*J. Anat.* (1986), **149**, pp. 77–87
*With* 19 *figures*
*Printed in Great Britain*



# Meckel's cartilage in *Xenopus laevis* during metamorphosis: a light and electron microscope study

D. A. R. THOMSON

*Department of Anatomy, University Medical School, Teviot Place, Edinburgh EH8 9AG, Scotland*

(*Accepted* 23 *January* 1986)

## INTRODUCTION

Many amphibians undergo a radical change in body form at metamorphosis which takes place with remarkable rapidity. This is accompanied by corresponding changes in the cellular architecture of many of the body systems and the cartilaginous skeleton undergoes such changes independent of the centres of ossification which are appearing during metamorphosis.

In the tadpole, the lower jaw consists of the two Meckel's cartilages which become fused together through a median inferior labial cartilage, resulting in a single curved bar of cartilage (hereafter referred to as Meckel's cartilage) by the commencement of metamorphic climax (NF Stage 57, Sedra & Michael, 1957). Its shape at this stage is that of a shallow curved bar convex anteriorly (Paterson, 1939).

By the end of metamorphosis, Meckel's cartilage is becoming surrounded by the developing membrane bone of the dentale and goniale. The cartilage, however, remains as a discrete structure. The developing bones surround it increasingly as development continues, resulting in a thin perichondrial collar of bone around the cartilage, similar to that present in early long bone development in mammals. However, its shape changes dramatically to a much deeper U-shaped curve (Fig. 1*a*, *b*), due largely to a considerable increase in anteroposterior length. The objective of the present study is to describe the changes in the structure of the tissue during metamorphic climax accompanying this alteration in shape.

## MATERIALS AND METHODS

Eggs were obtained by injecting a pair of adult *Xenopus laevis*, anaesthetised with MS 222 (tricaine methane sulphonate), with Pregnyl (Xenopus Ltd, Redhill, Surrey). The resulting tadpoles were reared in dechlorinated tap water at 25 °C and fed on nettle powder. During development the tadpoles were staged using the external criteria in the Normal Table of *Xenopus laevis* (Nieuwkoop & Faber, 1956), which describes the stages between fertilisation and the completion of metamorphosis. The period of metamorphic climax occupies Stages 57–66.

In order to obtain a sample of animals which were developing as nearly as possible at the same rate, tadpoles reaching Stage 55NF on the same day were transferred to a separate aquarium. This group was examined daily, and animals reaching the same stage on the same day were removed from the aquarium and killed with an overdose of MS 222. The lower jaws were removed and processed for either light or electron microscopy. The lower jaws for examination by light microscopy were fixed in Bouin's solution, embedded in paraffin wax and serial sections cut at 10 $\mu$m in

the horizontal plane. The sections were stained with Heidenhain's iron haematoxylin. The jaws for examination by transmission electron microscopy were fixed in 1 % osmium tetroxide dissolved in distilled water, using the technique of Sprinz & Stockwell (1976), sectioned at 80 nm and stained with lead citrate and uranyl acetate, prior to viewing in a Philips EM 301 electron microscope. It appeared that *Xenopus* cartilage is particularly prone to fixation damage and following experimentation with a range of agents, this technique was found to give the most consistent results.

The tissues were examined at four stages during metamorphic climax, 5 animals at each stage being examined by each technique.

(*a*) Stage 57NF – prometamorphosis;
(*b*) Stage 60NF – during early metamorphosis;
(*c*) Stage 63NF – prior to the increase in the matrix;
(*d*) Stage 66NF – at the end of metamorphic climax.

Tissue was removed from the cartilage bar by transverse sectioning. The flakes of bone ossifying around the cartilage in the later stages were trimmed away, prior to thin sectioning.

## RESULTS

### *Light microscopy*

Prior to the onset of metamorphic climax, at stage 57NF, the tissue consists almost entirely of large lacunae, 20–40 $\mu$m in diameter, and irregular in shape (Fig. 2). The amount of interlacunar matrix present is very small, forming a very thin boundary line between the lacunae, resulting in a characteristic net-like appearance. The perichondrium is very thin, nowhere more than 1 or 2 cells thick, with the surrounding epithelium lying close against it along much of the length of the cartilage. At its articulation with the quadrate area of the chondrocranium the peripheral cells are more closely packed, and lie in smaller lacunae, with more matrix present at the articular surface (Fig. 3). The perichondrium appears to be continuous with the joint capsule. The very tenuous nature of the tissues in the tadpole at this stage may be responsible for the susceptibility to damage during fixation.

As the metamorphic changes proceed the lacunae become smaller and the cells

---

Fig. 1(*a–b*). (*a*) Cleared whole mount of lower jaw prior to metamorphic climax showing Meckel's cartilage (MC) as a shallow curved bar. By the end of metamorphic climax its shape has changed to a deeper U-shaped curve. (*b*) Meckel's cartilage at the end of metamorphic climax, showing the change of shape to a deep U-shaped curve.

Fig. 2. Meckel's cartilage at Stage 57NF with large lacunae and little matrix present. × 64.

