The choroid plexus in experimental hydrocephalus

A light and electron microscopic study in normal, hydrocephalic, and shunted hydrocephalic dogs

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Experimental hydrocephalus was created in dogs by injection of kaolin into the cisterna magna. One month after the kaolin injection, ventriculojugular shunts were performed on certain of the hydrocephalic dogs. Shunted hydrocephalic dogs were killed 1 day or 1 week after placement of the shunt. Cerebrospinal fluid (CSF) pressures were measured prior to the kaolin administration and/or 1 month post-kaolin injection and/or after the shunting procedure. Choroid plexuses from control, hydrocephalic, and shunted hydrocephalic dogs were examined by light and electron microscopy. The hydrocephalic dogs had choroid plexuses with a flattened epithelium, compacted cytoplasm, and multiple large vacuoles usually containing small, rounded membrane-bound structures; it was postulated that these vacuolar structures were dilated multivesicular bodies possibly related to CSF resorption. Choroid plexuses from hydrocephalic dogs examined 1 day post-shunt closely resembled choroid plexuses from the control dogs. Intracytoplasmic, apical lipid inclusions, 1.0 to 6.0 μ in diameter, were noted within many choroidal epithelial cells of dogs shunted for 1 week. This change was probably related to the trauma of shunt insertion. It was concluded that the morphology of the canine choroid plexus returned to normal 1 day after the ventriculojugular shunt.

Key Words: choroid plexus, hydrocephalus, cerebrospinal fluid, ventriculojugular shunt, electron microscopy, capillaries

Since Burr and McCarthy conducted the first studies on experimental internal hydrocephalus, many investigators have created internal hydrocephalus in numerous mammals by various methods: mechanical obstruction within the ventricular system; aqueductal stenosis secondary to viral infections or radiation; intraventricular India ink or lampblack injection; intracisternal injection of kaolin; hypo- or hypervitaminosis A; and subarachnoid infusion of silicone oil. Neurosurgical procedures have been used to shunt cerebrospinal fluid from the ventricles of animals with kaolin-induced hydrocephalus, thereby decreasing both the intracranial pressure and the degree of ventricular dilatation.
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To the best of the author's knowledge, there have been no experiments correlating cerebrospinal fluid (CSF) pressures with light and electron microscopic observations of the choroid plexus. The purpose of the present study is to define the histology and ultrastructure of the choroid plexus in normal, hydrocephalic (kaolin-induced) and shunted hydrocephalic dogs and relate the choroidal morphology to changes in CSF pressure.

Materials and Methods

Twenty-four adult, female mongrel dogs, weighing 20 to 25 kg, were anesthetized with sodium pentobarbital (22 mg/kg) and placed in a prone position. The neck was flexed, and obstruction of the airways was avoided.

Controls (11 Dogs)

A cisternal puncture was done and the CSF pressure measured with a manometer containing sterile saline. A semilunar incision was made in the scalp, extending across the midline, and the muscle dissected from the temporal bone. A burr hole, placed 1 to 2 cm to the left of the midline, was enlarged and the dura mater opened. The gyrus lateralis was incised, the left lateral ventricle entered, and the choroid plexus gently stripped from the floor of both the anterior horn and body of the left lateral ventricle. After the choroidal biopsy the dog was perfused through the left ventricle of the heart with saline followed by 10% formalin. Following perfusion, the brain and superior cervical spinal cord were dissected out and placed in 10% formalin.

Hydrocephalic Animals (6 Dogs)

Control CSF pressures were obtained by cisternal puncture. Kaolin (20 mg/kg in 0.5 ml sterile saline) was then injected into the cisterna magna as described by Dixon and Heller. Immediately after the injection the head was lowered and left in a dependent position for 5 min. Following the procedure, the dog was put in a lateral recumbent position, 15 min per side. One month after kaolin injection a craniotomy was performed by the same method as in the controls. The ventricular pressure was measured with a sterile saline manometer and a choroid plexus biopsy was taken. The dog was then perfused with saline followed by 10% formalin. Both the brain and superior cervical spinal cord were dissected out and immersed in 10% formalin.

