THE JOURNAL OF COMPARATIVE NEUROLOGY 231:27-41 (1985)

Embryonic Development of the Rat Cerebellum. II. Translocation and Regional Distribution of the Deep Neurons

JOSEPH ALTMAN AND SHIRLEY A. BAYER
Laboratory of Developmental Neurobiology, Department of Biological Sciences, Purdue University, West Lafayette, Indiana 47907 (J.A.), and Department of Biology, Indiana University-Purdue University, Indianapolis, Indiana 46223 (S.A.B.)

ABSTRACT

In thymidine radiograms and plastic-embedded sections, the migration of cerebellar deep neurons was traced from their germinal source to their final settling sites. The route proved to be roundabout and three developmental events could be distinguished during the process. First, between days E14 and E16, transversely oriented cells of the nuclear transitory zone move in an arc from the ventrolateral neuroepithelium of the lateral cerebellar primordium in a medial direction. Second, between days E16 and E18, the cells of the rostral component of the nuclear transitory zone assume a longitudinal orientation. We postulated that this is the period of axonogenesis, the longitudinally oriented cells issuing efferents that join the superior cerebellar peduncle ipsilaterally and the transversely oriented cells (representing the neurons of the caudal fastigial nucleus) sending decussating fibers to the uncinate fasciculus (the hook bundle of Russell). Third, between days E18 and E21, the earlier-produced superficial cells of the nuclear transitory zone and the later-produced deep cells of the cortical transitory zone (the young Purkinje cells) exchange positions. The descent of the deep neurons is in the direction of the fibers of the inferior cerebellar peduncle, which becomes distributed throughout the cerebellum on day E17. The ascent of the Purkinje cells is in the direction of the external germinal layer, which begins to spread from caudal to rostral on day E17. The three deep nuclei, the lateral (dentate), interpositus, and medial (fastigial), can be distinguished before their descent into the depth of the cerebellum, and by day E22 a small-celled and a large-celled subdivision is identifiable in each nucleus.

Key words: cerebellar development, deep cerebellar nuclei, cell migration, Purkinje cells

Rüdeberg ('61) proposed that an embryonic cell mass in the bovine and human cerebellar region, which he called migration A_2B_1, represents the future lateral (dentate) nucleus. Korneliussen ('67, '68), who investigated the development of the cerebellum in Cetacea and the rat, disputed this suggestion on the grounds that migration A_2B_1 is situated outside the boundaries of the future cerebellum (for an illustration, see Altman and Bayer, '85a: Figs. 6, 7). We postulated in an earlier report (Altman and Bayer, '78) that this cell mass, representing the earliest-differentiating cells of the cerebellum, is composed of young neurons of the deep nuclei because these are the earliest-generated cells of the cerebellum. Accordingly, we called this superficially located cell layer the nuclear transitory zone. In the preceding paper of this series (Altman and Bayer, '85a) we obtained some supporting evidence for this view. We found that a differentiating zone composed predominantly of cells produced on day E14 (which is the time when, according to thymidine radiographic evidence, the bulk of the deep neurons are produced; Altman and Bayer, '78) is apparently migrating medially from its ventrolateral source to form the nuclear transitory zone. We also noted that by day E18 (Altman and Bayer, '85a: Fig. 20C) this cell group has become separated from another, evidently extracerebellar cell mass, and now lies within the corpus of the developing cerebellum. Still, this identification of a *superficially* situ-

Accepted August 8, 1984.

ated early embryonic cell group with nuclei that characteristically are situated in the *depth* of the cerebellum presents a problem to be resolved.

In this report, we shall present further evidence of the early transverse migration of cells from the ventrolateral neuroepithelium dorsomedially to the nuclear transitory zone. Furthermore, we shall show that the nuclear transitory zone, which is situated superficially on day E17, becomes translocated on the subsequent days into the depth of the cerebellum, exchanging position with the Purkinje cells that migrate from the depth of the cerebellar primordium to its surface. We shall also describe some observations on the differentiation of these cells, the relationship between the translocation of the young deep neurons and the ingrowth of the inferior cerebellar peduncle, and, finally, the settling patterns of neurons of the deep nuclear complex.

MATERIALS AND METHODS

The material used in this study was identical with that utilized in the previous investigation and described there in detail (Altman and Bayer, '85a). Special use was made of the thymidine radiograms from embryos labeled with ^{3}H-thymidine on days E14 and E15 and killed thereafter at daily intervals up to day E22 and of the methacrylate-embryos, ages E17–E22.

RESULTS

Translocation of the deep neurons from the surface to the depth of the cerebellum

The superficial location of the nuclear transitory zone on day E17 was previously illustrated in sagittal and coronal sections (Altman and Bayer, '85a: Figs. 7, 17B). In horizontal sections of the cerebellum of rats of the same age two components of the nuclear transitory zone are distinguishable dorsally (Figs. 1A, 2A): a broader band situated caudally, composed of spindle-shaped, transversely oriented cells, and a more compact mass of small cells rostrally; the latter are interpreted as longitudinally oriented spindle-shaped cells (see Altman and Bayer, '85a: Figs. 7, 19). Ventrally, at a level reached by the dispersing external germinal layer (EGL) and with a Purkinje cell layer present (Figs. 1B, 2B; compare with Altman and Bayer, '85a: Fig. 7), the nuclear transitory zone is absent on day E17. The translocation of the medial component of the nuclear transitory zone from the dorsal to the ventral region of the cerebellum to form the medial (fastigial) nucleus is illustrated in a series of sagittal radiograms from rats injected with ^{3}H-thymidine on day E15 and killed between day E17 and E21 (Fig. 3). In the rat killed on day E17 (Fig. 3A), the nuclear transitory zone, composed predominantly of unlabeled cells, seems to lie outside the trajectory of the EGL. By day E18 (Fig. 3B), as the depth of the cerebellum decreases in association with the shrinkage of the ventricular neuroepithelium, the nuclear transitory zone gets situated beneath the trajectory of the EGL within the body of the cerebellum. By day E19 (Fig. 3C) the unlabeled cells of the nuclear transitory zone, now recognizable as the medial nucleus, come to lie under a contingent of labeled cells that apparently migrated superficially from the cortical transitory zone. Finally, by day E21 (Fig. 3D) the latter cells settle as the late-generated Purkinje cells of lobules IV-V of the anterior lobe, and the earlier-generated cells of the medial nucleus occupy their terminal position.

A corresponding series of plastic sections showed that on day E17 (Fig. 4A) the cells of the superficial nuclear transitory zone are all small (that is, they are spindle-shaped, transversely oriented; Fig. 2A) but by day E18 (Fig. 4B) those cells that seem to be translocating ventrally are larger and become vertically oriented. By day E19 (Fig. 5) the medial nucleus has sunk deeper and most of its cells, except those situated most dorsally, display a more mature appearance. Some of the cells may be migrating in a caudal direction, occupying space vacated by the Purkinje cells that migrate dorsally to form lobule VI. By day E20 (Fig. 6A) all the cells of the medial nucleus are in their final position. Cell packing density is still high and the growth of the medullary layer between the Purkinje cell layer and the medial nucleus is just beginning. By day E21 (Fig. 6B) the dispersal of the neurons of the medial nucleus is more advanced and the bulk of the medullary layer has increased greatly.

Essentially the same developmental pattern was seen more laterally in the region of the interpositus nucleus (Figs. 7, 8). On day E17 the cells of the future interpositus nucleus (Fig. 7A, label lc) can be distinguished from the lateral tip of the future medial nucleus (Fig. 7A, label tc) by their longitudinal orientation. The onset of descent to the depth of the cerebellum is less clear on day E18 (Fig. 7B) than in the medial nucleus (Fig. 4B) but is unquestionable by day E19 (Fig. 8A). It appears that on this day the nuclear transitory cells reach a position previously occupied by fibers of the inferior cerebellar peduncle (Fig. 7). By day E20 (Fig. 8B) the neurons of the interpositus nucleus are in their terminal position.