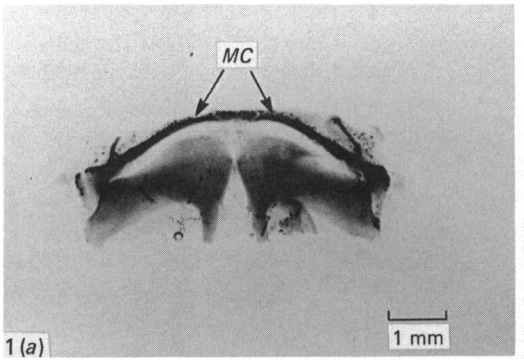
Fig. 3. Meckel's cartilage (*MC*) at its articulation with the quadrate cartilage (*Q*) at Stage 57NF. × 64.

Fig. 4. Meckel's cartilage at Stage 66NF, with smaller lacunae and an increased amount of matrix. The apparent change in shape of the joint surfaces may be due in part to the tenuous nature of the cartilage at Stage 57F and to the change in function of the joint during metamorphic climax. × 64.

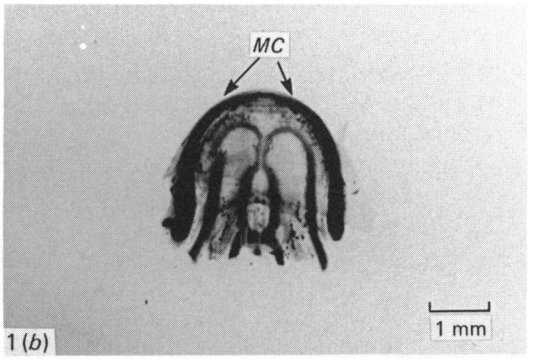
Fig. 5. Meckel's cartilage (*MC*) at its articulation with the quadrate (*Q*) at Stage 66NF, showing considerable increase in cellularity, especially on the joint surfaces. × 64.

Fig. 6. Ceratohyal cartilage at Stage 57NF. × 64.

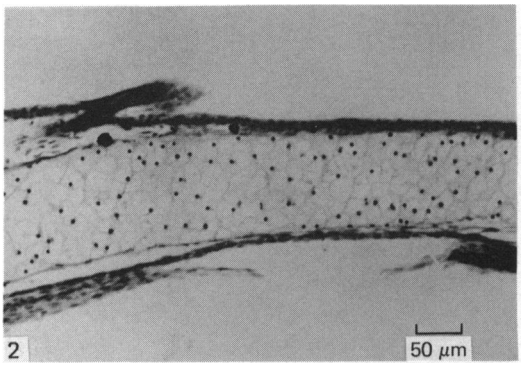
Fig. 7. Ceratohyal cartilage at Stage 66NF. The matrix increase evident in Meckel's cartilage during metamorphic climax has not occurred to the same extent in this cartilage. × 64.



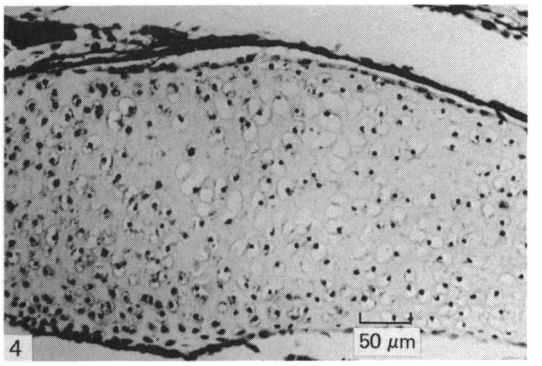

1 (*a*)



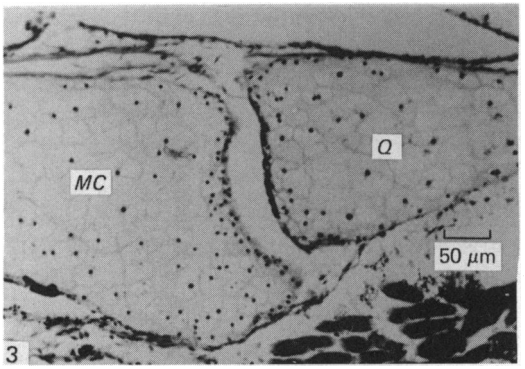

1 (*b*)