Hydrocephalic Animals with Shunts (7 Dogs)

Control cisternal CSF pressures and kaolin injections were performed in the manner above. One month post-kaolin injection, each dog was anesthetized and a right temporal craniotomy performed. The ventricular CSF pressure was measured with a sterile saline manometer. Then a 3-cm right-angle catheter was inserted into the body of the right lateral ventricle through the ipsilateral gyrus lateralis. A low-pressure Holter valve (drainage at 0 to 50 mm H2O) was connected to the ventricular catheter and inserted between the skull and the overlying musculature. From the valve a catheter was run beneath the subcutaneous tissue of the head and neck and sutured into the right external jugular vein. The wounds were closed in layers with interrupted sutures of silk.

One day postoperatively (3 dogs) and 1 week postoperatively (4 dogs) a left craniotomy was performed and the ventricular CSF pressure was measured with a manometer containing sterile saline. The choroid plexus of the left lateral ventricle was biopsied. Following perfusion with saline and 10% formalin, autopsies were performed on the dogs. The ventriculojugular shunts were tested and found to be functional in all animals. Brains and the superior cervical spinal cords were then dissected out and placed in 10% formalin.

Tissue Preparation

Each specimen of choroid plexus was divided into two pieces. One piece was fixed in a formalin-acetic acid-alcohol solution, embedded in paraffin, and sectioned for light microscopy. Sections 6 and 2 μ thick were cut and stained with hematoxylin and eosin and Heidenhain's connective tissue stain. The other piece of choroid plexus was minced in 5% glutaraldehyde-0.067 M cacodylate at 4°C, pH 7.4; after mincing the tissue remained in the fixative for 3 hours, and was then rinsed overnight in 0.2 M cacodylate-7.5% sucrose at 4°C, pH 7.4. Then the tissue was postfixed for 1
hour in 1% phosphate-buffered osmium tetroxide at 4°C, pH 7.4; dehydrated through graded alcohols; and embedded in Epon 812. Sections were cut on a Porter-Blum MT-1 ultramicrotome with glass knives. Sections 0.5 μ thick were mounted on glass microscope slides, stained with toluidine blue, and examined by light microscopy. Ultrathin sections were mounted on plain copper grids, stained with uranyl acetate, and lead acetate or lead citrate, and examined in a Philips EM200 electron microscope.

**Results**

*Experimental Hydrocephalus*

Several days after the intracisternal injection of kaolin, the dogs became listless. Over the ensuing month the dogs showed increasing lethargy, loss of appetite, and great difficulty in standing. After the ventriculojugular shunt, they rapidly became alert and active, and had an increased appetite.

Cerebrospinal fluid pressures in the control dogs ranged from 10 to 55 mm H₂O with a mean pressure of 35.0 mm H₂O. Of the 13 dogs rendered hydrocephalic, the CSF pressures, measured 1 month after kaolin injection, increased from 2 to 14 times relative to the pressures recorded before the intracisternal administration of kaolin (P: 26.5 vs 110.0 mm H₂O). The seven hydrocephalic dogs in whom ventriculojugular shunts were placed had CSF pressures of 0 to 5 mm H₂O (Table 1).

Inspection of fixed brains from the control dogs revealed a 1.0 to 1.5 cm longitudinal incision in the left gyrus lateralis with the rest of the brain grossly within normal limits. Upon coronal sectioning of the brains, blood was noted within the left lateral ventricle, and the segment of choroid plexus from the left foramen of Monro to the body of the lateral ventricle was missing. The ventricular system appeared of normal size as did the thickness of the white matter and surrounding cortex. Although variations in ventricular size have been reported in mongrel dogs, no enlargement of the ventricular system was noted in any control dog.

