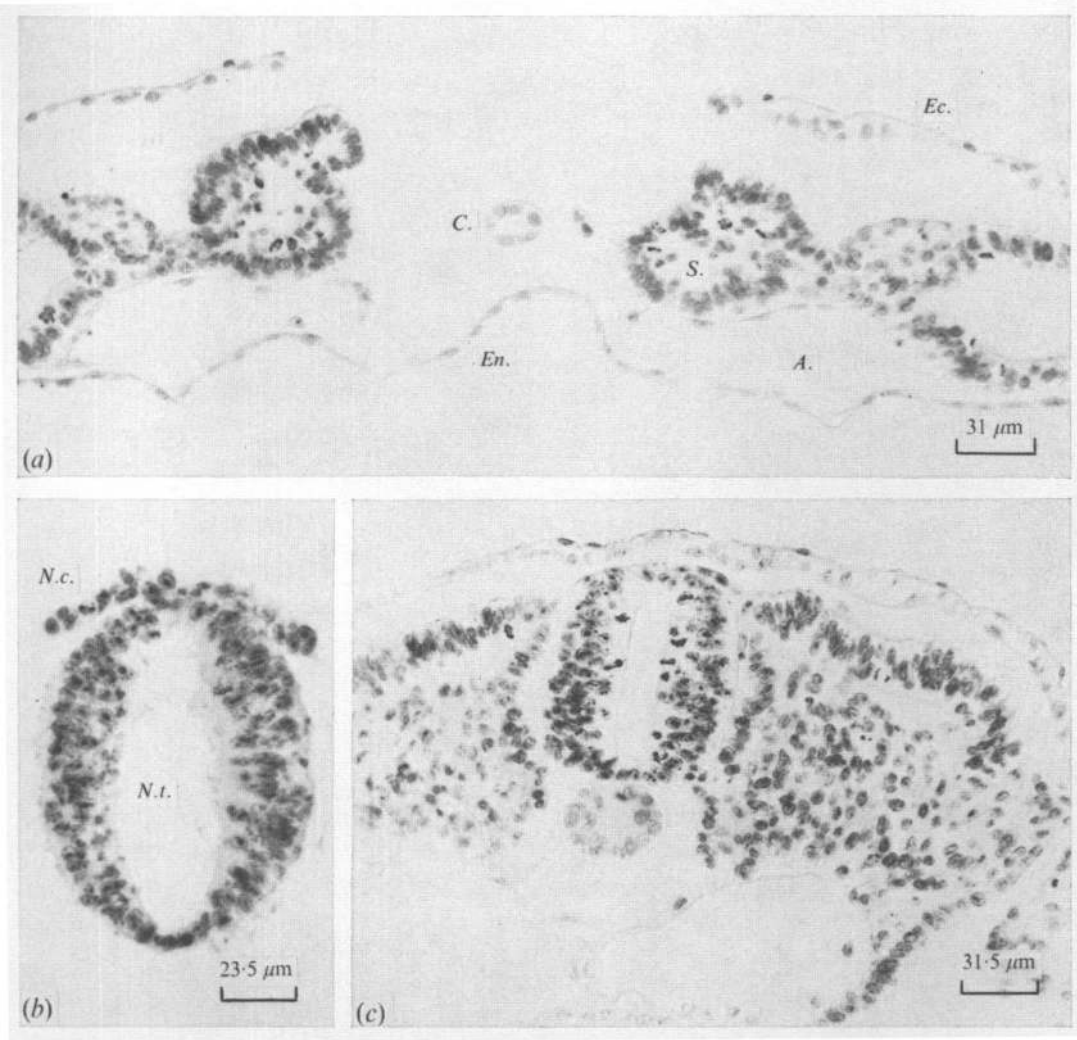
Fig. 2. Experimental procedure of the isotopic and isochronic graft of a fragment of quail neural *Anlage* in a chick embryo.

(*a*) Excision of the neural primordium in the chick. Transverse section through a 18-somite chick embryo after the excision of the neural *Anlage* between the 13th and the 18th somite. Feulgen and Rossenbeck staining.

(*b*) Neural tube (*N.t.*) with associated neural crests (*N.c.*) isolated from a 25-somite quail embryo. A transverse strip of the quail embryo, corresponding to the level of the 20th–25th somites, has been treated by a 0·1 % solution of trypsin in Ca–Mg-free Tyrode. After the dissociation the neural *Anlage* is completely devoid of neighbouring mesenchymal cells. Feulgen and Rossenbeck staining.

(*c*) The quail neural tube is implanted orthotopically in a chick embryo. Transverse section at the level of the graft in the chick host embryo 12 h after the operation. The quail neural tube is incorporated in the axial structures of the host and has been covered by the host ectoderm. Feulgen and Rossenbeck staining.

A., Dorsal aorta; *Ec.*, ectoderm; *En.*, endoderm; *C.*, notochorde; *N.c.*, neural crest; *N.t.*, neural tube; *S.*, somite.

are removed. When the operation is performed in the segmented region, the level elected is that of the posterior somitic area, and the most often that of the last 4 or 6 somites (Table 1, series 2–7). In some embryos of 6- to 11-somite stage (Table 1, series 1), the excision is made from the rhombencephalo-mesencephalic constriction to the level of the first somite. In older embryos (25–30 somites), the neural *Anlage* is excised in the posterior unsegmented part of the body (Table 1, series 8).