Abbreviations

c	caudal	tc	transversely oriented cells	LV	lateral vestibular nucleus
CE	cerebellar primordium	v4	fourth ventricle	Me	medial eminence
ctz	cortical transitory zone	v4lr	lateral recess of fourth ventricle	ML	medullary layer
EGL	external germinal layer	WH	white matter of cerebellum	MN	medial (fastigial) nucleus
GT	germinal trigone	III	vermian lobule III; lobulus centralis, dorsal	MNc	medial nucleus, caudal part
hb	hook bundle of Russell	IV	vermian lobule IV; culmen, ventral	MNr	medial nucleus, rostral part
ic	isthmal canal	V	vermian lobule V; culmen, dorsal	NIV	trochlear nucleus
icp	inferior cerebellar peduncle	VBC	trigeminal boundary cap	nV	trigeminal nerve
if	intermediate fibrous layer	VN	trigeminal nerve	NE	neuroepithelium
IN	interpositus nucleus	VI	vermian lobule VI; declive	ntz	nuclear transitory zone
INc	interpositus nucleus, caudal part	VII	vermian lobule VII; tuber	PO	pons
lc	longitudinally oriented cells	VIII	vermian lobule VIII; pyramis	PL	Purkinje cell layer
LN	lateral nucleus	VIIIBC	boundary cap of the auditory nerve	pri	primary fissure
LNc	lateral nucleus, caudal part	VIIIN	auditory nerve	r	rostral
LNr	lateral nucleus, rostral part	IX	vermian lobule IX; uvula	sec	secondary fissure
lr	lateral recess of the fourth ventricle	X	vermian lobule X; nodulus	SV	superior vestibular nuclear

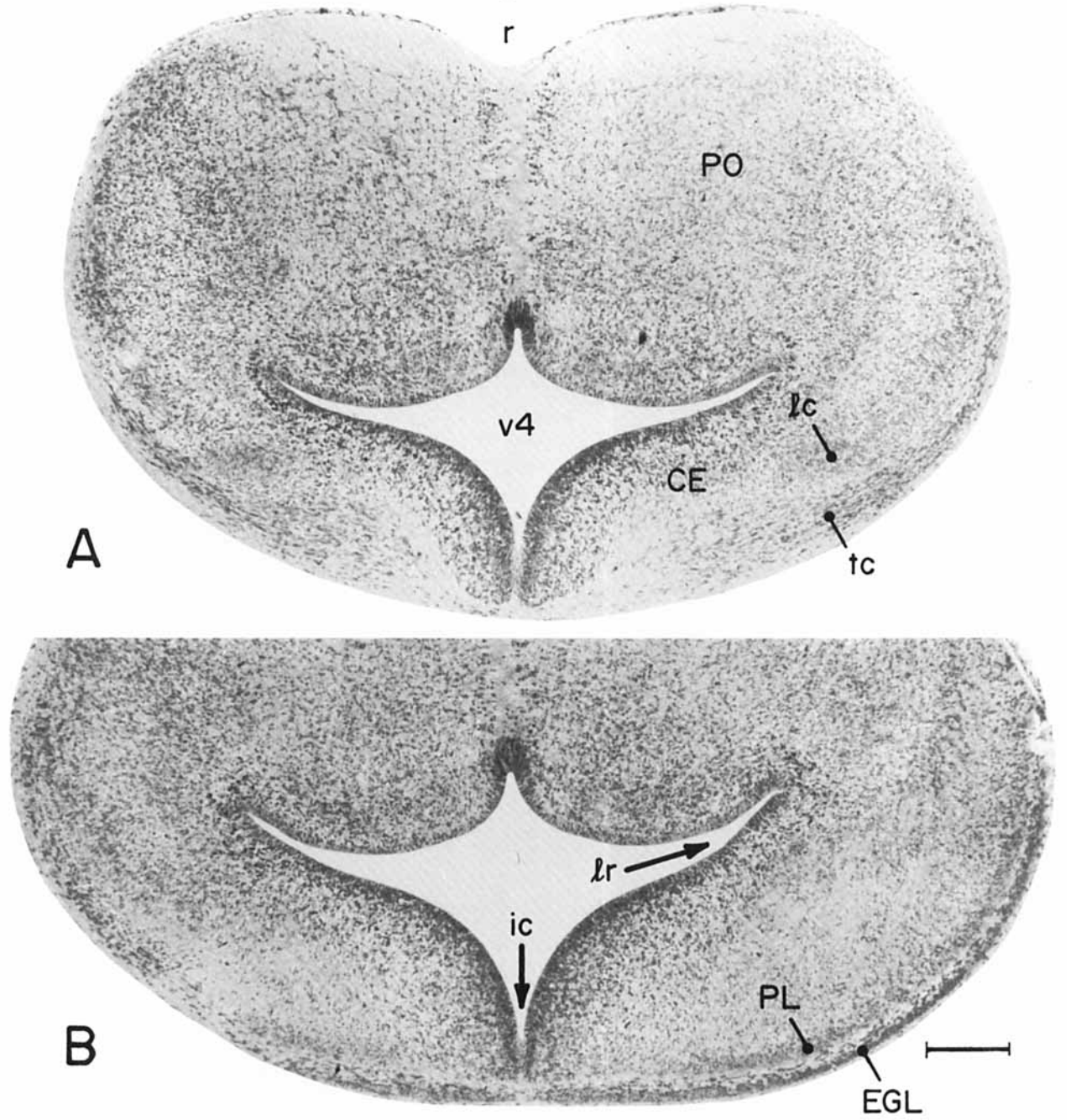

Fig. 1. Horizontal sections, from dorsal (A) to ventral (B), through the cerebellar primordium and pons of a day E17 rat. The transversely oriented cells of the nuclear transitory zone are prominent in the cerebellum dorsally. Methacrylate; scale: 100μm.

The same pattern was also observed for the lateral nucleus (not illustrated) except that the translocation is less conspicuous because of the relatively shorter distances involved in the shallower volume of the lateral cerebellum during this phase of development.

Penetration of the inferior cerebellar peduncle

The translocating cells of the nuclear transitory zone do not seem to passively "sink" into the vacant space left by the receding ventricular neuroepithelium and the migrating Purkinje cells but move in the direction of a fiber tract that is most conspicuous on day E17 and E18 in the region of the intermediate (Fig. 7A, B) and lateral nuclei. In lateral sections this fiber bundle has been identified as the inferior cerebellar peduncle. The inferior cerebellar peduncle first emerges on day E16 as a small fiber tract caudal to the root of the trigeminal nerve and rostral to the root of the eighth nerve (Fig. 9A). Some fibers of this bundle curve

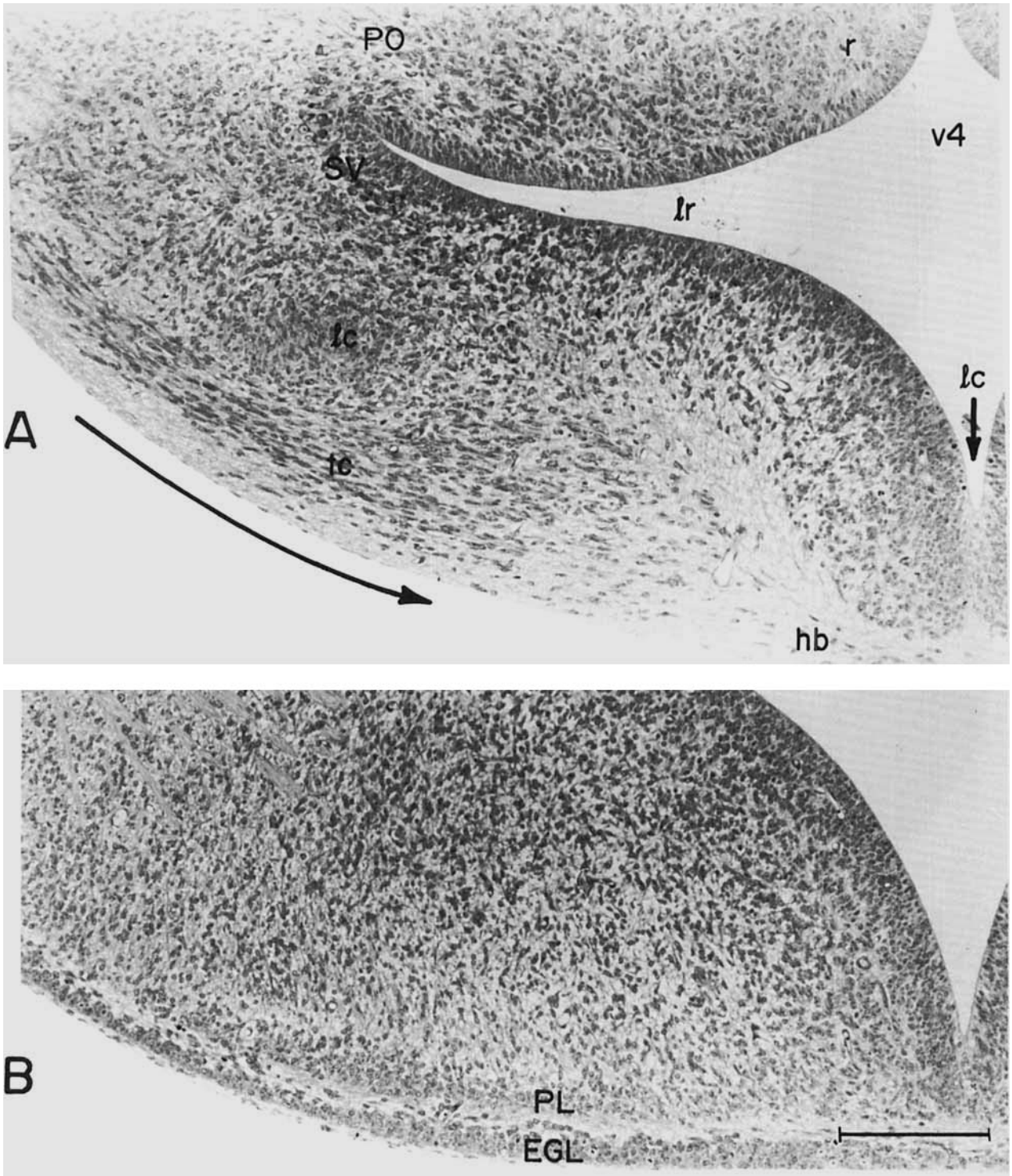

Fig. 2. Enlargement of the cerebellar region shown in Figure 1. Scale: 50 μm.