Brains from nonshunted hydrocephalic dogs had slightly flattened gyri. An incision identical to the one described in the controls was noted in the left gyrus lateralis. A mixture of kaolin and fibrous tissue surrounded the superior cervical spinal cord and much of the medulla oblongata extending across the anterior aspect of the pons to encompass the pituitary (Fig. 1). Fibrous adhesions had grossly occluded one or two of the foramina of the fourth ventricle. The lower

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<th>Ventricular Pressure (post-shunt procedure) mm H₂O</th>
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*The sensitivity of the saline manometer was not enough to accurately measure intraventricular CSF pressures below 5 mm H₂O.

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portion of the cerebellar vermis was herniated into the foramen magnum in most specimens. Coronal sectioning of the brains demonstrated a dilated ventricular system (Fig. 2). Cortical thickness was normal but the periventricular white matter was thinned in all of the hydrocephalic brains examined. Residual blood was seen in the left lateral ventricle, and the anterior portion of the choroid plexus therein was missing.

The brains from shunted hydrocephalic dogs killed 1 day after the ventriculojugular shunt appeared macroscopically similar to those killed 1 week after the shunt. Gyri and sulci were normal. In the left gyrus lateralis was an incision as described in the control and hydrocephalic dogs. A hole 3 mm in diameter, through which the shunting catheter had passed, was located in the right gyrus lateralis extending toward the right lateral ventricle. The base of the brain stem and the superior cervical spinal cord were covered by kaolin and fibrous tissue. In most specimens fibrous tissue appeared to occlude several or all of the foramina of the fourth ventricle. Clotted blood and an absence of the anterior portion of the choroid plexus were noted within the left lateral ventricle upon coronal sectioning. The track of the ventricular catheter extended from the surface of the right gyrus lateralis into the body of the right lateral ventricle. An enlargement of the ventricular system, somewhat less severe than that in the nonshunted hydrocephalic groups, was present in all shunted hydrocephalic dogs. However, the degree of dilatation appeared to be less in the dogs shunted for 1 week than in those shunted for 1 day. All ven-

Choroid Plexus

Light Microscopy

The choroid plexuses from control dogs were composed of arteriole, venule, and capillary loops, each loop being surrounded by a continuous single layer of cuboidal cells. Connective tissue and scattered mononuclear cells were located between the epithelium and the vascular core of the choroid plexus. Nuclei were rounded and centrally located within the choroidal epithelial cells. All choroid plexuses from control, hydrocephalic, and shunted hydrocephalic dogs contained approximately the same amount of connective tissue. Unlike the control plexuses, however, sections of the choroid plexuses from hydrocephalic dogs showed focal areas where choroidal epithelial cells were flattened or occasionally missing. In general, the epithelium was low cuboidal, containing central nuclei and intracytoplasmic vacuolar areas. The interstitium contained collagen and a moderately increased concentration of mononuclear cells.

Cuboidal epithelial cells, which possessed rounded central nuclei and a nonvacuolated cytoplasm, were noted in the choroid plexuses of treated hydrocephalic dogs 1 day and 1 week after placement of the shunt. In the dogs examined at 1 day after shunting, nu-

FIG. 1. Kaolin and fibrous tissue encompassing the pituitary and surrounding the basal portion of the brain stem and superior cervical spinal cord. Nonshunted hydrocephalic dog (D18H).

FIG. 2. Coronal sections of canine brains showing dilatation of the ventricular system and flattening of the gyri in the specimens from the hydrocephalic dog (D12H) on the right as compared to that of the control dog (D5C) on the left.
merous polymorphonuclear neutrophils were present in the interstitium and between the cells of the choroidal epithelium. In dogs killed 1 day after shunting, certain of the choroidal epithelial cells contained golden brown pigment granules resembling hemosiderin. Histological examination of the choroidal plexuses from dogs killed 1 week after shunting showed an increased concentration of mononuclear cells within the interstitium and scattered between choroidal epithelial cells. Macrophages loaded with golden brown pigment granules resembling hemosiderin were also present in the choroidal interstitium.