In a second step, the removed fragment of neural tube is replaced by a homologous neural segment of a quail embryo at the same developmental stage. The whole transverse strip of the donor quail blastoderm from the appropriate level is treated with 0·1 % trypsin in Ca-, Mg-free Tyrode's solution at 2 °C during 10–15 min. Then all the adherent tissues can be removed from the neural tube (Fig. 2b). Excess trypsin is eliminated by rinsing in Tyrode's solution with 10 % horse serum. The fragment of quail neural tube is grafted orthotopically in the chick host. The craniocaudal orientation of the quail neural tube can be done by marking its cranial end with carbon particles soon after the dissociation. The right dorsoventral orientation of the explants is easily achieved as they are lightly stained by neutral red before the graft. The quail neural tube usually incorporates well in the axial structures of the host and becomes covered by chick ectoderm a few hours after the intervention (Fig. 2c). The grafted neural tube undergoes normal histogenesis and the associated neural crest cells spread into the neighbouring chick mesenchyme and migrate through apparently normal pathways as judged from the histogenesis of well-known systems such as sensory ganglia, sympathetic chains, aortic plexus etc. (Le Douarin & Teillet, 1970).

Histological techniques

Only embryos which satisfy the following requirements (about 70 % of the surviving operated embryos) were retained for histological observation: good healing, normal location of the graft and absence of morphological anomalies of the host in the area of the graft. The presence of a transverse strip of quail-like pigmented feathers (Teillet & Le Douarin, 1970; Teillet, 1971) is a criterion of a successful graft.

The digestive tract of the host embryos is fixed at various ages according to the experimental series: from the 11th to the 18th day of incubation in the experiments performed to determine the level of origin of enteric ganglion cells, and much earlier, 3rd (stage 17–18 of Hamburger & Hamilton, 1951) and following days to study the chronology of the migration of the presumptive neuroblasts.

When the embryos are fixed from the 9th incubation day to the end of the incubation, the gut is divided into several parts (Fig. 3) and fixed in Zenker's or Bouin's fluid. Following Zenker fixation, serial sections of the gut are treated by Feulgen & Rossenbeck's reaction (1924). Following Bouin, sections from the same block are mounted alternately on two different slides; one slide is treated

Table 1. *Presence of quail cells in the digestive tract of the chick embryo host after the graft of a quail Anlage*

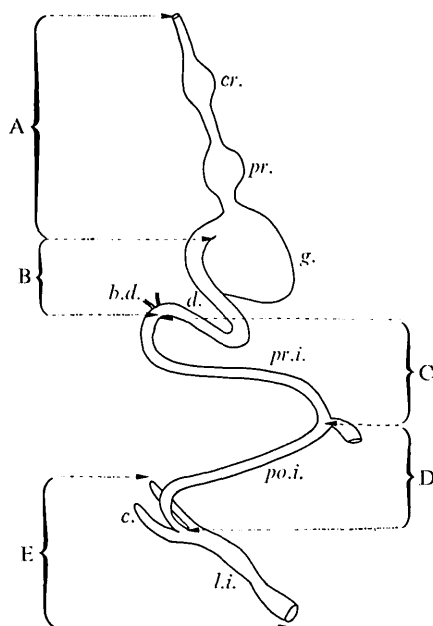| Experimental series	Stage of the embryos at the moment of the graft	Level of the graft	Nos. of embryos observed	Parts of the digestive tract of the chick host				
				A	B	C	D	E
1	6–11 somites	From the rhombo-mesencephalic constriction to the 1st somite	8	1	0	0	0	1
2	6–9 somites	From the rhombo-mesencephalic constriction to the 6th somite	17	16	16	16	16	16
3	6–9 somites	From the 1st to the 6th somite	12	12	2	12	12	12
4	8–11 somites	From the 4th to the 9th somite	10	9	9	9	9	9
5	8–13 somites	From the 6th to the 10th somite	11	8	8	8	8	8
6	13–18 somites	From the 7th to the 13th somite	11	2	0	0	0	0
7	13–30 somites — 13 to 15 somites	From the 8th to the 13th somite	5 ⎫	0	0	0	0	0
	15 to 18 somites	From the 10th to the 15th somite	4 ⎪	0	0	0	0	0
	18 to 20 somites	From the 13th to the 18th somite	10 ⎬ 51	0	0	0	0	0
	22 to 24 somites	From the 18th to the 22nd somite	11 ⎪	0	0	0	0	0
	25 to 27 somites	From the 21st to the 25th somite	14 ⎪	0	0	0	0	0
	28 to 30 somites	From the 23rd to the 28th somite	7 ⎭	0	0	0	0	0
8	25–30 somites	Unsegmented part of the body	14	0	0	0	5	9

Fig. 3. Diagram showing the different parts of the gut observed. (A) *cr.*, Crop; *pr.*, proventricule; *g.*, gizzard. (B) *d.*, Duodenum; *b.d.*, biliary ducts. (C) *pr.i.*, Pre-umbilical ileum. (D) *po.i.*, Post-umbilical ileum. (E) *c.*, Caeca; *l.i.*, large intestine.

by the silver reaction according to Tinel (in Gabe, 1968) and the other by the Feulgen reaction. Thus, in adjacent sections, the same cells may be identified as to species by Feulgen staining and as to ganglionic nature by silver impregnation. When the embryos are sacrificed between the 3rd and 9th days of incubation, they are fixed in Zenker's fluid, and the serial transverse sections of the whole embryo are stained by Feulgen and Rossenbeck's technique.

