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HISTOLOGICAL STUDIES ON APOPTOSIS AND CELLULAR PROLIFERATION IN THE PAROTID GLAND OF THE ADULT ONE-HUMPED CAMEL (CAMELUS DROMEDARIUS)

(With 15 Figures)

By
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دراسات هستولوجيه علي موت الخلايا (الفسيولوجى) والتكاثر الخلوي في الغدة النكفية في الجمل وحيد السنام البالغ

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تم إجراء هذا البحث علي عشرة جمال بالغة سليمة ظاهريا من كلا الجنسين لدراسة ظاهرة موت الخلايا (الفسيولوجي) وكذلك التكاثر الخلوي في الخلايا البارنشيميه للغدة اللعابية النكفية باستخدام الميكروسكوب الضوئي والإلكتروني النافذ. أوضحت الدراسة تواجد ظاهرة موت الخلايا (الفسيولوجى) في مختلف أنواع الخلايا البارنشيمة للغدة النكفية موضع الدراسة، حيث ظهرت هذه الخلايا موزعة بصورة فردية بين الخلايا الطلائية السليمة. وتميزت الخلايا التى تمر بهذه الظاهرة بانكماشها واحتوائها علي نواة غامقة الصبغة (تغلظيه) وكذلك سيتوبلازم حمضي غامق . وقد أظهر الميكروسكوب الإلكتروني النافذ مراحل التغيرات المورفولوجية المصاحبة لهذه الظاهرة والتي اشتملت علي تجمع الكروماتين علي الغشاء النووي وتكاثف السيتوبلازم مع الحفاظ علي سلامة الأغشية الخلوية للعضيات ، ثم تشديف النواة وتكوين أجسام بيضاوية أو مستديرة الشكل. وأظهرت الدراسة أن مصير هذه الأجسام ينتهي إلى الالتهام بواسطة الخلايا الطلائية السليمة المجاورة أو بالخلايا وحيدة النواة البلعمية أو الطرد داخل تجويف النهايات المفرزة والقنوات. كما أوضحت الدراسة تواجد الانقسام الميتوزي في الخلايا العنيبية المفرزة و خلايا الاقنية العنبية، وهذا يعكس قدرة هذه الخلايا علي الاستبدال الخلوي الذاتي. أما الاقنية المخططة فلم يلاحظ بها إنقسام ميتوزى أو خلايا قاعدية. بينما وجدت الخلايا القاعدية في القنوات بين الفصيصات ، والتي أظهرت صفات الخلايا الجذعية الغير مميزة ، حيث تتميز بدورها لتعويض الخلايا الفاقدة بها نتيجة الموت الفسيولوجي. هذا وقد نوقشت نتائج هذا البحث لبيان أهمية ظاهرة موت الخلايا (الفسيولوجي) وكذلك التكاثر الخلوي لبارنشيما الغدة النكفية في الجمال البالغة .

SUMMARY

Light and transmission electron microscopical investigations were conducted on ten adult apparently healthy camels of both sexes to

describe the process of apoptosis (physiological cell death) and the proliferative process as a mode of cellular replacement within the parotid gland. All types of the parenchymal cells of the parotid gland of the adult camel were demonstrated undergoing apoptotic death. Under the light microscope, these apoptotic cells were singly demonstrated among the viable neighbouring epithelial cells. They were characterized by their shrinken-appearance, deeply-stained pyknotic nuclei and deeply-stained acidophilic cytoplasm. By the transmission electron microscope, the apoptotic cells were observed undergoing series of morphological changes including chromatin aggregation upon the nuclear membrane, cytoplasmic condensation, with preserved cellular integrity of the membranous organelles, and nuclear fragmentation with formation of oval or rounded apoptotic bodies. The fate of these bodies was either the phagocytosis by healthy neighbouring epithelial cells or by a mononuclear phagocyte or the extrusion into the lumen concerned. Mitotic activity was more frequently observed within the cellular elements of the secretory acini than the intercalated ducts. Such activity reflects the proliferative capacity of these cells for self-replacement. Mitotic activities and basal cells could not be observed within the striated duct cells. The basal cells within the interlobular duct revealed the microscopical features of undifferentiated stem cells, which underwent differentiation to mature elements, replacing the apoptotic cells within this segment.