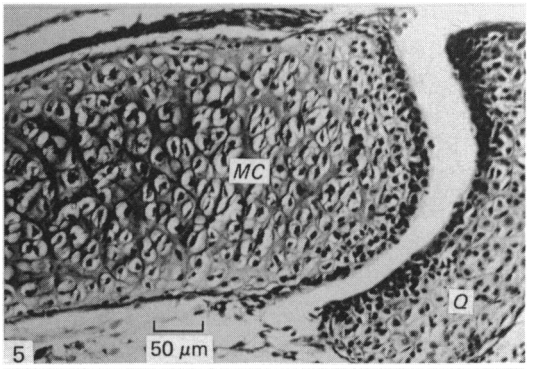

2



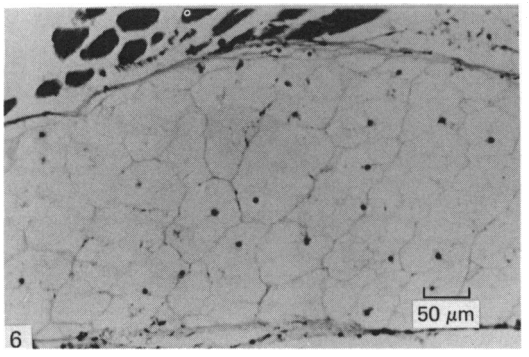

4



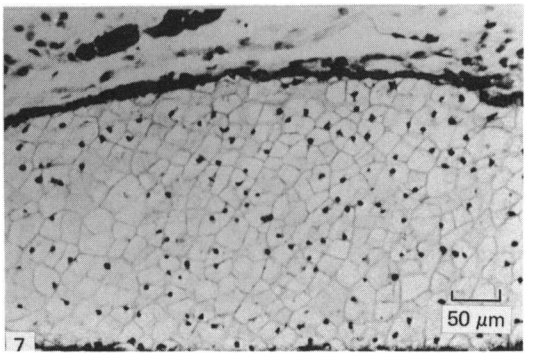

3




5




6




7

more densely packed, though the amount of matrix surrounding them does not at first appear to increase markedly. Small amounts of bone begin to form within the perichondrium from stage 60NF, onward, ossification of the goniale on the medial side of Meckel's cartilage occurring a little in advance of the dentale, which develops on the lateral side of the cartilage. Where ossification is not taking place, the perichondrium is still rather thin, and the lacunae are now smaller (10–20 $\mu$m in diameter), though still surrounded by only a thin rim of matrix.

From Stage 63NF on, the volume of bone increases in thickness and the volume of matrix also starts to increase, giving rise to a reduction in the size of the lacunae, although the tissue still presents a 'net-like' appearance.

By the end of metamorphic climax (Stage 66NF) the amount of matrix has increased markedly and the lacunae are now separated, often in groups of two or three. The more peripheral cells and those near the articular ends are closely packed together, having more prominent cytoplasm and less densely staining nuclei than the deeper cells (Fig. 4). The membranous bone around Meckel's cartilage is increasing in volume, but there is no evidence of endochondral ossification up to the end of metamorphic climax. The goniale and dentale are absent in the midline area and at the articular surfaces. The perichondrium is thin but quite dense, except at the articular ends where it is thicker, again being continuous with the joint capsule. At the articulation there is a dense concentration of cells on both joint surfaces (Fig. 5) which is not evident in the earlier stages of development. Apart from this area of cell concentration, the density of cells appears to be constant throughout the remainder of the cartilage.

At Stage 57, the structure of Meckel's cartilage is quite similar in appearance to that of the ceratohyal cartilages lying just caudal to it in the lower jaw, although the lacunae in the latter appear larger (Fig. 6). It is interesting to note that similar cellular and matrix changes to those observed in Meckel's cartilage are occurring in the ceratohyals, though the process of matrix volume increase is less well advanced in these cartilages (Fig. 7).

### *Electron microscopy*

The structure of Meckel's cartilage was examined in the superficial, intermediate and deep regions and, since the appearances at Stages 57 and 60NF were very similar, the results from these two stages were grouped together.

#### *Early metamorphosis (Stages 57 and 60NF)*

At this stage, the cells on the periphery of the cartilage are flattened, with their long axes parallel to the tissue surface. They show large nuclei, some granular endo-

---

Fig. 8. Meckel's cartilage during early metamorphosis, showing flattened peripheral cells (*P*) and larger, spheroidal deeper zone cells (*D*). Stage 57/60NF.

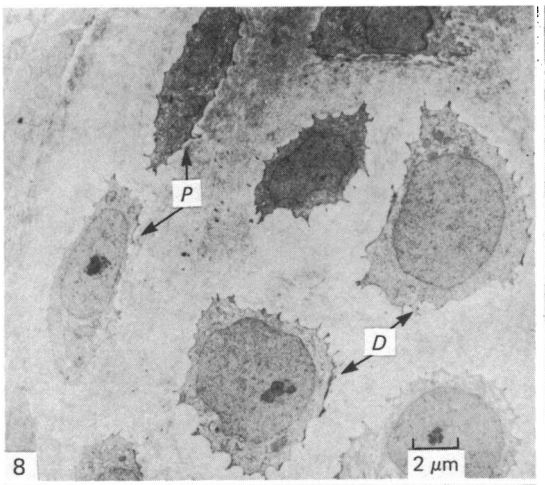
Fig. 9. Cell column, lying perpendicular to the surface and deep to the peripheral zone cells. The arrow indicates the direction of the periphery of the cartilage. Stage 57/60 NF.

Fig. 10. Cell from intermediate zone deep to the cell columns. Stage 57/60NF.

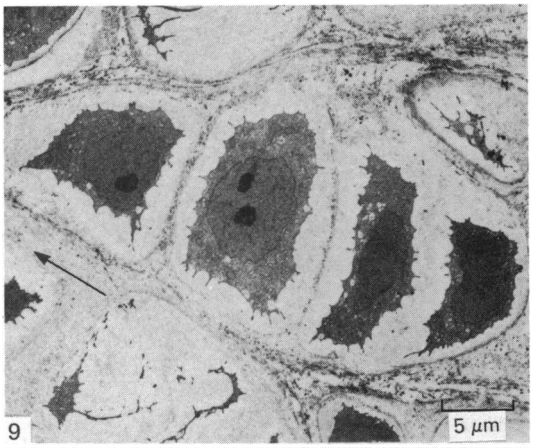
Fig. 11. Degenerating cell from the deepest area of the cartilage, showing fragmentation of membranes and cytoplasm. Stage 57/60 NF.