RESULTS

1. *Determination of the level of origin of enteric ganglion cells*

The results of experimental series involving grafts at various levels of the chick host neural axis are summarized in Table 1. When the quail neural tube is grafted from the mesencephalo-rhombencephalic constriction to the 1st somite, quail cells are found in the digestive wall of the host in 1 case out of 8 embryos. In this single case, only a few quail cells are found. In the seven other cases the intramural ganglion system is exclusively made up of chick cells.

In experimental series 2–4, quail cells have colonized the digestive tract of the host embryo and are present in the two ganglionic plexuses – the inner, sub-mucous plexus of Meissner and the outer, myenteric plexus of Auerbach. Many ganglia exclusively formed by quail cells are found in the regions A, B and C of the gut, down to the level of the umbilicus (Figs. 4, 5, 9). In series 2 and 3, very
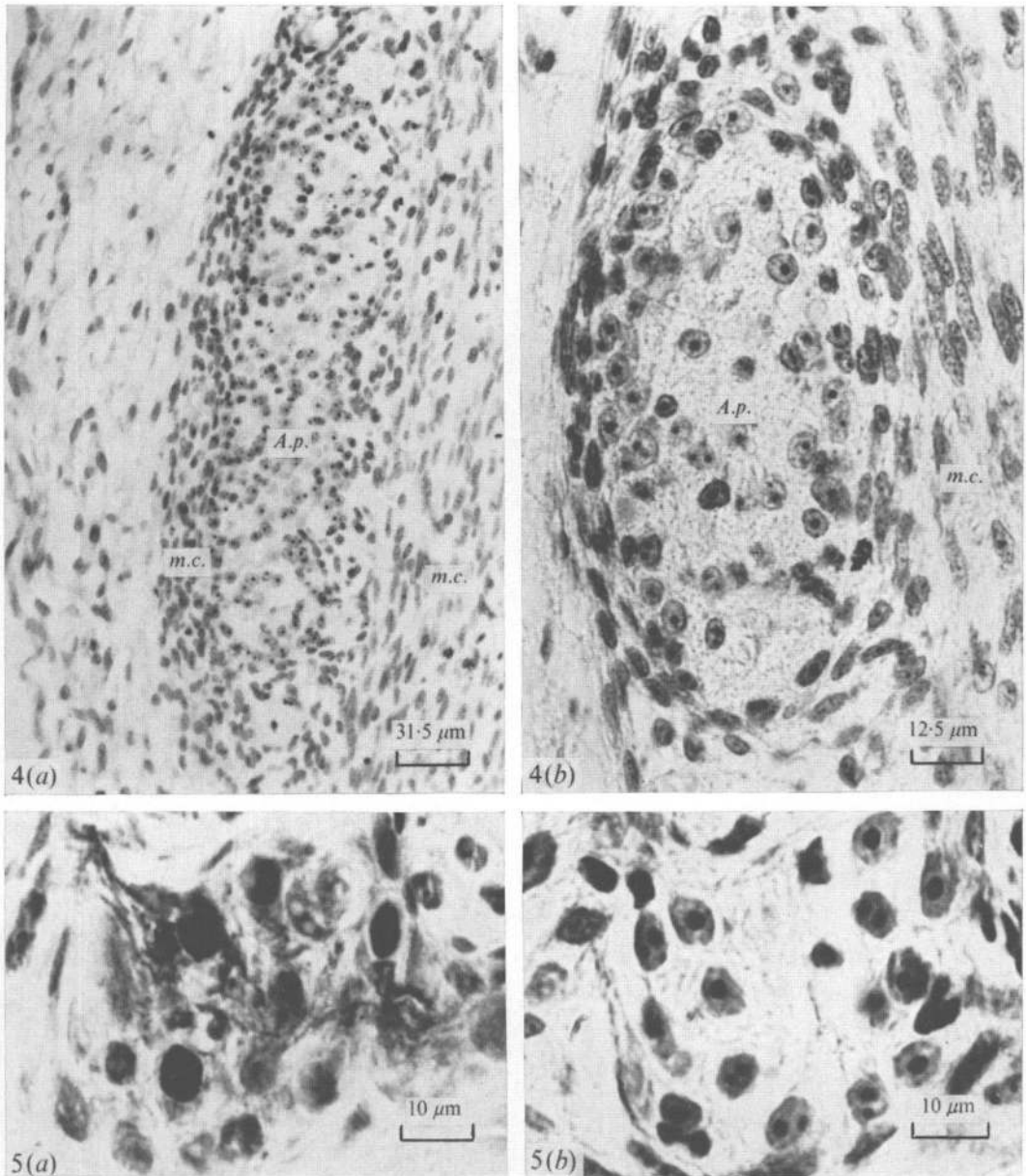
Fig. 4. Sections through the gizzard of an 11-day chick embryo which has received at 7-somite stage an isotopic graft of quail neural tube at the level of the 1st to the 6th somites. The ganglia of Auerbach's plexus (*A.p.*) are made up of quail cells. *m.c.*, Muscle cells of the host embryo gizzard. Feulgen and Rossenbeck staining.