Key words: *Apoptosis, phagocytosis, mitosis, stem cells, cellular proliferation, parenchymal cells, parotid gland, camel.*

INTRODUCTION

The last few years have witnessed an explosion of both interest and knowledge about apoptosis. Apoptosis (physiological cell death) is a process by which a cell actively commits suicide in a controlled and programmed manner in response to specific stimuli (Anilkumar, Sarraf and Alison, 1992). This occurs during the development of many tissues and organs as well as in adult tissues in almost all-multicellular organisms (Hecht, Connelly, Marchetti, Ball and Hand, 2000). Apoptotic cell death was heavily studied in many tissues as a single process or in accompanying with mitosis and cellular proliferation. Both of the two processes were recorded in the rat parotid gland (Walker and Gobè, 1987), in the mouse (Denny and Denny, 1999) and rat submandibular gland (Takahashi, Nakamura, Suzuki, Islam, Domon,

Yamamoto and Wakita, 2000) as well as in the sublingual gland of the latter animal (Takahashi, Shinzato, Nakamura, Domon, Yamamoto and Wakita, 2002).

The apoptotic cell death and the cellular proliferation within the salivary glands of the farm animals are lacking in the available literature. Therefore, the current study has been performed to describe the apoptotic process and to observe the proliferative processes as a mode of cellular replacement within the parenchymal cells of the parotid gland of the adult camel (Camelus dromedarius) as well as to discuss their possible significance.

MATERIAL and METHODS

This study was carried out on the parotid gland of ten adult apparently healthy camels of both sexes.

For light microscopical investigation, pieces of the parotid gland were taken, fixed in Bouin's fluid, processed for paraffin embedding, sectioned and stained with haematoxylin and eosin.

For transmission electron microscopy, samples from the parotid gland were fixed in a mixture of 2.5% paraformaldehyde and 2.5% glutaraldehyde in 0.1M Na-cacodylate buffer, pH 7.3 for 4 hours at 4°C. They were washed in the same buffer used and then post-fixed in 1% osmic acid in 0.1 M Na-cacodylate buffer for further 2 hours at 4°C. The samples were then dehydrated in ethanol and embedded in Araldite-Epon mixture (Anderson and Andre, 1968). Semithin sections were cut and stained with toluidine blue, while the ultrathin ones were stained with uranyl acetate and lead citrate (Reynolds, 1963) and examined under JOEL 100 CX II transmission electron microscope.

RESULTS

1. Histological examination of apoptosis:

The secretory acini and the surrounding myoepithelial cells as well as the cells lining the intercalated, striated and interlobular ducts of the parotid gland of the adult camel showed singly scattered apoptotic cells among the apparently healthy neighbouring cellular elements.

The light microscopic observation of apoptosis revealed that, the detectable apoptotic cells within the parotid parenchyma were few. These apoptotic cells were characterized by their shrinken-appearance and deeply-stained pyknotic nuclei as well as deeply-stained acidophilic cytoplasm (Fig. 1). Later on, the nuclear chromatin condensed and

formed large masses upon the nuclear membrane and the cell became surrounded by a clear halo (Fig. 2). Then after, these cells formed membrane bounded oval or rounded structure containing nuclear fragments surrounded by rim of cytoplasm called apoptotic bodies (Fig. 3).

At the ultrastructural level, the apoptotic cells were recognized among the healthy cellular elements by aggregation of most of its nuclear chromatin in compact granular masses that abut on the nuclear envelope. The nuclear outline became convoluted, however the nuclear pores were still recognizable (Fig. 4). Concomitant with these early nuclear changes, the cytoplasm of the apoptotic cells started to condense and became more electron-dense, while the cytoplasmic organelles presented no structural alteration (Fig. 4).

With the progress of the apoptotic process, the cell volume decreased, the nuclear chromatin became more condensed, the nuclear contour became more corrugated and the nuclear pores were not more detectable (Fig. 5). At this stage, the cytoplasmic condensation was progressed, resulting in marked crowding of its organelles, which retained their normal integrity. The overall nuclear and cytoplasmic compaction was frequently associated with the appearance of translucent cytoplasmic vacuoles as well as separation of cellular attachment of the apoptotic cells from their viable neighbours. The breaking down of this cellular attachment was observed firstly basolaterally, where the cytoplasmic processes of the apoptotic cells became smaller and fewer than those of the healthy elements (Fig. 5). Then after, fragmentation of the nucleus began (Fig. 6) and progressed by time (Fig. 7).