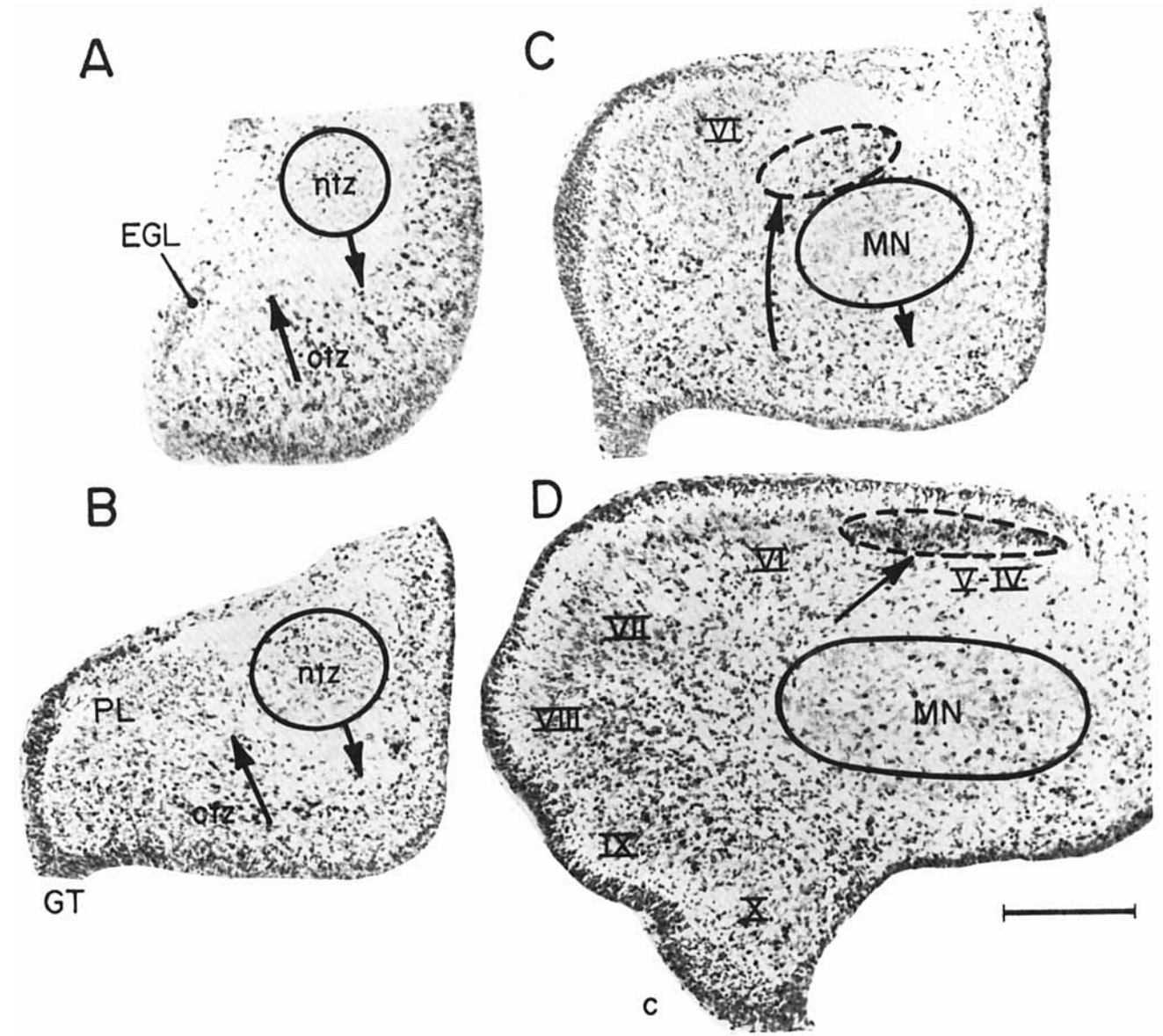

Fig. 3. Parasagittal thymidine-radiograms of the cerebellar region of rats labeled with ^{3}H-thymidine on day E15 and killed on day E17 (A), E18 (B), E19 (C), and E 21 (D). Downward arrows indicate the translocation of the mostly unlabeled cells of the nuclear transitory zone which , by day E19, can be recognized to form the medial (fastigial) nucleus. Upward arrows show the presumed migration of the mostly labeled Purkinje cells of the cortical transitory zone to form lobules IV and V of the anterior lobe. Paraffin; scale: 200 μm.

around the anterior margin of the lateral recess of the fourth ventricle but do not penetrate far into the cerebellar tissue. This occurs on day E17 (Fig. 9B) when this fiber tract has greatly increased in volume and its separate bundles penetrate the cerebellum from its caudal tip to about half of its length. The orientation of the fibers is longitudinal in lateral sections but their concurrent transverse distribution is evident in more medial sections (Fig. 7A, B). The exact relationship between the penetrating fibers and the migration or translocation of the deep neurons is not clear from this material. The observation that the penetration of the fibers of the inferior cerebellar peduncle lags behind the migration of deep neurons medially (Fig. 10) suggests that this cell migration is not triggered by the arrival of their afferents. However, such an effect cannot be ruled out with regard to the translocation of the deep neurons from the surface to the depth of the cerebellum.

Regional differentiation of the deep nuclei

The young neurons of the medial (fastigial), interpositus, and lateral (dentate) nuclei appear as separate cell masses before they settle beneath the formative cerebellar cortex. As described earlier, the three components may be distinguished on the basis of their locations in the cerebellar primordia, and the spindle-shaped cells of the medial and interpositus nucleus on the basis of their orientation. After

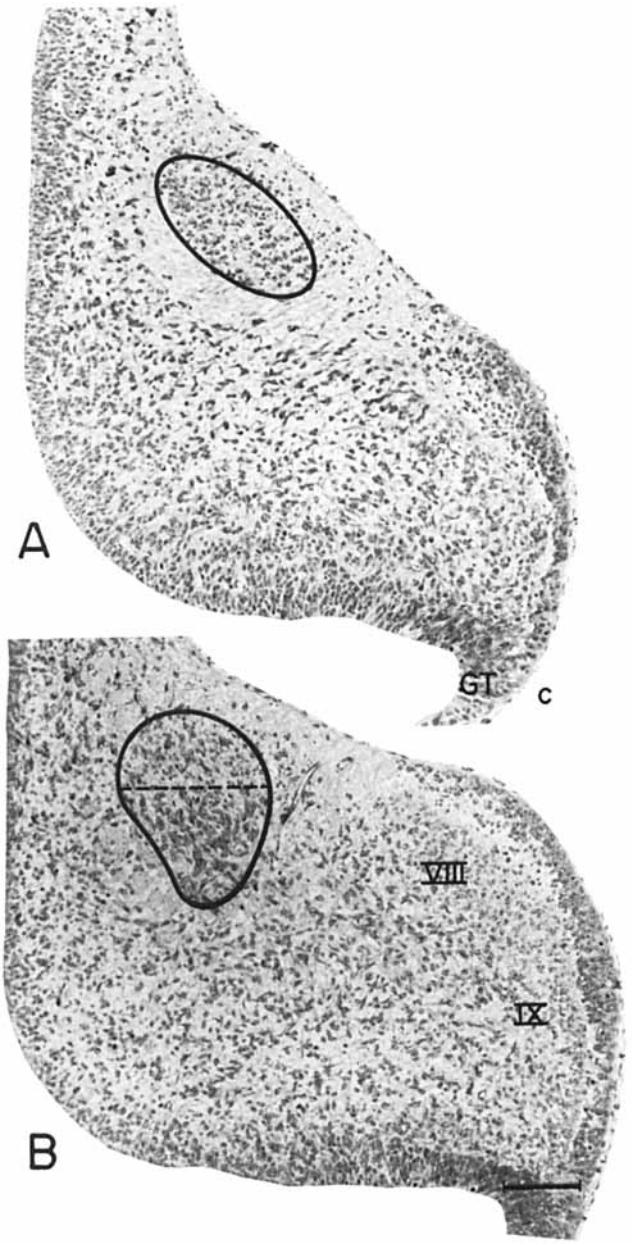

Fig. 4. Midsagittal sections showing the transversely oriented, spindle-shaped cells (small in cross section in the encircled area) on day E17 (A), and the change in their appearance in the ventral part of the zone as the translocation of the cells begins on day E18 (B). Methacrylate; scale: 100μm.

these cells have settled and begin to disperse, and after the boundaries of the lateral, subisthmal, and postisthmal cerebellar primordia became less distinct as a result of morphogenetic changes (Altman and Bayer, '84b), the separation between the adjacent nuclei becomes uncertain in some places (Fig. 11A, B). Neither in rats injected on day E14 and killed on day E22, in which most of the deep neurons are labeled (not illustrated), nor in rats injected on day E15 and killed on day E22, in which practically all the deep neurons are unlabeled (Fig. 11A, B), was there clear evidence of a cytogenetic gradient or of regional differences in labeling pattern. This agrees with earlier observations in the mouse (Pierce, '75) and the rhesus monkey (Gould and Rakic, '81).