Fig. 5. Ganglion in the wall of the pre-umbilical gut of an 18-day chick embryo which has received at the 8-somite stage an isotopic and isochronic graft of a quail neural *Anlage* at the level of the 1st to the 6th somites. (*a*) Silver impregnation according to Tinel. (*b*) Feulgen and Rossenbeck staining on the section immediately adjacent.

few chick ganglion cells are found in these levels of the gut. In the posterior parts (D and E) of the digestive tract most ganglion cells are of quail origin but they are mixed with some chick elements. In experimental series 5, ganglia all along the digestive tract contain mixed quail and chick cells (Fig. 6), except the ganglion of Remak, which contains only chick cells.

In experimental series 7, where the quail neural tube was grafted between the 8th and 28th somites at various levels and on a length of 4–6 somites (Table 1), no quail cells are found in Auerbach's or Meissner's plexus in any part of the digestive tract in 51 experimental embryos. One can see on Fig. 8 a transverse section of the pre-umbilical small intestine of a chick embryo on which a fragment of quail neural tube has been grafted at 13-somite stage at the level of the 8th to 13th somites; the ganglia are made up of chick cells. This result can be compared to that which is obtained when the graft has been performed at the level of the somites 1–6 (Fig. 9). In this latter case, the ganglionic cells derive from the quail grafted tissue.

When the neural tube is grafted behind the 28th somite (series 8), quail cells are once again encountered in the enteric ganglia but only in the D and E regions of the gut. In these cases, the ganglia are never entirely made up of quail cells (Fig. 7).

In this last experimental series the ganglion of Remak contains many cells from the graft. In embryos grafted at the 25 to 30-somite stage with the whole posterior neural tube behind the presumptive or real level of somite 28, that part of the ganglion of Remak located in the post-umbilical gut is entirely composed of quail cells (Fig. 10).

2. *Chronology of the migration of the vagal presumptive enteric neuroblasts*

The chronology of migration has been studied for neuroblasts migrating to the gut from the vagal level. Two different aspects have been considered: the stage at which all presumptive enteric neuroblasts have left the vagal *Anlage* and the time of their arrival at the different levels of the gut. Some observations have also been made concerning the migration of the neuroblasts coming from the lumbo-sacral level of the neural axis.

(a) *The start of migration of the enteric neuroblasts*

Late extirpation of the neural tube and neural crest of the chick was performed between somites 1 and 8 and was followed by isotopic and isochronic grafts of quail neural tube and crest, between the 13-somite and the 16-somite stages. In all the 20 cases observed, quail cells were present in the enteric ganglia, but only a few quail cells participated in the formation of these structures when the graft was done after the 14-somite stage. In these cases the enteric ganglia contained a large number of chick cells.