Finally, the apoptotic cells had lost their attachment with the healthy neighbours and formed a rounded or oval structure containing nuclear fragments and some cellular organelles called apoptotic bodies (Fig. 8). These bodies were either phagocytosed or shed off from the surface into the acinar or ductal lumen. Phagocytosis of these apoptotic bodies occurred either by the healthy neighbouring epithelial cells as indicated by the presence of large phagocytic vacuoles containing cellular debris within these cells (Fig. 9), or by mononuclear phagocytes, whose cytoplasmic extensions were observed surrounding the apoptotic cell (Fig. 10).

2. Histological examination of cellular proliferation:

Proliferation of the parenchymal cells of the parotid gland of the adult camel occurred either by mitosis of the cellular elements of the secretory acini and the intercalated ducts or by differentiation of the

basal cells within the interlobular ducts. Examination of histological sections revealed various stages of mitosis within the cells lining the secretory acini and the intercalated ducts. These mitotic activities were more frequently observed within the acinar cells (Figs. 11a-c).

By the transmission electron microscope, the dividing acinar cells were characterized by the lack of secretory granules (granule-free cells) and the peripherally located other cell organelles. The acinar cells passing the metaphase stage were characterized by aggregation of chromosomes at the equatorial plane (Fig. 12), while in those presenting anaphase, the chromosomal sets were observed at the apposite poles of the cell (Fig. 13).

The basal cells were demonstrated only at the interlobular ducts. They were small cells attaching to the basal lamina with hemidesmosomes and to the surrounding cells with cytoplasmic interdigitations and desmosomes. They displayed embryonic-like features represented by scanty cytoplasm with few organelles and large nucleus with diffuse chromatin and large nucleolus (Fig. 14 & inset). During cellular replacement, the basal cells were differentiated into mature varieties, replacing the apoptotic cells, which were observed undergoing extrusion into the duct lumen (Fig. 15).

DISCUSSION

The present study revealed that, deletion of unwanted parenchymal cells of the parotid salivary gland of the adult camel was accomplished by typical apoptotic process. These apoptotic cells were characterized by their shrunken appearance with pyknotic nuclei and condensed eosinophilic cytoplasm simulating that observed by Wyllie, Kerr and Currie (1980); Salem (1997) and El-Kablawy, Maxwell, Williamson, Anderson and Hamilton (2001). Due to the preliminary condensation, the apoptotic cells were noticeably smaller than healthy ones (Anilkumar *et al.*, 1992), owing to the loss of water and ions (Campana and Cleveland 1996).

Ultrastructurally, the apoptotic cells were observed in all parenchymal cells of the parotid gland of the adult camel. They involved stereotyped sequences of morphological changes including aggregation of nuclear chromatin, condensation of the cell cytoplasm with intact membranous organelles and finally fragmentation of the nucleus and formation of apoptotic bodies. These morphological features were similar to those observed in the acinar cells of the parotid (Walker and Gobé, 1987), submandibular (Chisholm and Adi, 1995; Takahashi *et al.*,

2000) and sublingual glands of rat (Takahashi *et al.*, 2002), in the intercalated duct cells (Hecht *et al.*, 2000) as well as in the myoepithelial cells of the rat submandibular gland after ligation of the excretory duct (Takahashi, Nakamura Shinzato, Domon, Yamamoto and Wakita, 2001).

The presence of nuclear fragments within a membrane-bounded apoptotic body is the most diagnostic feature of apoptosis (Wyllie *et al.*, 1980; Anilkumar *et al.*, 1992). Within these bodies, the preserved cellular integrity is believed to be due to the increased tissue transglutaminase activity. This enzyme crosslinks lysine and glutamine residues and is believed to tighten the membrane of the apoptotic bodies and prevent their lysis before phagocytosis and intracellular degradation (Bursch, Oberhammer and Schulte-Hermann, 1992). This prevent spillage of harmful substances such as DNA to come in contact with healthy tissues, preventing any transfer of mutated genes (Kerr, Searle, Harmon, Bishop, 1987) and consequently, the inflammatory reactions were avoided (Campana and Cleveland, 1996).