In plastic sections regional differences were evident on day E22 in terms of cell size and nuclear configuration (Fig. 12). In the medial nucleus (Fig. 12A, B) there is a large-cell component rostrally and medially and a more extensive small-cell component caudally and laterally. In the interpositus nucleus (Fig. 12C) the predominant cell is the large type. At this state of development the lateral nucleus is the largest of the three deep nuclei (Fig. 12D, E). The bigger cells are concentrated rostrally and medially and the smaller cells caudally and laterally.

DISCUSSION

The migratory path of deep neurons

Observations in perinatal rats injected with ^{3}H-thymidine on day E15 (Fig. 11) confirmed a previous quantitative finding in adult rats (Altman and Bayer, '78) that the peak generation time of deep neurons antedates the production of Purkinje cells by 1 day. This fact, in combination with the examination of serially sectioned, short-survival thymidine radiograms and plastic-embedded embryos at daily intervals, made it possible to unravel the roundabout migratory path of the cerebellar deep neurons.

In rats injected on day E14 and killed on day E15 (Altman and Bayer, '85a: Fig. 12A) labeled cells were present in a superficial migratory band extending from the ventrolateral region of the lateral cerebellar primordium medially. In rats injected on day E15 and killed on day E16 (Altman and Bayer, '85a: Fig. 13) the same cell group was largely unlabeled, with the exception of the cells located in the vicinity of the neuroepithelium. These observations ruled out the possibility that the superficial band is composed of Purkinje cells because a high proportion of the latter is labeled with injections made on day E15 (Fig. 11). Because this superficial band of cells lies outside the trajectory of the external germinal layer at early stages of development Korneliussen ('68) opposed Rüdeberg's ('61) suggestion that these could be cells of the deep nuclei. What we have identified here as the medial (fastigial) nucleus in a superficial position on days E17 and E18 in the rat (Figs. 2–4) was described by Das ('77: Figs. 1, 2) as cluster X of the Purkinje cells. In accordance with our interpretation, Goffinet ('83) identified this region in the mouse cerebellum as a deep nucleus and he stated that subsequently "the nuclei become buried in the depth of the cerebellum" (Goffinet, '83: p. 81). Goffinet has observed that in reeler mutant mice, in which the Purkinje cells do not become properly arranged in a superficial position, the deep neurons still settle ventrally in a near-normal fashion. This leaves as a possibility our suggestion that the ventral translocation of deep neurons is guided by the penetrating fibers of the inferior cerebellar peduncle (Figs. 9, 10).

The superficially situated, medially migrating deep neurons (the cells of the nuclear transitory zone) were identified in plastic sections as transversely oriented spindle-shaped cells; in the posterior cerebellum these were traced to the vicinity of the midline by day E17 (Altman and Bayer, '85a: Figs. 15B, 17B). By this age the continuity of the nuclear transitory zone with the neuroepithelium was no longer evident (Fig. 1A). The orientation of spindle-shaped cells is not sufficient evidence either of migration or of migration in a particular direction. In a recent study (Altman and Bayer, '84c) we showed that the vertically and horizontally oriented relay neurons of the embryonic spinal cord do not

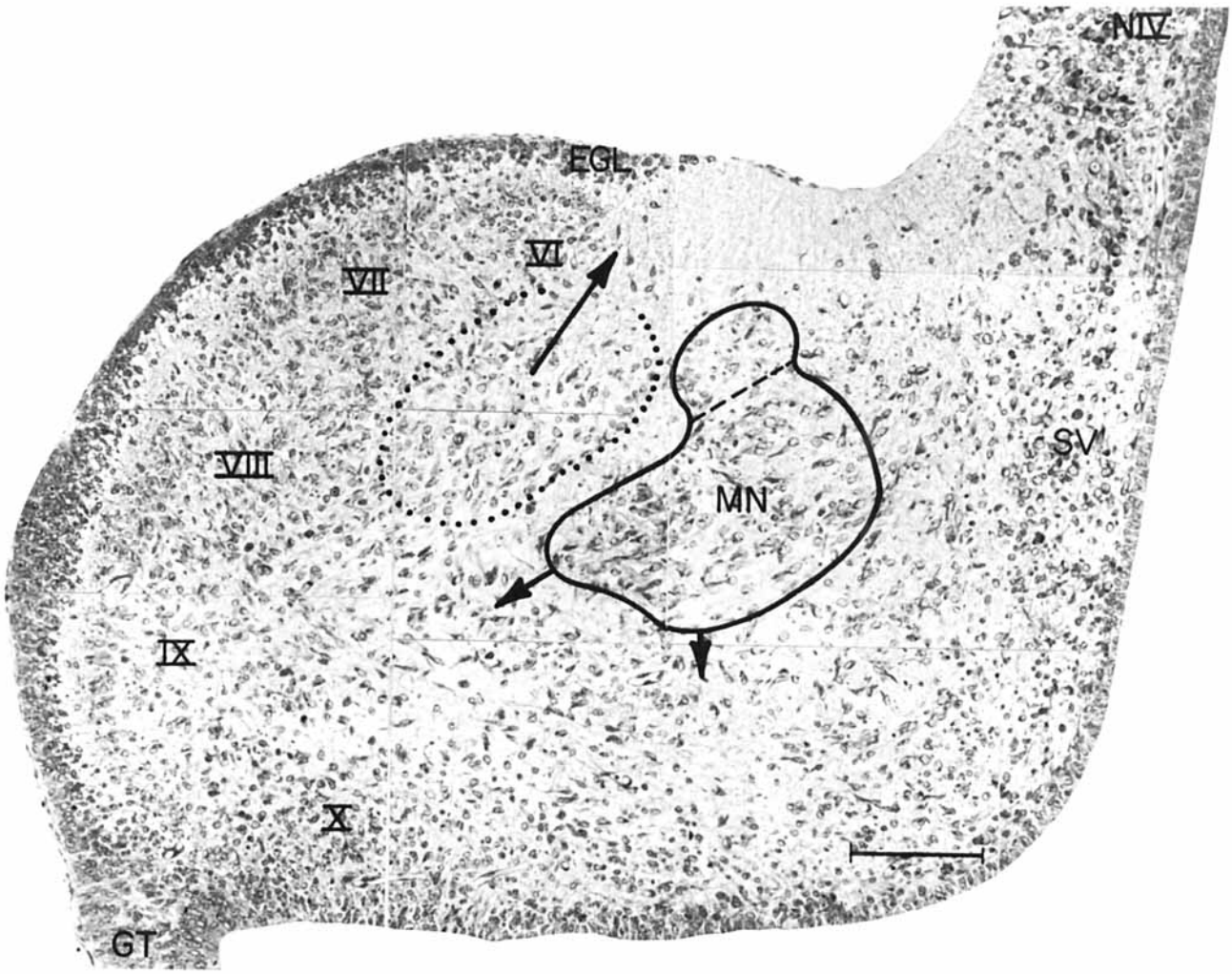

Fig. 5. By day E19, the majority of the cells of the nuclear transitory zone (medial nucleus) have changed their appearance and are approximating their settling sites (lower arrows) ventrally. Upper arrow shows presumed migratory path of the Purkinje cells that will form lobules V–VI of the anterior lobe. Methacrylate; sagittal; scale: 100 μm.

migrate; rather, the shape of the cells and their orientation reflect the sprouting of axons in a particular direction. Similarly, in this series of studies we have observed that the nuclear transitory zone has two components, one with transversely oriented cells and another with longitudinally oriented cells (Fig. 2A; see also Altman and Bayer, '84a: Figs. 7, 17, 19). The transversely oriented cells are associated with a decussating fiber tract, what we think may be the hook bundle of Russell (Figs. 1A, 2A; see also Altman and Bayer, '85a: Fig. 17B). We suggested that these two groups of cells represent two kinds of deep nuclear neurons: those which are the source of efferents that cross to the opposite side within the cerebellum and those that join the superior cerebellar peduncle ipsilaterally and decussate in the midbrain. Available evidence indicates that the cells that are the source of efferents crossing within the cerebellum are located mostly in the caudal fastigial nucleus (Jansen and Jansen, '55; Thomas et al., '56; Angaut and Bowsher, '70; Faull and Carman, '78; Haroian et al., '81). Our observation of the rostral location of the longitudinally oriented cells in the posterior cerebellum on day E17 and the caudal location of the transversely oriented cells (Figs. 1A, 2A; see also Altman and Bayer, '85a: Figs. 7, 17, 19) agrees with this pattern of localization. In line with this evidence we postulate that after the migratory cells of the nuclear transitory zone reach a point on their trajectory, some turn longitudinally to sprout axons that grow in the anterodorsal direction while others retain their transverse orientation and send axons to the opposite side of the cerebellum.