Fig. 12. Degenerating cell from the deepest zone with large numbers of fibrils (*F*) surrounding the irregularly shaped nucleus. Stage 57/60NF.

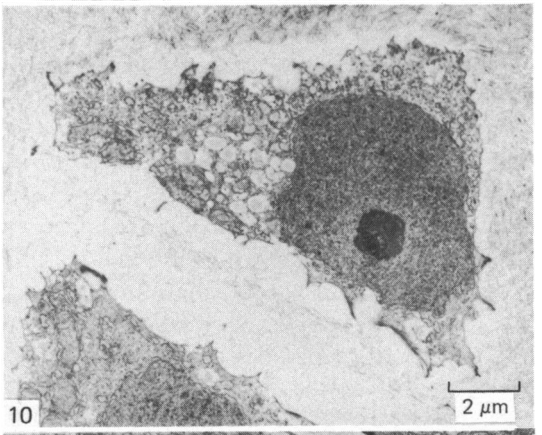
Fig. 13. Dense bodies (*D*) close to lacunar boundaries. Stage 57/60NF.



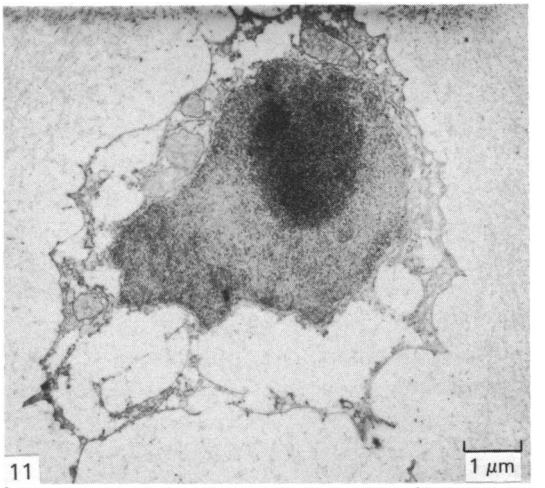

8



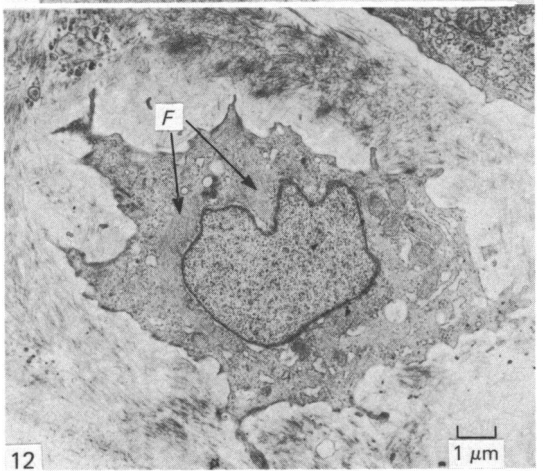

9



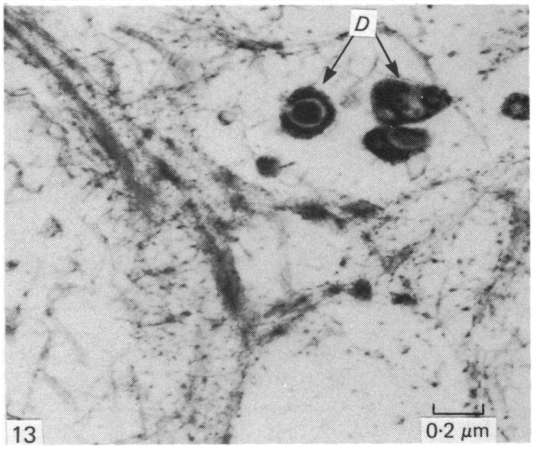

10




11




12




13

plasmic reticulum and large mitochondria. The perinuclear cisternae are dilated and some ribosomes are present on the outer nuclear membrane. Many of the cells exhibit a well-defined Golgi complex close to the nuclear envelope. Their processes are short and the lacunar matrix around each cell is not well defined (Fig. 8). This layer is only 1–2 cells thick, lying superficial to a zone of larger spheroidal cells. These intermediate cells also have a large nucleus with prominent perinuclear cisternae and an extensive granular endoplasmic reticulum is present. They have short processes and the lacunar matrix is somewhat better demarcated. Some of the matrix fibrils show aggregation into small bundles at the lacunar margins. The matrix contains large numbers of fine, randomly oriented fibrils interspersed with small matrix granules 10–15 nm in diameter. However, on the lateral sides of the cartilage bar, this transition from flattened to rounded cells is interrupted by an additional zone. Here the cells are arranged in distinct columns, perpendicular to the surface, just deep to the flattened peripheral cells (Fig. 9). The cell density in this area is high, and two cells are frequently seen lying in the same lacuna. The nuclear material is evenly distributed and one or both nucleoli are often prominent. Mitochondria are numerous and the endoplasmic reticulum well developed, often with a well-defined Golgi region near the nucleus. The cells possess short, fine processes, confined within the lacuna, and the interlacunar matrix is clearly distinguishable, forming a thin rim of more densely packed fibrils defining the territorial zone of each cell. In some situations the fibrils in the lacunar matrix appear to be aggregating to form such a rim, separating cells that have recently divided.