6 A.p. M.p. 10 µm

7 M.p. 10 µm

8 15 µm

9 A.p. M.p. 15 µm
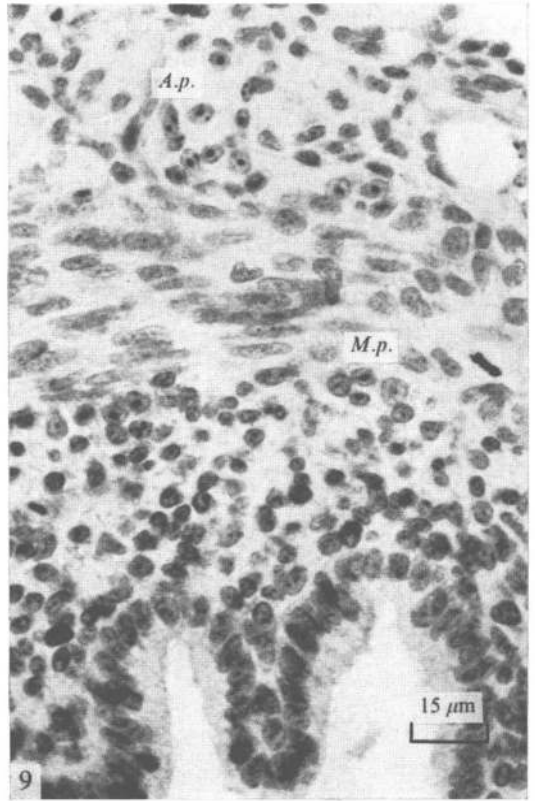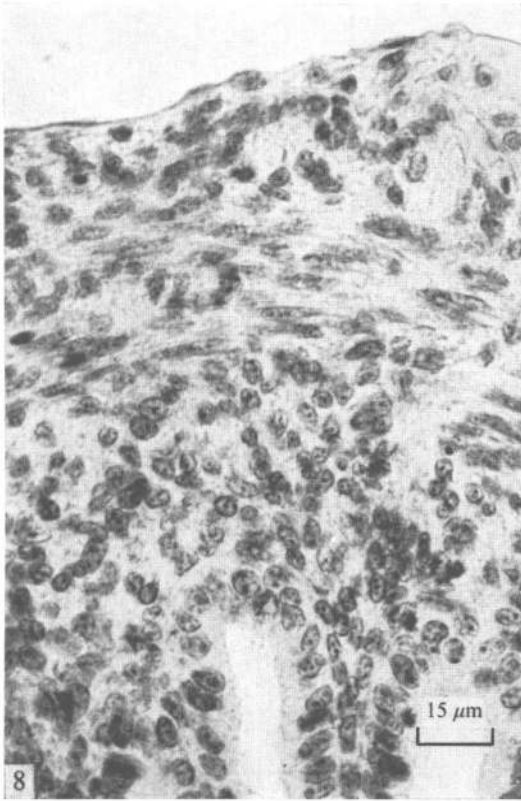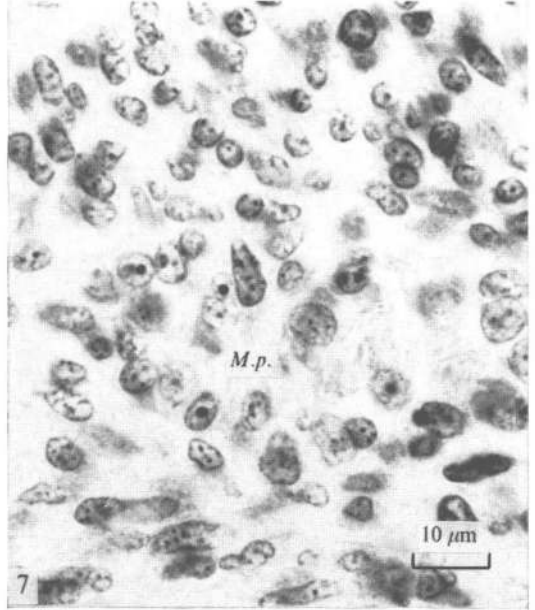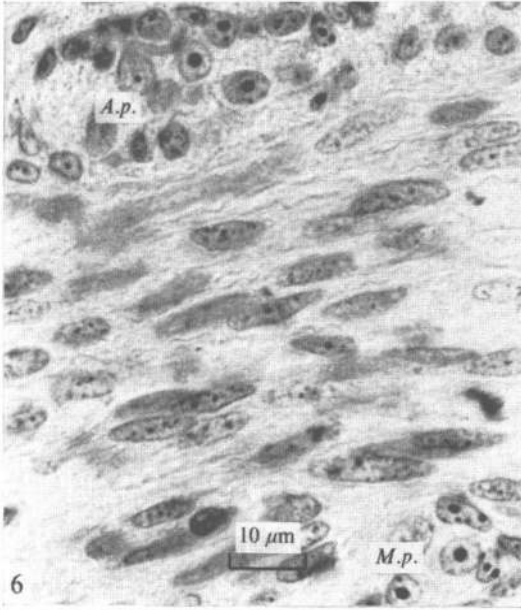
(b) The arrival of neuroblasts at the different levels of the gut

Isotopic and isochronic grafts of quail neural primordium were performed at the level of 1st–8th somite in 8 to 12-somite stages. The host embryos were fixed *in toto* at various times after the intervention and the colonization of chick host gut by quail neuroblasts was followed. Twenty embryos of this series have been observed.

In the 3-day-old chick embryo (stage 17–18 of Hamburger & Hamilton, 1951) quail cells can be found in the differentiating oesophagus (two embryos examined).

In one embryo (stage 20 of Hamburger & Hamilton) quail cells were present in the digestive wall down to the level of the hepatic ducts.

At 5 days of incubation, the enteric neuroblasts have colonized the gut down to the level of the umbilicus; they do not appear in the rectum before 8–8·5 days of incubation.

These results show that some neural crest cells accomplish long-term migrations which may last 6 days or more.

In the front of the migration, the presumptive neuroblasts, which are not numerous, are scattered in the splanchnopleural mesenchyme (Fig. 11). Later they become distributed in the presumptive Auerbach and Meissner plexuses when the muscular layers of the gut begin to differentiate at each level.

The migration of the lumbo-sacral presumptive neuroblasts was followed in embryos which had received a graft of quail neural tube behind the level of the 28th somite at the 28-somite stage. In our experimental conditions, quail cells from this source are not found in the hind-gut before the 7th day of incubation.

FIGURES 6–9

Fig. 6. Transverse section through a caecum of a 14-day chick embryo after the isotopic and isochronic graft of a quail neural *Anlage*, at 9-somite stage between the 6th and the presumptive level of the 10th somites. Ganglia of the Auerbach (*A.p.*) and the Meissner (*M.p.*) plexus are made up of a mixture of quail and chick cells. Feulgen and Rossenbeck staining.

Fig. 7. Transverse section through the rectum of a 14-day chick embryo after the graft of a quail neural *Anlage*, at 28-somite stage, behind the level of the 28th somites. Feulgen and Rossenbeck staining. *M.p.*, Meissner plexus ganglion in which chick and quail cells are mixed.