The outgrowth of the axons of the deep neurons is in full progress on day E17. Thereafter the cell bodies begin their descent to the depth of the cerebellum. The earliest indication for this was obtained on day E18 (Fig. 4B); by day E19 it was recognized with certainty (Fig. 5). We call this movement "translocation" not because of any evidence that the mechanism of motility is any different in this instance from the preceding movement in the transverse direction but rather in order to distinguish the two as temporally and spatially different components of the embryonic migration

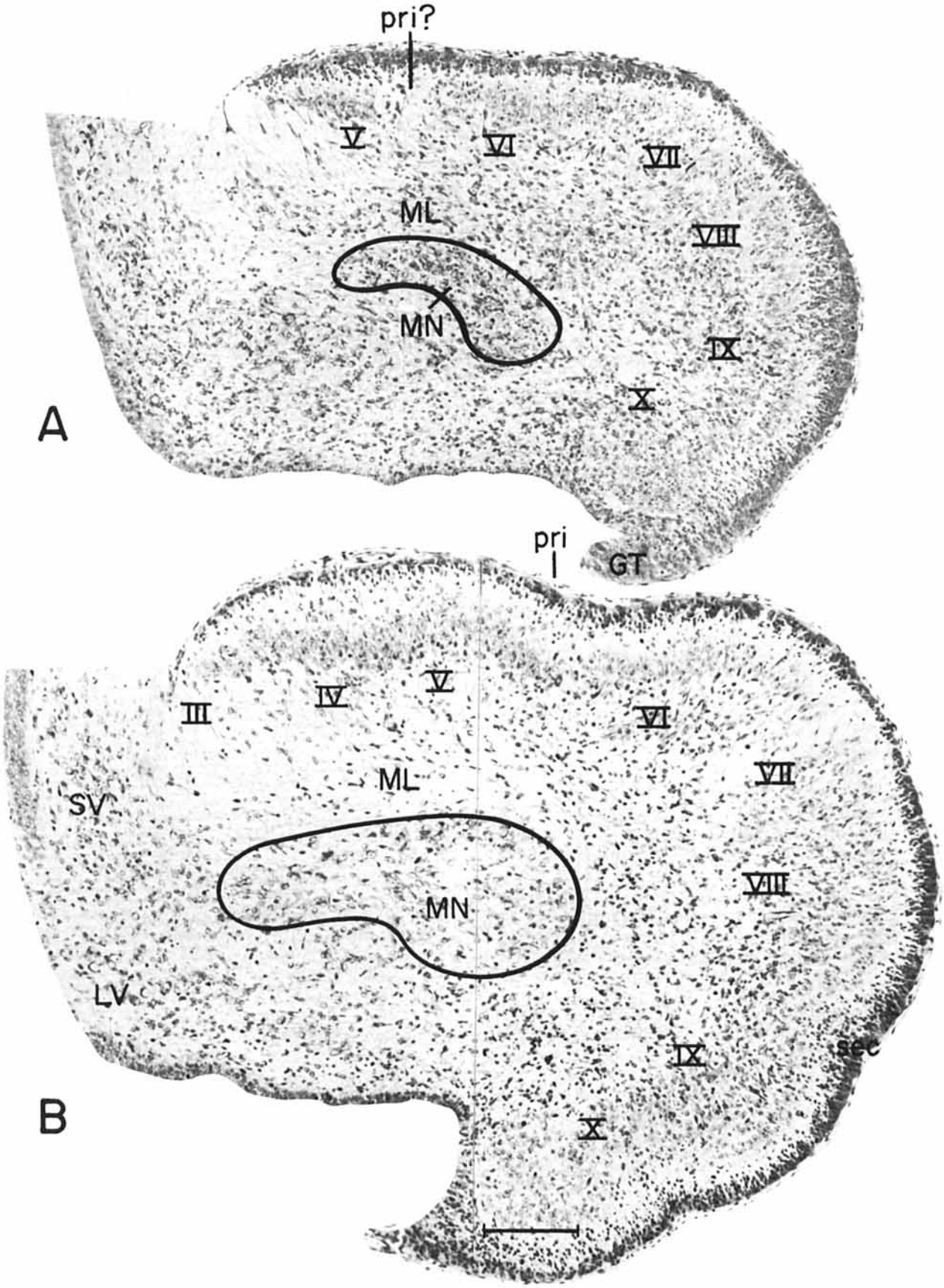

Fig. 6. The cells of the medial nucleus have settled in the depth of the cerebellum by day E20 (A) and begin to disperse on day E21 (B). Methacrylate; midsagittal; scale: 100 μm

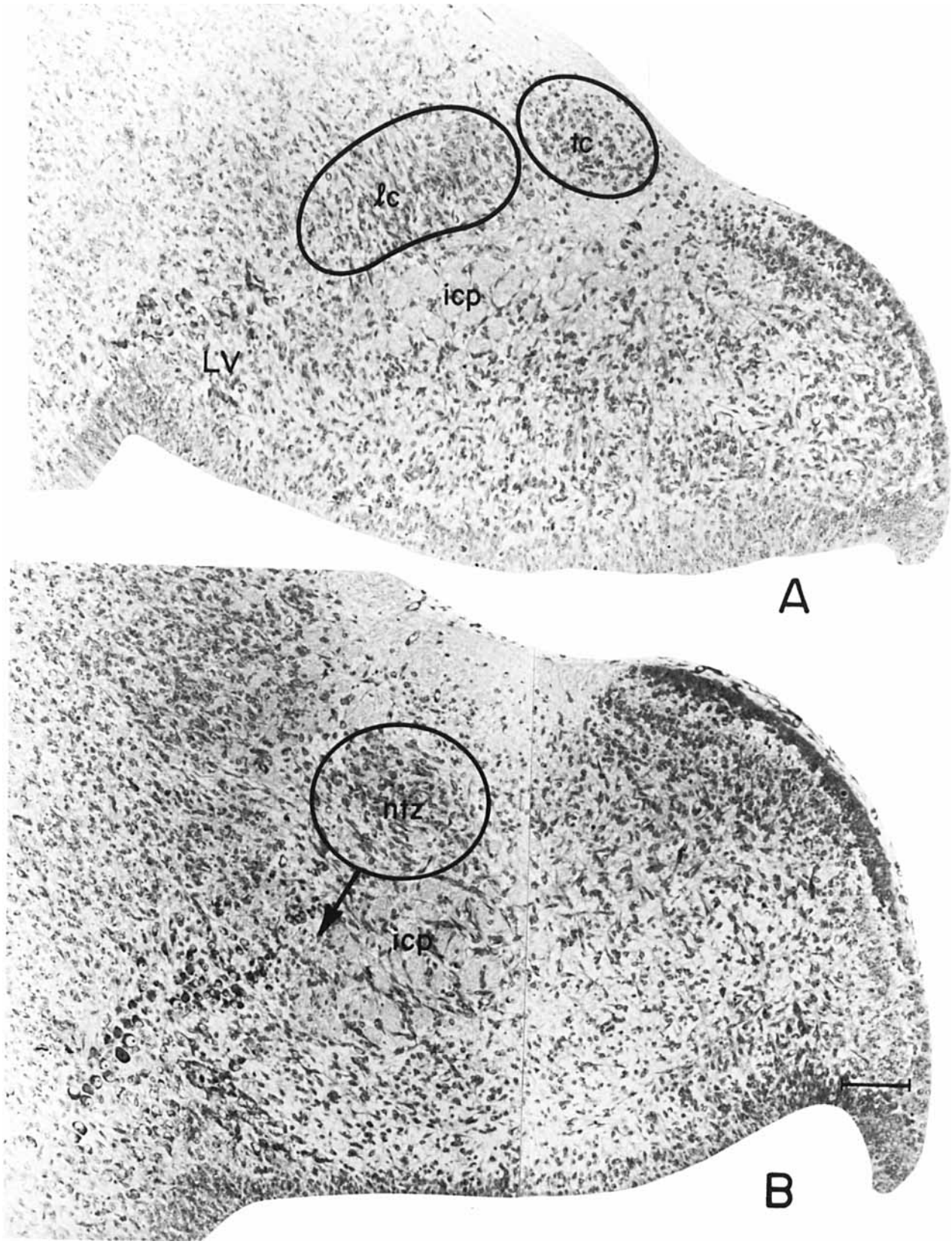

Fig. 7. The longitudinally oriented cells of the nuclear transitory zone in the intermediate portion of the cerebellum on day E17 (A) and day E18 (B). Methacrylate; parasagittal; scale: 100 μm.