Deep to this proliferative zone the cells are of varied shape and occupy irregularly shaped zones of lacunar matrix. An extensive juxtanuclear Golgi area is associated with vacuoles, some of which appear to be opening into the lacunae, and may contain matrix components. The cells exhibit a prominent granular endoplasmic reticulum with dilated cisternae. Each cell is surrounded by a small lacuna, and has a few short processes. The interlacunar matrix in some areas shows longer fibrils than the more superficial zones. They are frequently irregularly arranged and are interspersed with small matrix granules (Fig. 10).

In the deepest zone of the cartilage, interspersed with hypertrophic cells, are cells with a very large nucleus, ruptured cell membranes and apparently fragmenting cytoplasm. They are filled with large amounts of material similar to the lacunar matrix. The mitochondria are distended and there is only a little granular endoplasmic reticulum. These cells that exhibit features suggestive of degeneration are usually found singly within the cartilage (Fig. 11). Also within this deep zone are found single cells with irregularly shaped nuclei, whose cytoplasm contains large numbers of fine filaments lying mainly around the nucleus (Fig. 12).

---

Fig. 14. Periphery of Meckel's cartilage at Stage 63NF showing flattened cells, with condensing interlacunar matrix (*IL*).

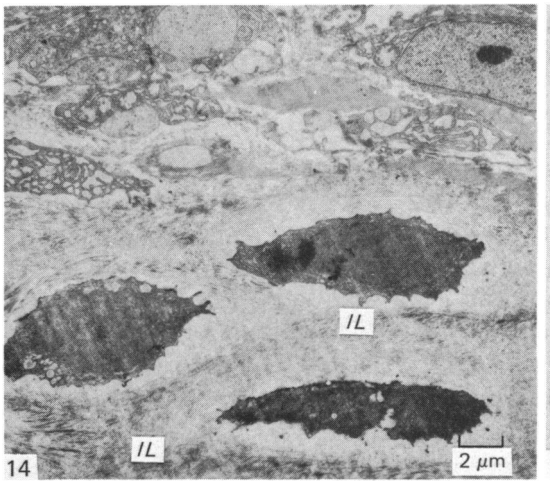
Fig. 15. Deeper zone cell showing extensive Golgi complex (*G*) and mitochondria (*M*). Stage 63NF.

Fig. 16. Deeper zone cell showing a single cilium (*C*) with its basal body (*B*) and a second centriole (↑). Stage 63NF.

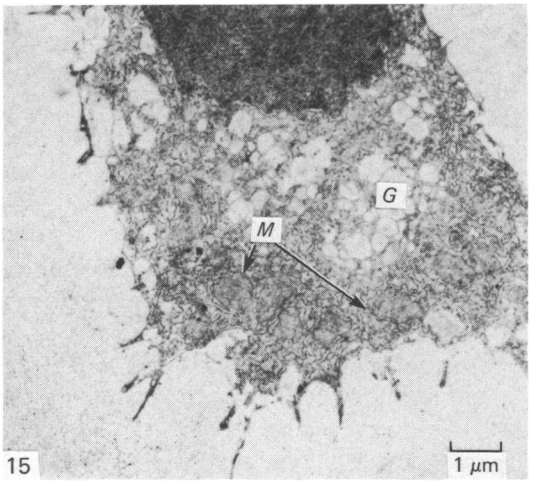
Fig. 17. Meckel's cartilage at Stage 66NF, showing sub-peripheral cell.

Fig. 18. Cartilage cell showing three lysosome-like bodies (↑). Stage 66NF.

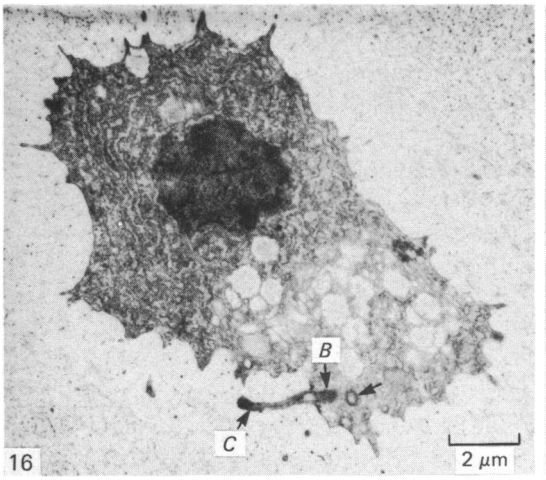
Fig. 19. Degenerating cartilage cell from the deepest zone, showing fragmentation of membranes and cytoplasm. Stage 66NF.