The present study revealed, that apoptotic cells were eliminated either by extrusion into the lumen concerned as recorded by Anilkumar *et al.* (1992), Karam and Leblond (1993c) and Salem (1997), or phagocytosed by neighbouring healthy epithelial cells or mononuclear phagocytes (Walker and Gobé, 1987; Hecht *et al.*, 2000; Takahashi *et al.*, 2000). The latter cells appear to recognize by their lectin, altered sugar groups on the apoptotic cell surface or they may apparently recognize a phosphatidylserine, a negatively charged phospholipid found on the extracellular leaflet of the plasma membrane of the apoptotic cells (Kassel, 1998).

In agreement with Campana and Cleveland (1996), Kassel (1998) and Sapunar, Vilović, England and Saraga-Babic (2001), the detectable apoptotic cells were few, due to the speed of this process (30 to 60 minutes) and the efficient phagocytosis of the apoptotic cells (Campana and Cleveland, 1996).

It could be accepted that apoptosis of the parenchymal cells of the parotid gland of the adult camel would provide the basis for a protective role against disease, infact that it eliminate old, damaged or excessive cells as mentioned by Bursch *et al.* (1992). Defective expression of molecules that induce apoptosis may contribute to the development of neoplasia by prolonging cell survival (Campana and Cleveland, 1996)

The present study revealed that, the mitotic activities were more frequently observed within the acinar cells of the parotid gland of the

camel. Similar results were also observed by Chai, Klauser, Denny and Denny (1993); Denny, Chai, Klauser and Denny (1993) and Denny and Denny (1999) in normal adult mouse submandibular gland as well as Man, Ball, Marchetti and Hand (2001) in adult rat sublingual gland acinar cells. On the other hand, such activities were recorded within the acinar cells of the rat parotid gland, only after duct obstruction (Takahashi, Schoch and Walker, 1998) or ligation (Walker and Gobé, 1987). This mitotic activity reflects a proliferative capacity of the parotid gland acinar cells for self-renewal as suggested by Burford-Mason, cummins, Brown, Mackay and Dardick (1993) and He, Xu and Akio (1996), where the newly generated cells replace those undergoing apoptosis.

In accordance with Taga and Sesso (2001), the proliferative activity of the acinar cells of the rat parotid gland provided also cells, that presumably dedifferentiated into intercalated duct cells, whereas cells produced in the intercalated duct compartment migrated to, and differentiated into, cells of the striated duct compartment, where the latter showed neither mitotic activities nor stem cell. The myoepithelial cells may probably have a proliferative capacity for self-replacement as mentioned by Burgess, Dardick, cummins, Burford-masson, Bassett and Brown (1996).

Concerning, the mitotic activities of the intercalary ductal cells, it was not so high as in the acinar cells. This disagrees with that observed by Denny *et al.* (1993), Chai *et al.* (1993), He *et al.* (1996) and Man *et al.* (2001), where they were recorded high proliferative activities in the intercalated duct cells of adult mouse and rat submandibular glands as well as rat salivary glands, respectively. Contradictive speculations were mentioned concerning the mitotic activity of the intercalated duct cells. Schwartz-Arad, Arber, Arber, Zajicek and Michaeli (1988); Takahashi *et al.* (1998) and Man *et al.* (2001) suggested that, the intercalated duct cells differentiate into acinar ones. This contradicts with that mentioned by Redman (1995) and Taga and Sesso (2001), as the intercalated duct cells originate from redifferentiation of the acinar cells. This suggestion was confirmed by Denny *et al.* (1993) in the adult mouse submandibular gland as they could not observed any evidence of conversion of the intercalated duct to acinar cells, and suggested, that most, if not all, proliferative activity leading to acinar cell population maintenance occurs by self-proliferation.

It could be speculated, that the mitotic activities of the intercalated duct cells may responsible for self-replacement of the

apoptotic cells within this duct segment and probably those of striated duct but not the acinar cells due to the more frequently observed mitotic activities within the acinar cells.