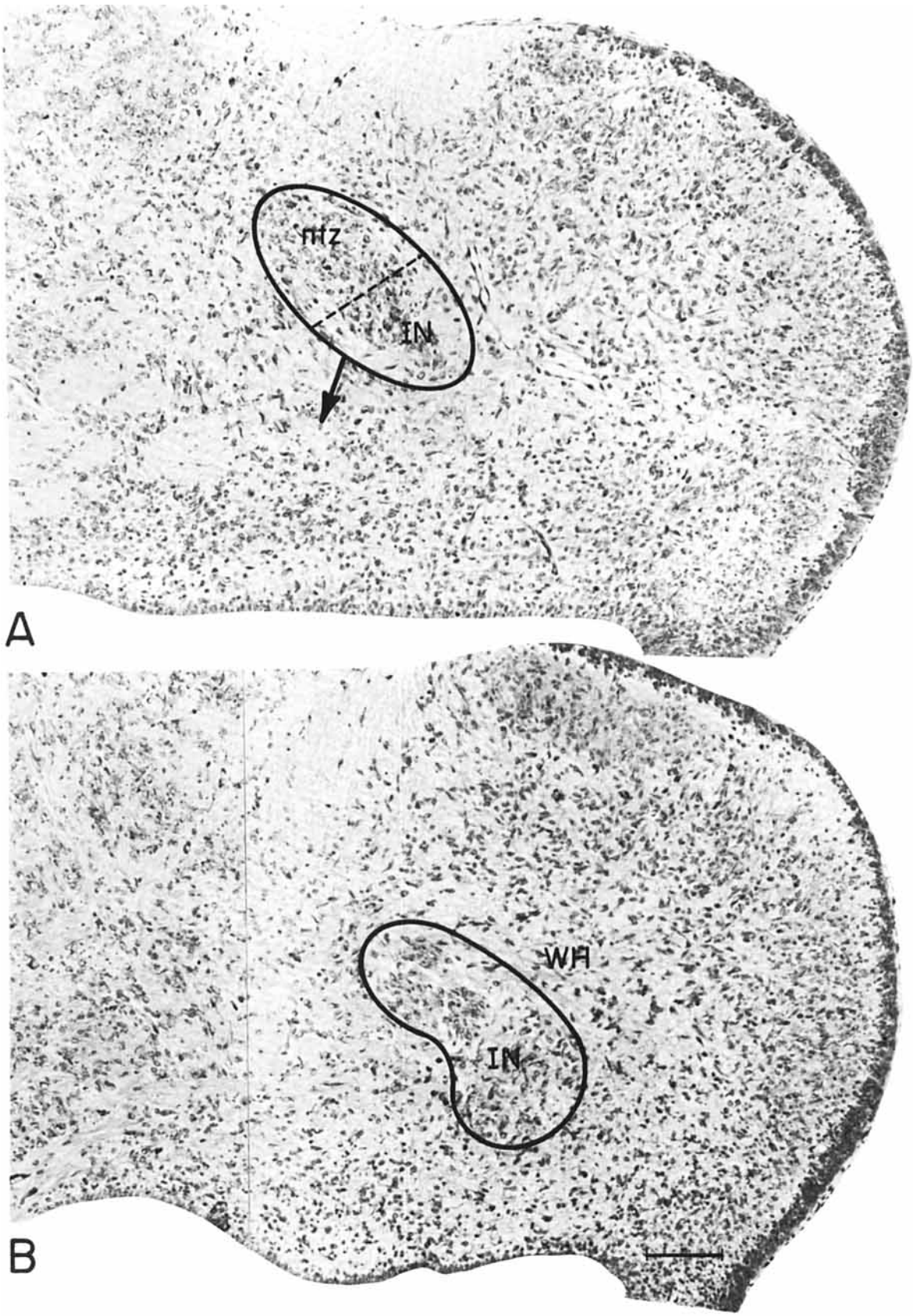

Fig. 8. The translocation of the cells of the nuclear transitory zone on day E19 (A) and their settling by day E20 (B) as the neurons of the interpositus nucleus. Methacrylate; parasagittal; scale: 100 μm.

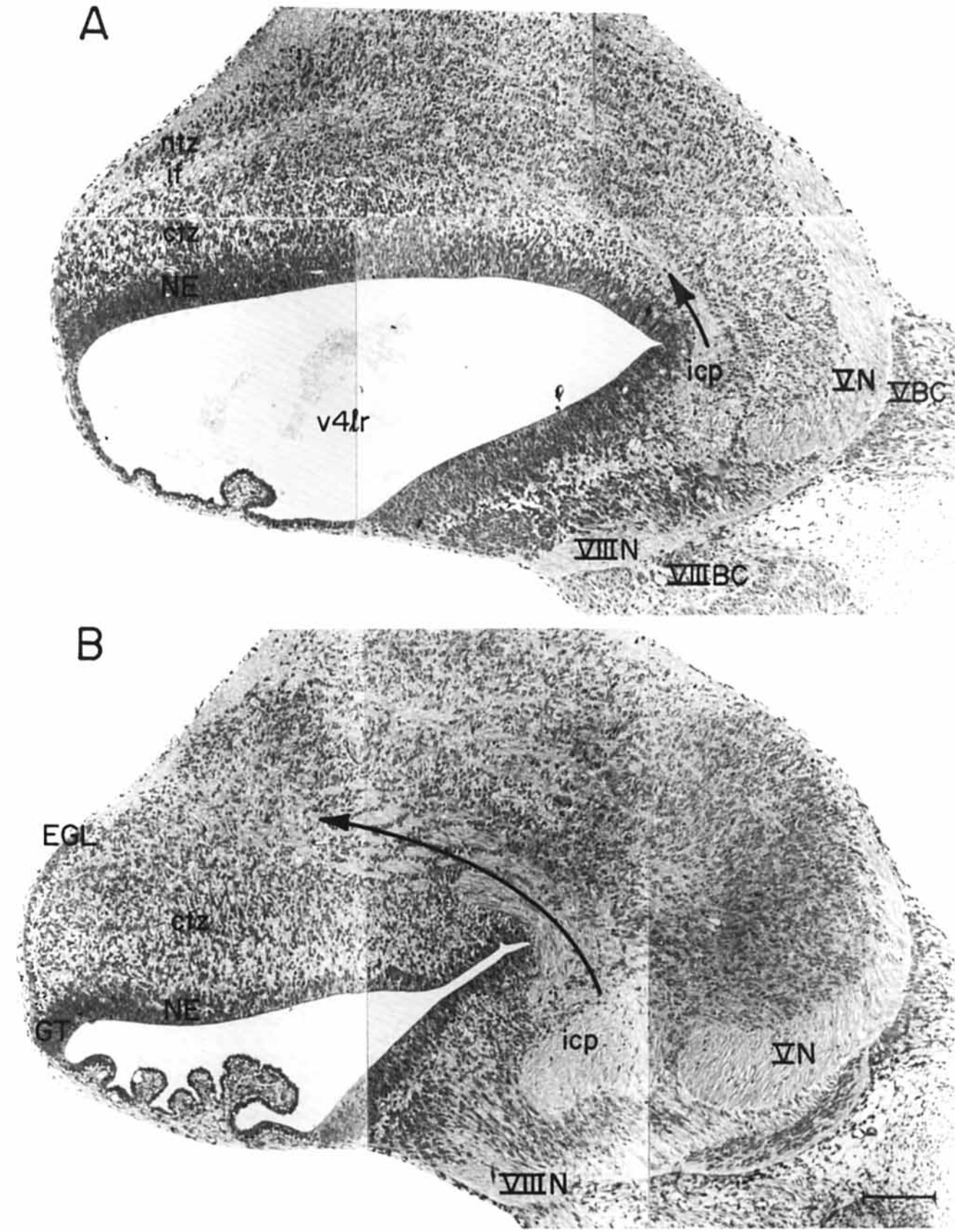

Fig. 9. The fibers of the inferior cerebellar peduncle on day E16 (A) as they begin to curve caudally to penetrate the cerebellar primordium. By day E17 (B), the fibers of the enlarged inferior cerebellar peduncle have penetrated halfway caudally into the cerebellum. Methacrylate; parasagittal; scale: 100 μm.