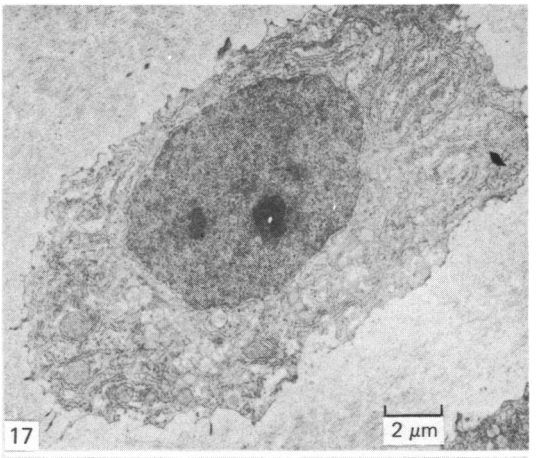
14



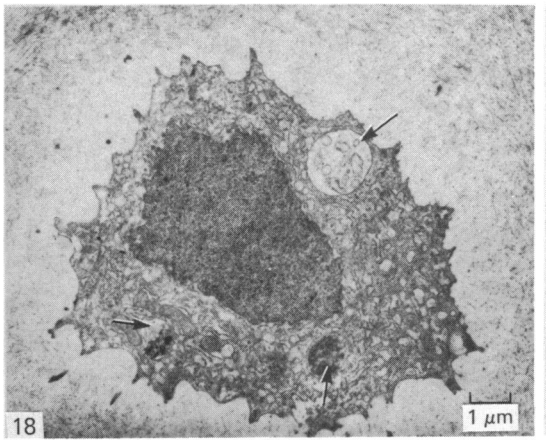
15



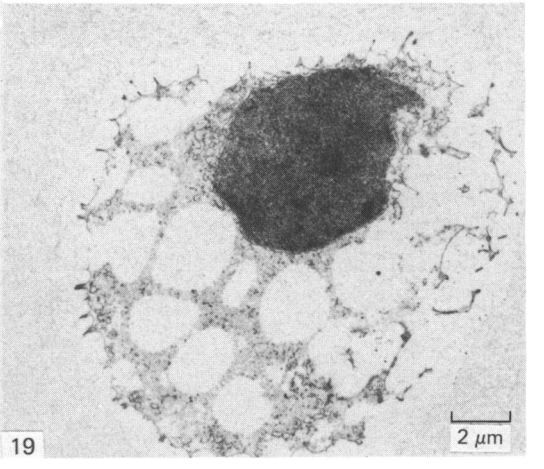
16



17



18



19

In many other sites in all zones of the cartilage, even amidst apparently proliferating cells, dense, irregular bodies, some of which appear to be membrane-bound, are seen, usually near the junctions of areas of interlacunar matrix (Fig. 13).

*Stage 63NF (before matrix increase)*

At this stage, a characteristic feature of the cartilage is the absence of the cell columns seen earlier. The peripheral cells are flattened, being rather irregular in shape with short, fine processes. Most cells show an extensive granular endoplasmic reticulum, a Golgi apparatus and numerous secretory vesicles filled with moderately dense material. The lacunar matrix forms a narrow zone around the cells, and some condensation of fibrillar materials is apparent in the lacunar matrix with some orientation of the fibrils (Fig. 14). This peripheral zone is now several cells thick and merges into the deeper cell layers gradually.

The deeper cells have a more irregular shape with an extensive granular endoplasmic reticulum, the cisternae of which are dilated and filled with material of moderate electron density. There is a large and elaborate Golgi apparatus situated close to the nucleus. Many of the cells possess a large number of vesicles containing amorphous material, some of which appear to be opening to the surface. There are large numbers of irregularly shaped mitochondria, often concentrated at one end of the cell (Fig. 15). Some of the deeper cells were observed to have a single aberrant cilium. These cilia have a basal body which is one of the centrioles of the cell, and this is accompanied by a second centriole close by (Fig. 16).

At this stage, as in early metamorphosis, a number of solitary cells showing degenerative changes as well as areas of cellular debris were observed in all zones of the cartilage.

*Stage 66NF*

By the end of metamorphic climax, the most obvious feature of the cartilage is the increase in the amount of interlacunar matrix in all zones. The peripheral zone of the cartilage is now composed essentially of matrix with very few cells. In the intermediate zone the cells are numerous, irregularly shaped, and lie in well-defined small lacunae. They exhibit irregularly shaped nuclei, numerous mitochondria and large quantities of granular endoplasmic reticulum with frequently a prominent Golgi apparatus. The cell membrane has a few fine processes extending into the lacuna. The interlacunar matrix consists of irregularly arranged, closely aggregated fibrils, interspersed with matrix granules (Fig. 17).

A feature of many cells in all zones within the cartilage is the presence of lysosome-like structures (Fig. 18) not observed in cells during the earlier stages. These structures usually have a narrow electron-lucent zone between the limiting membrane and the homogenous, moderately electron-dense contents.

As in early metamorphosis and at Stage 63NF, solitary cells, apparently showing evidence of degenerative changes are present in the tissue, mainly concentrated in the deepest areas (Fig. 19).

## DISCUSSION

The similarity between the cell zones in Meckel's cartilage during early metamorphosis and those described in the epiphyseal cartilage in *Rana* by Dickson (1982) is quite striking. The arrangement of the cells into reserve and hypertrophic zones is present in all parts of the cartilage, with, in the lateral parts, an arrangement of cells

into columns similar to Dickson's (1982) proliferative zone. The appearance of the matrix at all stages is similar to that described by Dickson (1982) in *Rana*, the fibrils becoming more condensed as the matrix volume increases during climax. This resemblance is interesting, as Meckel's cartilage in mammals does not show such an appearance.

Sheldon (1983) described the lacunar matrix in mammalian cartilage as containing few of the normal fibrils of cartilage matrix, and stated that this is the result of maturation and polymerisation of newly synthesised matrix components taking place in this area. As the fibrillar material within the lacuna also contains fewer fibrils in *Xenopus*, it seems probable that similar processes are occurring in the maturing *Xenopus* cartilage.