The observed basal cells at the interlobular ducts, possessed characteristic features of undifferentiated stem cells, similar to that observed by Karam and Leblond (1993a), as these cells are capable for DNA synthesis and mitosis (Daradick, Byard and Carnegie, 1990). From the obtained results, it could be suggested, that the basal cells can replace the apoptotic cells within the interlobular duct of the parotid gland of the camel, as they reproduce themselves and give rise to other cell types (Hall, 1989; Karam and Leblond, 1993a). Further suggestion was reported by Alberts, Bray, Lewis, Raff, Roberts and Watson (1989) where they stated that, the stem cells are not terminally differentiated and have the ability to divide without limit throughout the lifetime of the organism.

Taken together, the results of the present study strongly suggest that, the actual parenchymal cell population would therefore, be the outcome of a balance between the rate of cell death by apoptosis and rate of cell birth by mitosis, which results in steady state (cellular homeostasis) of the parotid gland parenchyma of the adult camel. Consequently, disruption of this balance might induce certain pathological features in disease states.

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LEGENDS

Figs. 1-3: Photomicrographs, showing apoptotic cells within epithelial lining of the striated duct of the parotid salivary gland of the adult camel. Hx. & E. (Oc. X 10; Ob. X 100).

1. Apoptotic cell (arrow) with deeply stained nucleus and deeply stained acidophilic cytoplasm.

2. Apoptotic cell (arrow) with nuclear condensation in compact masses, surrounded by a clear halo.

3. Apoptotic body (arrow) with nuclear fragments.

Figs. 4-10: Electron micrographs of the apoptotic process within the parenchymal cells of the parotid salivary gland of the adult camel:

4. Apoptotic cell (Apc) within the secretory acinus, showing chromatin aggregation upon somewhat corrugated nuclear envelope with recognizable pores (arrow). Intact mitochondria (M) and rough endoplasmic reticulum (arrowhead), viable acinar cell (Vc), basal lamina (Bl), lumen (L). X 6545.

5. Apoptotic cell (Apc) at the intercalated striated duct junction, showing further nuclear changes and corrugation of the nuclear outline with undetectable pores. Mitochondria (M), cytoplasmic vacuoles (V), basolateral separation of the apoptotic cells (arrow), basal lamina (Bl), viable cell (Vc), lumen (L). X 6666.

6. Apoptotic myoepithelial cell (My), showing the beginning of nuclear fragmentation (arrow) and intact mitochondria (M). Viable acinar cell (Vc), basal lamina (Bl). X 7000.

7. Apoptotic cell in striated duct (oblique sectioned) with nuclear fragments (arrow) and intact mitochondria (M) within electron-dense cytoplasm. Viable cells (Vc), basal infoldings (F), basal lamina (Bl). X 7000.

8. Apoptotic body (Ab) within the intercellular space between the acinar secretory cells with nuclear fragments (arrow) and some mitochondria (arrowhead). Viable cell (Vc), basal lamina (Bl). X 9643.

9. Acinar cell, showing large phagocytic vacuole containing remnant of apoptotic body (arrow). X 22615.

10. Mononuclear phagocyte (arrow) surrounding with their processes (arrowhead) an apoptotic myoepithelial cell (My). Viable acinar cell (Vc), basal lamina (Bl). X 9333.

Figs. 11a-c: Photomicrographs, showing various stages of mitosis within the acinar and intercalated duct cells of the parotid gland of the adult camel. (Oc. X 10; Ob. X 100).

a)- Prophase in intercalated duct cell (arrow). Hx & E.

b)- Metaphase in the acinar cells (arrow). Hx & E.