Fig. 8. Transverse section through the pre-umbilical ileum of an 11-day chick embryo which has received at 13-somite stage an isotopic and isochronic graft of quail neural *Anlage* between the 8th and the 13th somites: cells originating from the quail neural grafted tissue are completely absent in both Auerbach's and Meissner's plexuses. Feulgen and Rossenbeck staining.

Fig. 9. Transverse section through the pre-umbilical ileum of an 11-day chick embryo which has received at 8-somite stage an isotopic and isochronic graft of quail neural *Anlage* between the 1st and the 6th somites. We can see quail cells in differentiating ganglia of Auerbach's and Meissner's plexus. Feulgen and Rossenbeck staining.
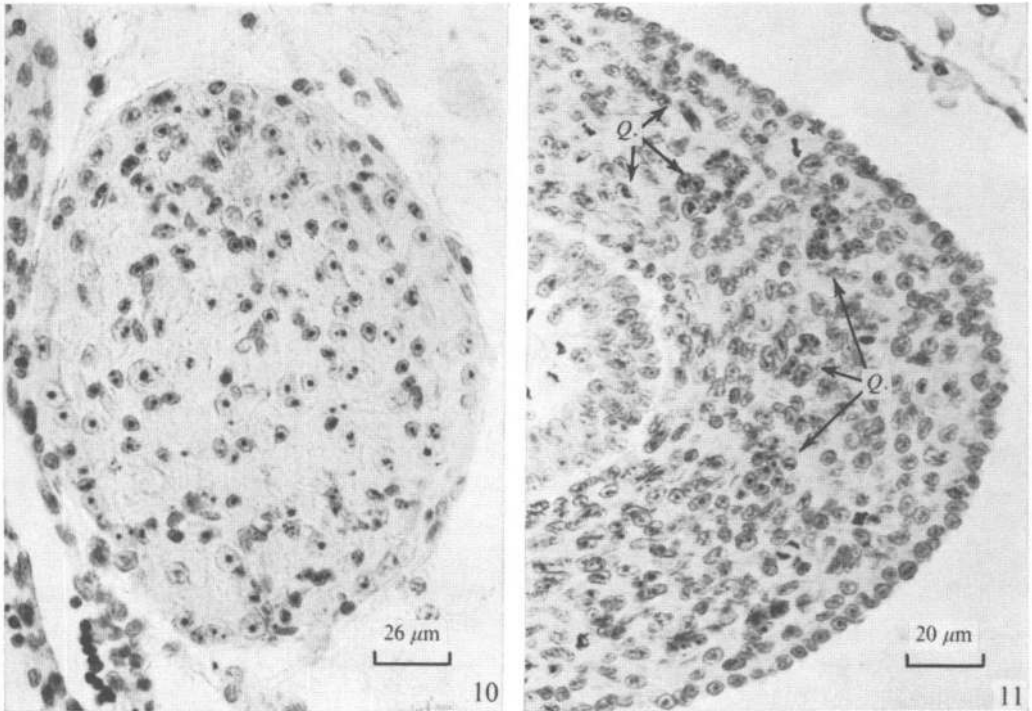
Fig. 10. Transverse section in the post-umbilical region of the gut of a 14-day chick embryo after the isotopic graft of a quail neural tube behind the level of the 28th somite at 28-somite stage. Cells of the ganglion of Remak are of graft origin. Feulgen and Rossenbeck staining.

Fig. 11. Transverse section through the duodenum of a 6·5-day chick embryo after the graft of a quail neural primordium between the 1st and the 6th somite at the 9-somite stage. The quail neuroblasts (Q.) are dispersed in the mesenchyme of the chick host duodenum. Feulgen and Rossenbeck staining.

The formation of the ganglion of Remak precedes the colonization of the hind-gut by the enteric ganglion cells. In the embryos operated in the posterior region of the neural axis (from the 28th somite to the end of the neural tube) one can find quail cells in the ganglion of Remak as soon as the 5th incubation day.

3. *The problem of the origin of enterochromaffin cells of the digestive epithelium*

We have submitted the hypothesis of the neural crest origin of enterochro-maffin cells to an experimental test by using the method described in the present paper. After having grafted fragments of the quail neural primordium at the various levels of the neural axis in chick embryos (Table 1) we looked for a possible migration of quail cells into the digestive epithelium of the host. In the 134 embryos examined, on serial sections of the digestive tract, we could find no quail cells in the endoderm of the chick host, even when the enteric ganglia belonged entirely to the grafted tissue. In these embryos, enterochromaffin cells were present in the digestive epithelium, but they belonged to the chick host.

CONCLUSION AND DISCUSSION

1. *Origin of enteric ganglion cells*

The experiments reported above indicate a double origin of enteric ganglion cells from two different levels of the neural axis. The most important contribution to these structures is from the neural crest corresponding to the posterior rhombencephalon located approximately at the level of somites 1 to 7. The results summarized in Table 1 show indeed that the most enteric ganglia of the host embryo are made up of quail cells when an orthotopic graft of a quail neural *Anlage* has been performed between the level of the 1st and the 7th somites (Table 1, series 2–4). In one case (Table 1, series 1) we have found a few quail cells in the enteric ganglia after the graft of the anterior part of a quail rhombencephalon in a chick and in two cases (Table 1, series 6) the same result has been obtained following a graft including the level of the 7th somite. Then it seems that the 1st and the 7th somite levels constitute the fringe area of the neural *Anlage* from which the enteric ganglion cells derive. The second source of these cells is the part of the lumbo-sacral spinal cord situated behind the level of the 28th somite. This part of the neural axis furnishes some neuroblasts to the post-umbilical gut, and is the main source of the cells which migrate to the ganglion of Remak (Fig. 12). It appears that the cervical and dorsal parts of the medullary neural *Anlage* do not participate in the formation of the enteric ganglia.