Single cilia, such as are observed on some of the deeper cells, have been described in a variety of fetal and adult cartilages (Scherft & Daems, 1967; Stockwell, 1971; Stockwell & Meachim, 1973; Wilsman, 1978; Wilsman & Fletcher, 1978). Such cilia have also been reported in a wide variety of tissues, summarised by Fawcett (1981), but do not appear to have been previously recorded in amphibian cartilage. They are probably non-motile, and since none of the functions attributed to them seem likely in a cartilage cell, it is possible that they are merely anomalous rudimentary structures as suggested by Fawcett (1981), though Carr & Toner (1982) suggest that they may represent a normal aspect of centriolar potential.

From the earliest stage examined (57NF) cells exhibiting evidence of degeneration are seen, along with cell debris, mainly in the deeper zones of the cartilage. The degenerating cells are generally found singly, and exhibit either fragmenting cytoplasm, distended mitochondria and ruptured cell membranes, or are cells with irregularly-shaped nuclei containing large numbers of fine fibrils.

The perinuclear accumulations of fine filaments seen in some cells of the deep zone are probably evidence of degenerative changes (Barnett, Cochrane & Palfrey, 1963; Meachim & Roy, 1967; Sprinz & Stockwell, 1976). The dense, irregular bodies seen in the matrix during early metamorphosis are similar to those described by Ghadially, Thomas, Yong & Lalonde (1978) and Dickson (1982) and probably represent the granular debris of cells. These structures occurring during prometamorphosis (Stage 57NF) amidst apparently proliferating cells indicate that even in areas where cell division is occurring, cells are also dying. Lipid accumulation, which is a feature of such changes in mammalian cartilage cells (Stockwell, 1979) does not appear to be so in the amphibian tissue during metamorphic climax, no lipid being observed in any of the cells in Meckel's cartilage at any stage examined.

The presence of lysosome-like structures has been described in the cells at the end of metamorphic climax (Stage 66NF). These organelles have been identified on morphological grounds in this study and their structure appears to be closely similar to those described by Daems & Van Rijssel (1961) in mouse liver cells, and those illustrated by Stockwell (1979) in rabbit articular cartilage. The presence of acid phosphatase activity, regarded by Stockwell (1979) as an essential criterion for distinguishing these bodies from other vacuoles, has not been investigated, and consequently only a tentative identification is possible.

Lysosomes in cartilage cells, in addition to their normal role in cell metabolism, are described as playing an important part in the local control of the matrix (Stockwell, 1979). Dingle (1975) describes exteriorisation of lysosomal enzymes by fusion of the lysosome with the cell membrane, followed by endocytosis of digested matrix components. These lysosome-like structures were not observed in the

material prepared at earlier stages, and it seems likely that the increase in lysosome activity is concerned with turnover of matrix components associated with the changing shape of the cartilage (Shaw, 1982).

The presence of apparently hydropic and degenerating cells, and cellular debris within the cartilage is particularly interesting during metamorphic climax, as Glucksmann (1951) states that cell death occurs in many organs and tissues including cartilage, from their earliest developmental stages, and probably plays an important part in their morphogenesis. He describes changes in the shape of organs as being brought about by integration of cell division, cell death and cell movement. He also indicates that degenerating cells would be expected in amphibia, associated with removal of, or changes of shape in, larval organs during metamorphosis, and Bowen & Lockshin (1981) state that virtually every tissue in the amphibian body undergoes extensive remodelling during this time.

This apoptotic cell death, where selected individual cells are eliminated to the advantage of the rest of the organism, is increasingly coming to be regarded as an important process in embryogenesis and metamorphosis in amphibians and insects (Bowen & Lockshin, 1981). Although the cells in *Xenopus* do not show the distinctive features of apoptosis in mammalian tissues, Bowen & Lockshin (1981) state that in lower animals apoptosis may manifest itself in different unspecified ways, and certainly it is isolated cells within Meckel's cartilage in *Xenopus* which are affected. It is therefore possible that the evidence of cellular degeneration and cell debris observed during this phase represents a form of apoptosis.

Meckel's cartilage is undergoing considerable change in shape during this phase (Shaw, 1982) and the presence of such apoptotic cells would be in accord with Glucksmann's hypothesis (1951). Although there is considerable evidence that the cartilage cell is constantly altering its outline by extending and retracting its processes (Chesterman & Smith, 1968), there is no evidence that the cells move bodily through the matrix, therefore the changing shape of Meckel's cartilage seems to be partly due to a balance between the cell division and cell death occurring within it, as well as to matrix changes.

It is interesting to note the close similarity between the tadpole cartilage in *Xenopus* and that found in invertebrates. Cartilage occurs in many groups of invertebrates, including Coelenterates, Annelids, Molluscs and Arthropods. The types of cartilage found in the latter two groups range from tissues resembling vertebrate hyaline cartilage, with relatively small numbers of cells embedded in abundant matrix, to extremely cellular cartilages with virtually no matrix. The odontophore cartilage of *Busycon canaliculatum* (Gastropoda), described by Person & Philpott (1967), is of this latter type and is strikingly similar to Meckel's cartilage in *Xenopus*, prior to the metamorphic changes occurring. However, in the case of *Xenopus* the structural changes together with the development of the perichondrial bones are probably associated with the change in feeding habit from filtration of organic particles by the tadpole to active predation in the post-metamorphic froglet. The change to a more consistent joint shape may also be associated with this more robust lower jaw function.