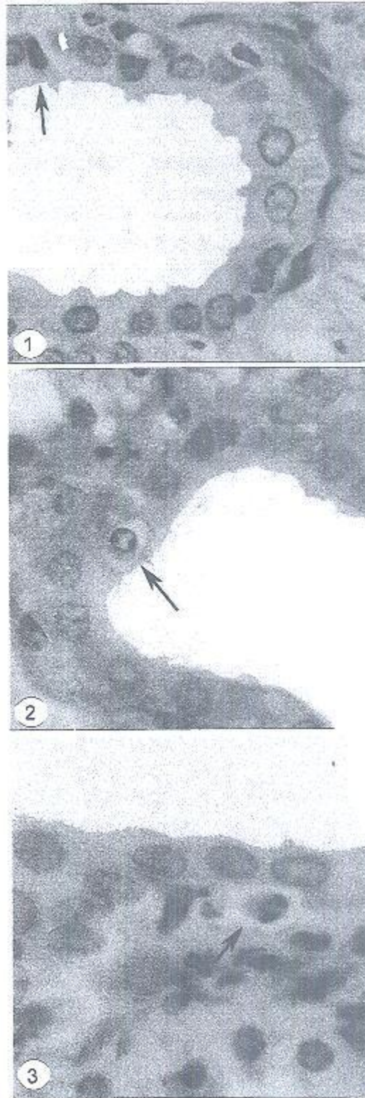
c)-Telophase in the acinar cells (arrow). Semithin section, toluidine blue.

Fig. 12: Electron micrograph of a dividing acinar cell in metaphase stage, showing the arrangement of densely-stained chromosomes (Chr) in the aquatorial plane. Peripherally arranged mitochondria (arrowhead) and rough enoplasmic reticulum (arrow). X 4295.

Fig. 13: Electron micrograph of a dividing acinar cell in anaphase stage, showing the densely-stained chromosomes (Chr) at the opposite poles of the cell. Peripherally arranged mitochondria (arrowhead) and rough endoplasmic reticulum (arrow). Non-dividing acinar cells (ac). X 6400.

Fig. 14 & inset: Electron micrographs, showing duct basal cells (Bc) resting below the apoptotic cell (Apc). The latter loses their attachments with viable cells (Vc), where their cytoplasmic processes appear few and small (arrow). X 6857. Inset: High magnification of a basal cell (Bc) with a characteristic large nucleus and scanty cytoplasm. X 8888. Desmosomes (arrowhead), basal lamina (Bl), lumen (L).

Fig. 15: Electron micrograph of an interlobular duct, showing the basal cell (Bc), which replaces an apoptotic cell (Apc) by another duct cell (dc). An apoptotic cell (Apc) undergoing extrusion into the lumen, mature cell (Mc), basal lamina (Bl), lumen (L). X 4275.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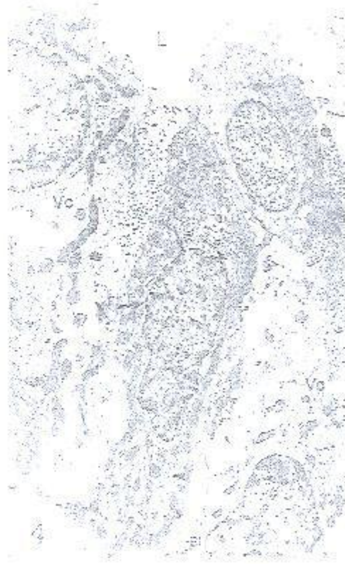
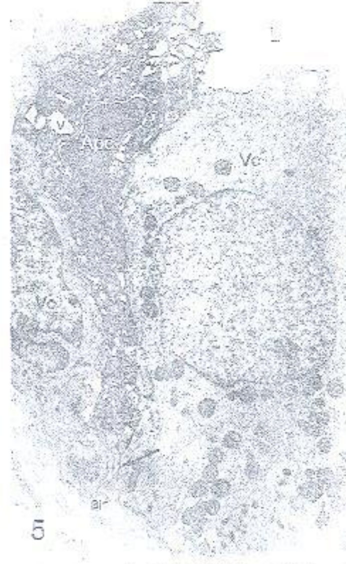
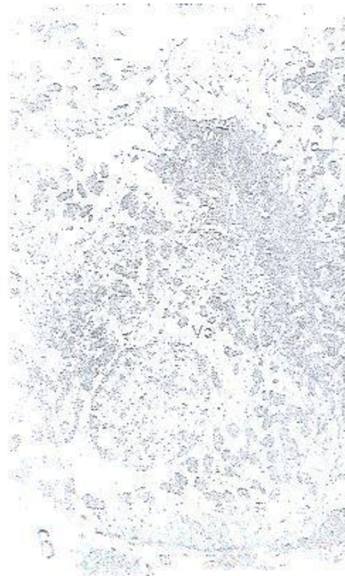
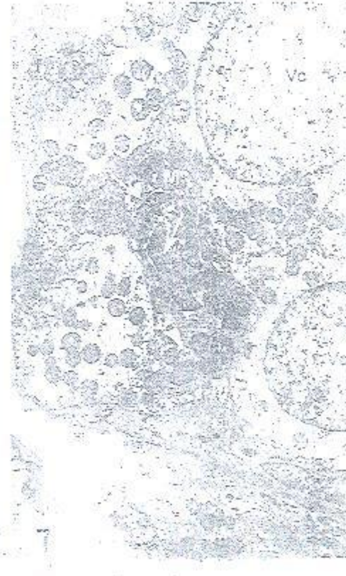
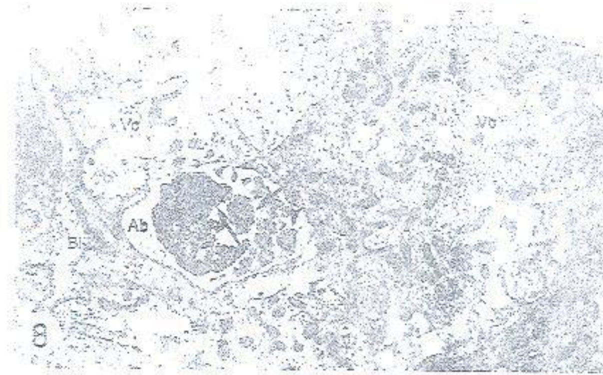