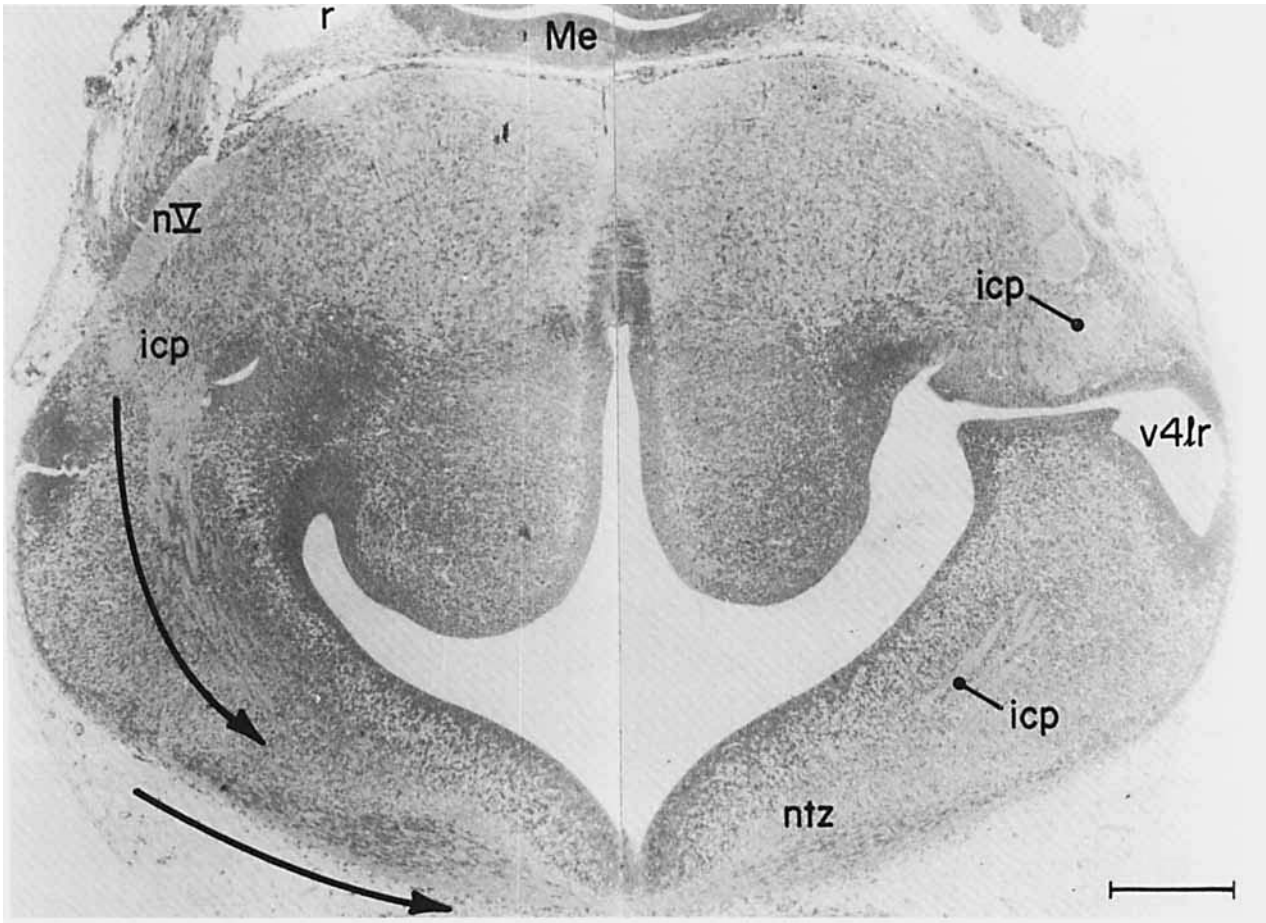

Fig. 10. Slightly oblique horizontal section from a day E17 rat. It shows the rostrocaudal course of the inferior cerebellar peduncle (upper arrow on left) above the lateral recess of the fourth ventricle (right). The transversely oriented cells of the nuclear transitory zone or medial nucleus (lower arrow) migrate ahead of the penetrating fibers of the inferior cerebellar peduncle. Methacrylate; scale: 200 μm.

of deep neurons. The morphogenetic significance of this roundabout path is not known. Possibly the deep neurons originating in the ventrolateral neuroepithelium can easily disperse medially in the traffic-free superficial cerebellum while the deeper regions of the bulk of the cerebellum are occupied by the cortical transitory zone and the radially migrating Purkinje cells. Our earlier suggestion (Altman, '82) that the initial superficial position of deep neurons is an arrangement that allows the radially migrating Purkinje cells to make contact with deep neurons on their route to the surface is not supported by our present observations in short-survival radiograms (Fig. 3). In fact, it appears that the Purkinje cells may actually make a detour around the descending cells of deep neurons when ascending to form the primitive cerebellar cortex.

The settling pattern of deep neurons

Goodman et al. ('63) distinguished three deep nuclei in the rat, — the medial, the interpositus and the lateral— whereas Korneliussen ('68) and Chan-Palay ('77) distinguished four by subdividing the interpositus into an anterior and a posterior component. We have not attempted to resolve this controversy because the boundaries of the deep nuclei are apparently less distinct in the perinatal rat (Fig. 11) than in adults. Indeed, a comparison of our observations with Korneliussen's ('68) report of the cellular composition of the different nuclei suggests that in the day E22 rat the deep nuclei have not yet acquired their final form. According to Korneliussen the medial nucleus is divisible into an extensive middle part, a caudomedial part, and a dorsolateral protuberance. The latter is described as containing many large cells but, in contrast, we have found that the large cells of the medial nucleus are concentrated rostrally and medially (Fig. 12A), not dorsolaterally, and the smaller cells laterally (Fig. 12B), not medially. Similarly there is a discrepancy in the location of small and large cells in the lateral nucleus. Korneliussen distinguished in adult rats a large-celled component medially. In the day E22 rat the large cells of the lateral nucleus are concentrated rostrally and the small-celled component caudally (Fig. 12D). It is quite possible that the deep nuclei undergo some rotation during postnatal development. It is also conceivable that the small and large cells distinguished in late embryos do not correspond to the small and large cells of the adult.

In day E17 rats—that is, before the descent of the deep nuclei—two components of the medial nucleus could be

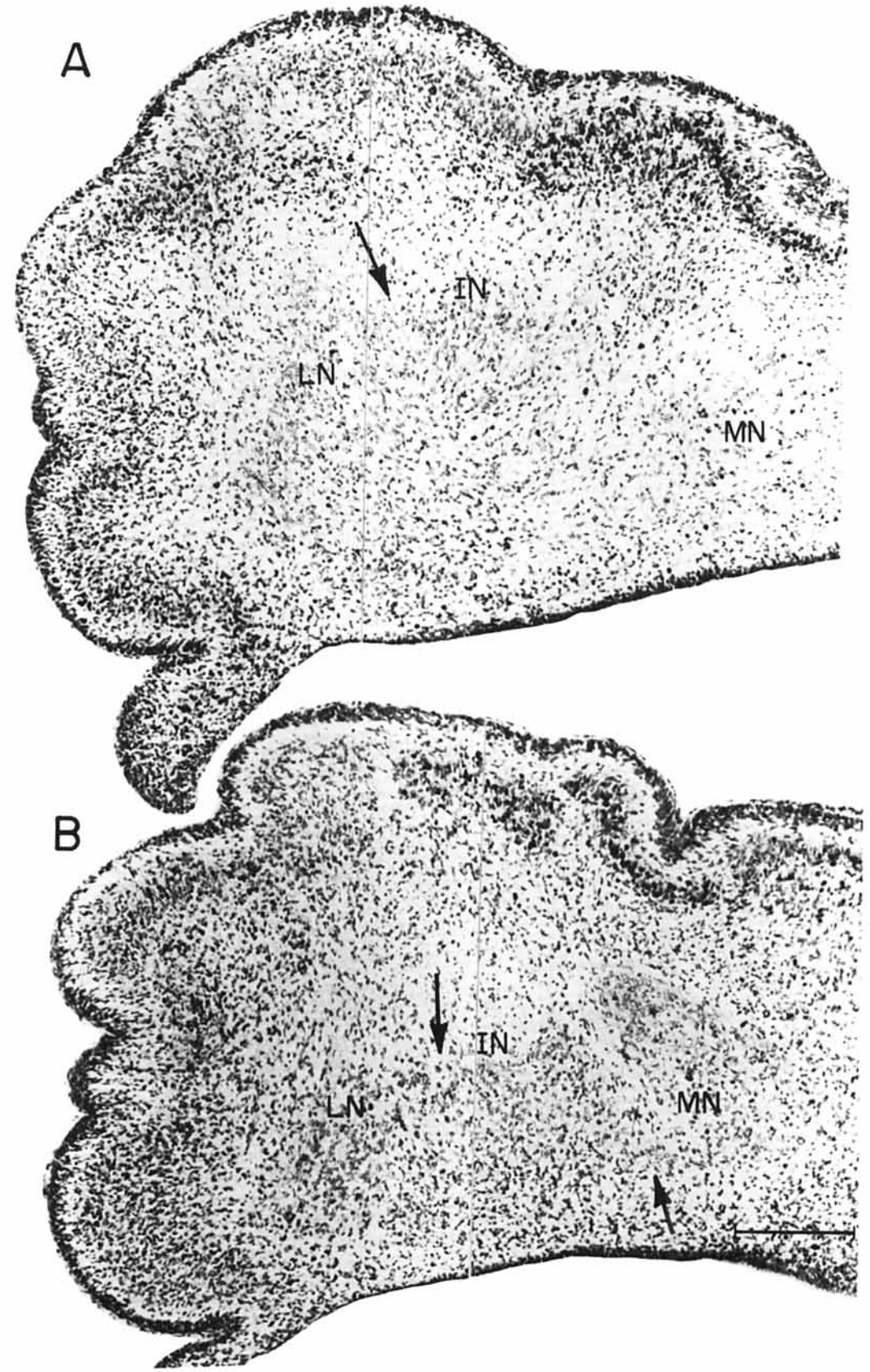

Fig. 11. Coronal sections , from rostral (A) to caudal (B) in a rat labeled on day E15 and killed on day E22. The majority of neurons of the three deep nuclei are unlabeled. Arrows point to cell bridges between the deep nuclei. Paraffin; scale: 50 μm.