## SUMMARY

Meckel's cartilage, in *Xenopus laevis* prior to metamorphosis, is a tissue exhibiting very large lacunae, separated by thin rims of matrix, presenting a net-like appearance, similar to that of cartilage in invertebrates. The cells on the periphery of the tissue

are rather more flattened, and more closely packed. On the lateral aspects of the cartilage distinct columns of apparently dividing cells are evident. During metamorphic climax, the amount of matrix separating the lacunae increases, with an associated decrease in lacunar size, and some of the deeper cells develop cilia, which are not seen either before or after climax. By the end of metamorphic climax there is a considerable increase in the amount of matrix present in the tissue, while many cells at all depths in the cartilage show the presence of lysosome-like structures, possibly associated with the changing shape of the cartilage.

Intramembranous ossification is proceeding around Meckel's cartilage, but there is no evidence of endochondral ossification up to the end of metamorphosis.

## REFERENCES


BARNETT, C. H., COCHRANE, W. & PALFREY, A. J. (1963). Age changes in articular cartilage of rabbits. *Annals of the Rheumatic Diseases* **22**, 389–400.

BOWEN, I. D. & LOCKSHIN, R. A. (1981). *Cell Death in Biology and Pathology*. London and New York: Chapman & Hall.

CARR, K. E. & TONER, P. G. (1982). *Cell Structure*, 3rd ed. Edinburgh, London, Melbourne and New York: Churchill Livingstone.

CHESTERMAN, P. J. & SMITH, A. U. (1968). Homotransplantation of articular cartilage and isolated chondrocytes. *Journal of Bone and Joint Surgery* **50**B, 184–197.

DAEMS, W. T. & VAN RIJSSEL, T. G. (1961). The fine structure of the peribiliary dense bodies in mouse liver tissue. *Journal of Ultrastructure Research* **5**, 263–290.

DICKSON, G. R. (1982). Ultrastructure of growth cartilage in the proximal femur of the frog. *Rana temporaria*. *Journal of Anatomy* **135**, 549–564.

DINGLE, J. T. (1975). The secretion of enzymes into the pericellular environment. *Philosophical Transactions of the Royal Society* **271**, 315–324.

FAWCETT, D. W. (1981). *The Cell*, 2nd ed. Philadelphia, London, Toronto: W. B. Saunders Co.

GHADIALLY, F. N., THOMAS, I., YONG, N. & LALONDE, J.-M. A. (1978). Ultrastructure of rabbit semilunar cartilages. *Journal of Anatomy* **125**, 499–517.

GLUCKSMANN, A. (1951). Cell death in normal vertebrate ontogeny. *Biological Reviews* **26**, 59–86.

MEACHIM, G. & ROY, S. (1967). Intracytoplasmic filaments in the cells of adult human articular cartilage. *Annals of the Rheumatic Diseases* **26**, 50–58.

NIEUWKOOP, P. D. & FABER, J. (1956). *Normal Table of* Xenopus laevis (*Daudin*). Amsterdam: North Holland Publishing Co.

PATERSON, N. F. (1939). The head of *Xenopus laevis*. *Quarterly Journal of Microscopic Science* **81**, 161–230.

PERSON, P. & PHILPOTT, D. E. (1967). On the occurrence and biologic significance of cartilage tissues in invertebrates. *Clinical Orthopaedics and Related Research* **53**, 185–212.

SCHERFT, J. P. & DAEMS, W. T. (1967). Single cilia in chondrocytes. *Journal of Ultrastructure Research* **19**, 546–555.

SEDRA, S. N. & MICHAEL, M. I. (1957). The development of the skull, visceral arches, larynx and visceral muscles of the South African clawed toad, *Xenopus laevis* (Daudin) during the process of metamorphosis. *Verhandelingen der Koninklijke Nederlandse Akademie van Wetenschappen, afd. Natuurkunde* **52**, 5–80.

SHAW, J. P. (1982). Teeth and jaws of *Xenopus laevis*. Ph.D. thesis, University of Edinburgh.

SHELDON, H. (1983). In *Cartilage*, vol. I (ed. B. K. Hall). New York and London: Academic Press.

SPRINZ, R. & STOCKWELL, R. A. (1976). Changes in articular cartilage following intra-articular injection of tritiated glyceryl trioleate. *Journal of Anatomy* **122**, 91–112.

STOCKWELL, R. A. (1971). The interrelationship of cell density and cartilage thickness in mammalian articular cartilage. *Journal of Anatomy* **109**, 411–421.

STOCKWELL, R. A. & MEACHIM, G. (1973). In *Adult Articular Cartilage* (ed. M. A. R. Freeman). London: Pitman Medical.

STOCKWELL, R. A. (1979). *The Biology of Cartilage Cells*. Cambridge, London and New York: Cambridge University Press.

WILSMAN, N. J. (1978). Cilia of adult canine chondrocytes. *Journal of Ultrastructure Research* **64**, 270–281.

WILSMAN, N. J. & FLETCHER, T. F. (1978). Cilia of neonatal articular chondrocytes – incidence and morphology. *Anatomical Record* **190**, 871–890.