Of the previous works devoted to the problem of the origin of enteric ganglia which have been extensively analysed and criticized by Andrew (1971) we will discuss only the most recent ones.

Our results are in agreement with those of Yntema & Hammond (1952, 1954, 1955) and Andrew (1970). These authors had shown that the vagal level of the neural axis gives rise to enteric ganglion cells. However, we do not agree with Yntema & Hammond (1954) regarding their opinion that all the enteric neurons come from this anterior level; we have in fact demonstrated a participation of lumbo-sacral neural primordium. Yntema & Hammond procured their evidence for the origin of enteric ganglia exclusively from the rhombencephalic neural primordium, by crest excision performed *in ovo*. They removed the dorsal part of the neural tube and the neural folds at vagal levels from embryos at 5 to 14-somite stages, and observed the lack of intramural ganglia in the embryos at 7- to 10-day incubation age. A possible explanation is that at this stage ganglion cells of lumbo-sacral origin have not yet differentiated.

On the other hand, the statement of Andrew (1969), that the whole trunk neural *Anlage* can give rise to the intestinal wall ganglia, is not confirmed by our results. The experimental approach of this author consists in the graft of fragments of young blastoderms in chorioallantois. It can be underlined that chorioallantoic grafts do not allow a normal morphogenesis of the embryonic structures, and if this technique can give interesting results concerning the developmental capabilities of the cells, it is not reliable for studying the normal

1st somite

7th somite
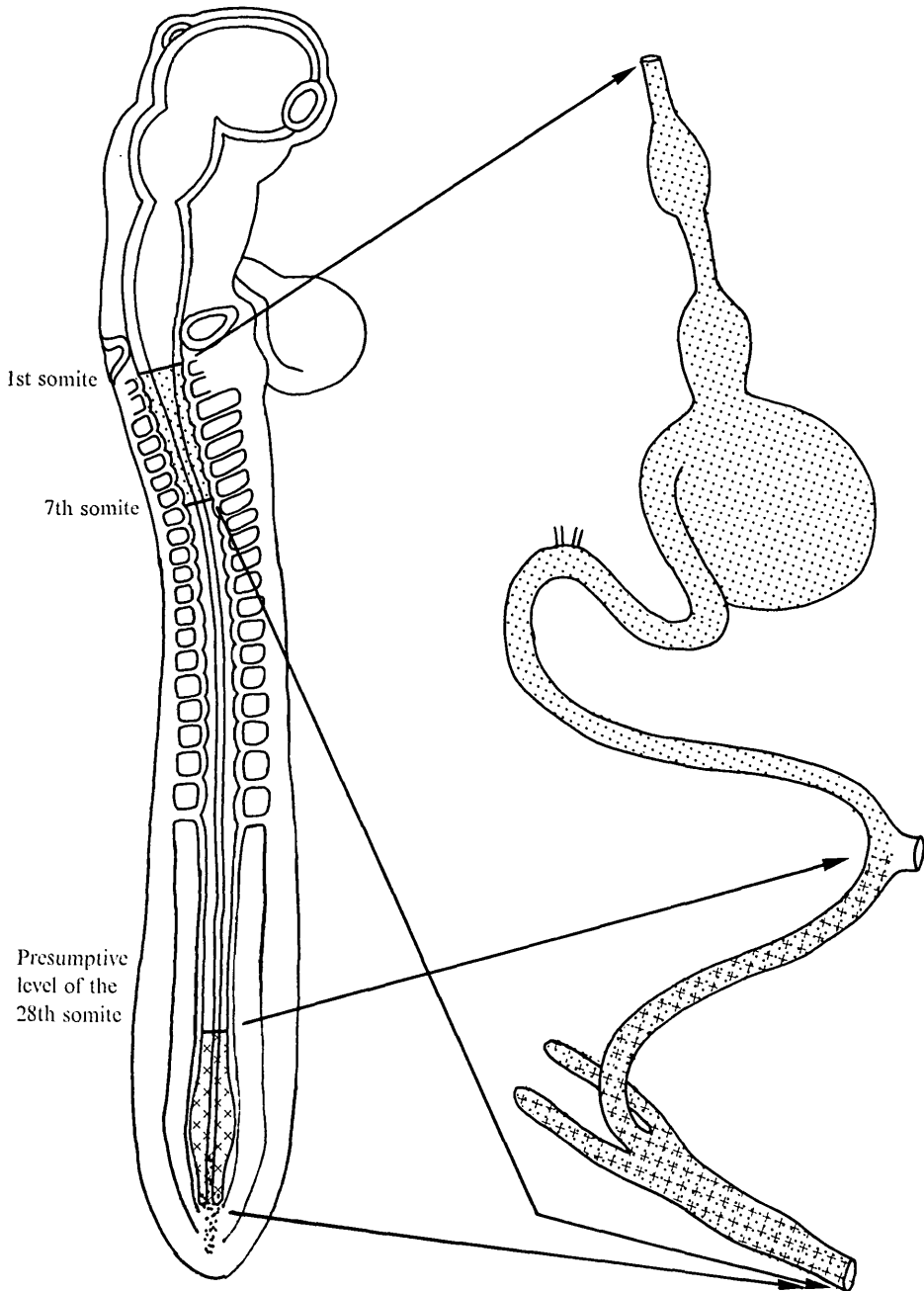
Presumptive
level of the
28th somite