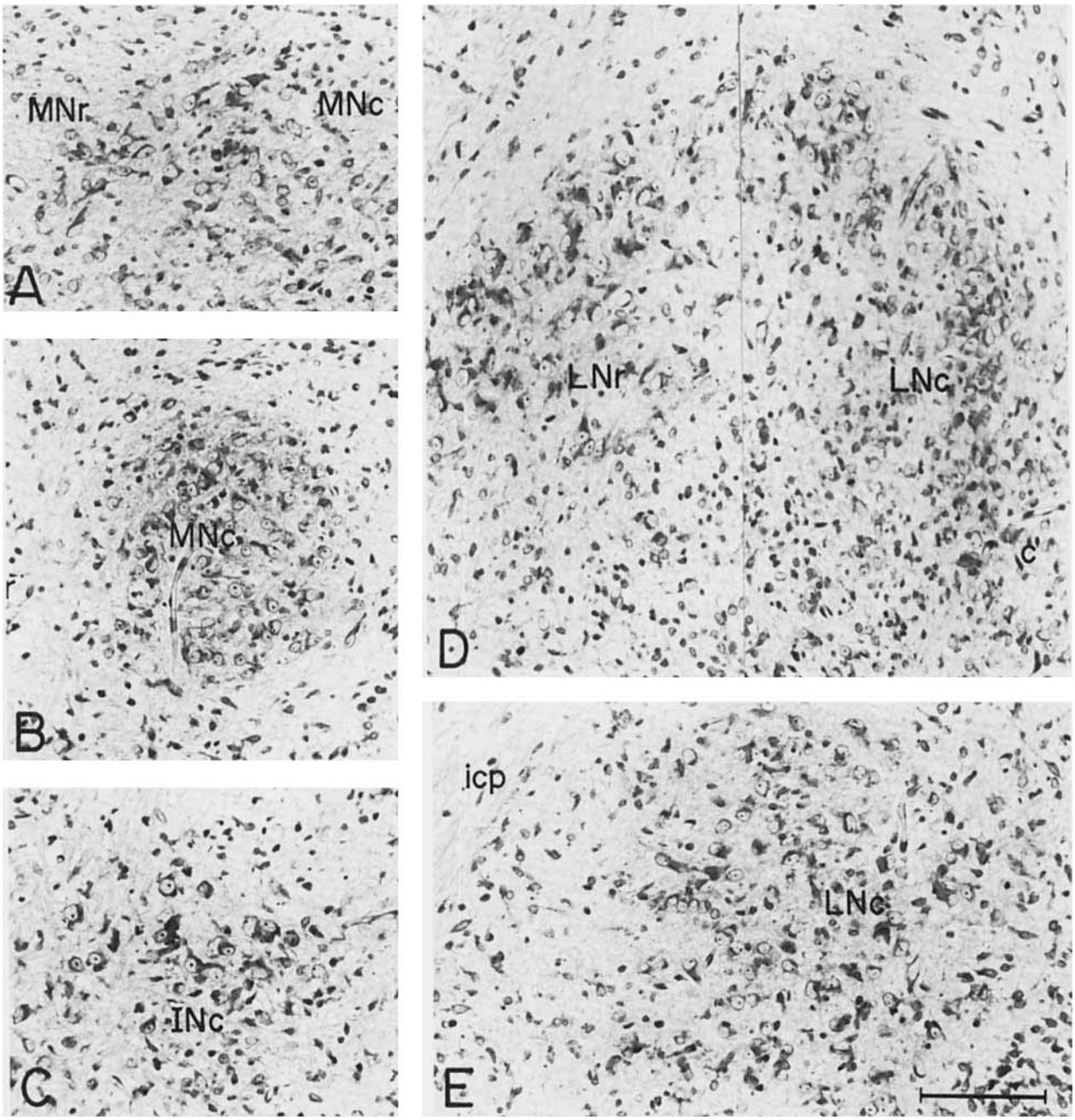

Fig. 12. The cellular composition of the medial nucleus (A, B), interpositus nucleus (C), and lateral nucleus (D, E) in sagittal sections of a day E22 rat to show the regional distribution of small and large deep neurons. Methacrylate; scale; 100 μm.

distinguished: a smaller rostral component with longitudinally oriented cells (Fig. 2A), which presumably join the superior cerebellar peduncle ipsilaterally (Altman and Bayer, '85a: Fig. 19), and a larger caudal component with transversely oriented cells. The latter were inferred to be the source of the fibers of the hook bundle of Russell, which join the ascending limb of the uncinate fasciculus contralaterally (Faull and Carman, '78). Relating the observations made in day E17 rats to those made in day E22 rats, it appears that the small rostral component is represented by the large deep neurons (Fig. 12A) and the larger caudal component by the smaller deep neurons (Fig. 13B). If this identification is correct, then the large cells of the medial nucleus (as seen on day E22) would be the source of fibers that join the superior cerebellar peduncle ipsilaterally while the small cells the source of fibers that decussate within the cerebellum and join the uncinate fasciculus. This is a testable hypothesis because these two pathways have been described to have different ascending termination patterns in the rat (Haroian et al., '81). Of course, such a scheme

cannot be applied to the lateral nucleus where there are similarly segregated small and large deep neurons but decussation within the cerebellum has not been described.

ACKNOWLEDGMENTS

This research program is supported by grants from the National Institutes of Health and the National Science Foundation. We are grateful for the technical assistance of William Boyle, Peggy Cleary, Cathe Frierman, Ann Hostetler, Janis Malone, Elizabeth McLaughlin, Vicki Palmore, Linda Ross, and Kathy Shuster.

LITERATURE CITED

Altman, J. (1982) Morphological development of the rat cerebellum and some of its mechanisms. In S. Palay and V. Chan-Palay (eds): The Cerebellum—New Vistas. Berlin: Springer, pp. 8–49.

Altman, J., and S.A. Bayer (1978) Prenatal development of the cerebellar system in the rat. I. Cytogenesis and histogenesis of the deep nuclei and cortex of the cerebellum. J. Comp. Neurol. *179*:23–48.

Altman, J., and S.A. Bayer (1985a) Embryonic development of the rat cerebellum. I. Delineation of the cerebellar primordium and early cell movements. J. Comp. Neurol. *231*:1–26.

Altman, J., and S.A. Bayer (1985b) Embryonic development of the rat cerebellum. III. Regional differences in the time of origin, migration and settling of Purkinje cells. J. Comp. Neurol. *231*:42–65.

Altman, J., and S.A. Bayer (1984c) The Development of the Rat Spinal Cord. (Adv. Anat. Embryol. Cell Biol., Vol. 85.) Berlin: Springer.

Angaut, P., and D. Bowsher (1970) Ascending projections of the medial cerebellar (fastigial) nucleus: An experimental study in the cat. Brain Res. *24*:49–68.

Chan-Palay, V. (1977) Cerebellar Dentate Nucleus. Berlin: Springer.

Das, G.D. (1977) Experimental analysis of embryogenesis of cerebellum in rat. II. Morphogenetic malformations following X-ray irradiation on day 18 of gestation. J. Comp. Neurol. *176*:435–452.

Faull, R.L.M., and J.B. Carman (1978) The cerebellofugal projections in the brachium conjunctivum of the rat. I. The contralateral ascending pathway. J. Comp. Neurol. *178*:495–518.

Goffinet, A.M. (1983) The embryonic development of the cerebellum in normal and reeler mutant mice. Anat. Embryol. *168*:73–86.

Goodman, D.C., R.E. Hallett, and R.B. Welch (1963) Patterns of localization in the cerebellar corticonuclear projections of the albino rat. J. Comp. Neurol. *121*:51–67.

Gould, B.B., and P. Rakic (1981) The total number, time of origin and kinetics of proliferation of neurons comprising the deep cerebellar nuclei in the Rhesus monkey. Exp. Brain Res. *44*:195–206.

Haroian, A.J., L.C. Massopust, and P.A. Young (1981) Cerebellothalamic projections in the rat: An autoradiographic degeneration study. J. Comp. Neurol. *197*:217–236.

Jansen, J., and J. Jansen (1955) On the efferent fibers of the cerebellar nuclei in the cat. J. Comp. Neurol. *102*:607–632.

Kappel, R.M. (1981) The development of the cerebellum in *Macaca mulatta*. Thesis. Gravenhage: Pasmans.

Korneliussen, H.K. (1967) Cerebellar cortocogenesis in Cetacea, with special reference to regional variations. J. Hirnforsch. *9*:151–185.

Korneliussen, H.K. (1968) On the morphology and subdivision of the cerebellar nuclei of the rat. J. Hirnforsch. *10*:109–122.

Pierce, E.T. (1975) Histogenesis of the deep cerebellar nuclei in the mouse: An autoradiographic study. Brain Res. *95*:503–518.

Rüdeberg, S.I. (1961) Morphogenetic studies on the cerebellar nuclei and their homologization in different vertebrates, including man. Thesis. Lund. Quoted from Kappel, '81.

Thomas, D.M., R.P. Kaufman, J.M. Sprague, and W.W. Chambers (1956) Experimental studies of the vermal cerebellar projections in the brain stem of the cat (fastigiobulbar tract). J. Anat. *90*:371–385.