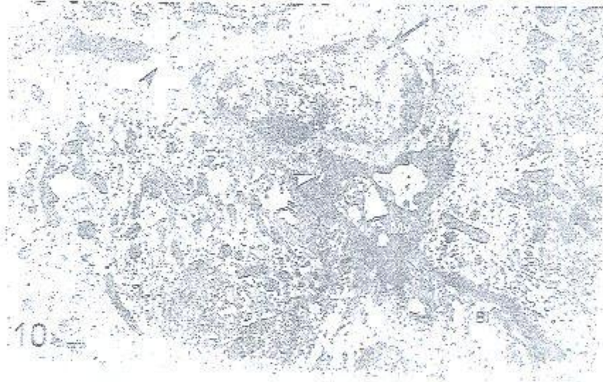


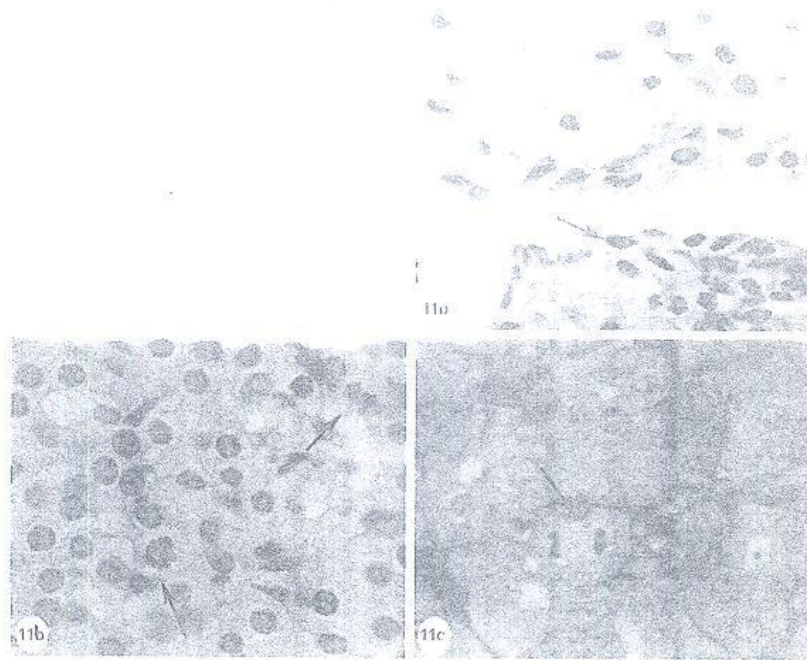





Vc
Vc
Ab
Bl
8

Vc
9


Bl
10


11a
11b
11c

Chr
Chr
Chr
13
12
L
Bl
Bc
15
Bc
Vc
Bc
L
Apc
Bc
Vc
Bl
14