Fig. 12. Diagram showing the anterior and posterior levels of the embryonic neural axis from which the enteric ganglion cells originate. The neuroblasts arising from the anterior level (comprised between the 1 and 7 somites) colonize the whole gut. Those which come from the posterior level located behind the 28th somite contribute only to the formation of the ganglia of the post-umbilical gut. The neural crest of the cervical and dorsal region (from the 8 to 28 somites) does not give rise to enteric ganglion cells.

migration pattern of the crest cells, which is undoubtedly controlled, at least partially, by the development of the surrounding embryonic structures. Our experiments show that in the normal developmental conditions, the trunk neural *Anlage* does not participate to the formation of the enteric ganglia but they do not confirm the previous Andrew's statement that this region of the neural axis has the ability to provide enteric ganglion cells in certain experimental conditions.

Concerning the chronology of the enteric neuroblasts migration, Yntema & Hammond (1954) found that extirpation experiments in the vagal region were unsuccessful in eliminating enteric ganglia, if performed after 9-somite stage. They concluded that crest migration must have started by the 10-somite stage. We can add to these findings that, in our experimental conditions, the migration of the presumptive enteric neuroblasts of vagal origin is most active before the 13-somite stage and continues sometime after the 16-somite stage. Well-individualized neural crest cells are no longer present in the vagal region, from about the 13-somite stage, neither in the quail nor in the chick. Thus, even after the neural crest has disappeared and seems completely dispersed, cells still leave the neural *Anlage*. Some participation of the neural tube in this process cannot be excluded, since our experimental intervention involves the neural tube, in addition to the crest. But as it has been previously demonstrated by Yntema & Hammond (1955), the neural crest is surely the main source of these structures.

2. *The problem of the ectodermal origin of enterochromaffin cells*

Our experiments show that the enterochromaffin cells of the digestive epithelium do not arise from the rhombencephalic or the medullary neural crest. If they are of ectodermal origin, they either come from more cephalic regions of the neural primordium, or they invade the endoderm from the ectodermal layer, at an earlier developmental stage than those used in the present experiments. Our results confirm those of Andrew (1963), who considered that the enterochromaffin cells of the gut do not derive from the neural crest.

RÉSUMÉ

L'origine des cellules ganglionnaires parasympathiques de la paroi du tube digestif a été étudiée par la technique des greffes isotopiques et isochroniques de l'ébauche neurale de caille sur l'embryon de poulet. Grâce à la structure particulière de leur noyau, les cellules de la caille japonaise se distinguent de celles du poulet et peuvent être utilisées comme 'marqueurs' pour l'étude de la migration des cellules des crêtes neurales. Nous avons pu démontrer par cette méthode que les cellules ganglionnaires parasympathiques de la paroi intestinale proviennent de deux niveaux distincts du névraxe embryonnaire correspondant aux centres parasympathiques vagal et lombo-sacré. La principale source des neuroblastes entériques est localisée au niveau du névraxe correspondant aux somites

1 à 7. Les neuroblastes issus de cette région accomplissent des migrations étendues puisqu'ils se dispersent dans l'ensemble du tube digestif y compris l'intestin postérieur. La seconde source de cellules ganglionnaires entériques se situe en arrière du niveau des 28èmes somites. Elle fournit des cellules ganglion- naires au tube digestif post-ombilical. Dans cette région, les ganglions des plexus d'Auerbach et de Meissner ont une double origine, vagale et lombo-sacrée. La partie du névraxe comprise entre les niveaux des 8èmes et 28èmes somites ne participe pas à la genèse des ganglions intramuraux du tractus digestif. La plupart des cellules destinées à fournir les neuroblastes entériques quittent les crêtes neurales vagales avant le stade de 13 somites. Toutefois, quelques cellules se détachent encore de l'ébauche neurale jusqu'au stade de 16 somites et quelque peu au-delà. La migration des cellules qui se localisent dans l'intestin postérieur est d'une durée qui peut être évaluée à 6 jours environ. Les cellules ganglion- naires entériques issues de la moelle lombo-sacrée n'atteignent l'intestin que vers le 7ème jour de l'incubation. Nous n'avons jamais observé au cours de nos expériences la migration de cellules de caille dans l'endoderme de l'embryon de poulet hôte. Nous considérons donc que les cellules entérochromaffines de l'épithélium digestif ne dérivent pas des niveaux rhombencéphaliques et médul- laires des crêtes neurales.

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