**Electron Microscopy**

**Control Dogs.** Each canine choroidal villus consisted of a capillary loop enveloped by a single layer of cuboidal epithelial cells joined to one another by tight junctions at the apical surfaces. Between the capillary and the epithelial investment was an interstitium composed of collagen fibrils and pial cells with long processes (Fig. 3). Every choroidal epithelial cell possessed a microvillous border (Fig. 4) and a plasma membrane which was infolded in the lateral and basal regions of the cell. The choroidal epithelium rested on a thin, mildly osmiophilic, homogeneous basement membrane. An occasional tuft of two to eight cilia was noted within the microvillous border of certain epithelial cells. Each cilium consisted of two central filaments and nine pairs of peripherally arranged filaments and was anchored to the apical cytoplasm by rootlets (Fig. 4). Pinoctytic vesicles were present in the cytoplasm adjacent to the plasma membrane. Vacuoles and occasional lipid droplets (0.5 to 0.8 μ in diameter) were noted at the apical surface of the choroidal epithelial cells.

Mitochondria were ubiquitous in the epithelial cytoplasm as were polyribosomes and rough endoplasmic reticulum. Chromatin was dispersed throughout the round centrally located nuclei with clumps of chromatin between the pores of the nuclear envelope. When noted, one to two nucleoli were present per nucleus. The Golgi apparatus was in a paranuclear position in the apical portion of the choroidal epithelial cytoplasm.
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Capillaries with an attenuated fenestrated endothelium and an outer investment of thin, mildly osmiophilic basement membrane formed the center of the choroidal villus. Choroidal capillaries were large, ranging up to 6 erythrocytes in diameter. In the apical* region of the choroid plexus, capillaries and a paucity of connective tissue elements were noted; near the basal* region, arterioles, venules, and an abundance of connective tissue elements predominated. Arterioles and venules were identified by the layer(s) of smooth muscle cells in the vessel walls.

Two types of epithelial cells, classified as "dark" and "light" on the basis of differing nuclear and cytoplasmic morphology, were present in the control choroid plexuses. The nucleus and cytoplasm of dark cells were uniformly more electron-dense than the nucleus and cytoplasm of light cells.

* The apical region of the choroid plexus is the region furthest from the point of attachment of the choroid plexus to the ventricular floor (basal region).

Hydrocephalic Dogs. In apical and basal regions of the choroid plexus, there was a flattening of the epithelium of many villi. Affected choroidal epithelial cells, measured from the apex to the base of the cell, were approximately one-third to one-fourth the height of control choroidal epithelium (Figs. 5 and 6). The microvilli were well preserved, and no separation was noted between adjacent choroidal epithelial cells or choroidal epithelium and the underlying basement membrane. The epithelial cytoplasm appeared to be more compact than the epithelial cytoplasm of the control choroid plexus. Resembling dilated multivesicular bodies, numerous large vacuoles were present containing many small, round membrane-bound structures just beneath the microvilli (Figs. 6 and 7) as were small apical vacuoles. Nuclei in the choroidal epithelium were ovoid with the longitudinal axis approximately parallel to the basement membrane (Fig. 8). Chromatin distribution in the nuclei was similar to that in the control dogs. Dark and light choroidal epithelial cells were present in all hydrocephalic dogs (Fig. 8).

Occasional plasma cells with cytoplasm rich in rough endoplasmic reticulum were noted within the interstitium. Capillaries showed the same structure in the control choroid plexuses as in the choroid plexuses from hydrocephalic dogs.

Shunted Hydrocephalic Dogs. In general, the morphology of the choroidal epithelium...
from both groups of shunted hydrocephalic dogs corresponded to that of control dogs. Nuclei, mitochondria, polyribosomes, Golgi apparatus, rough endoplasmic reticulum, and lipid droplets (0.5 to 0.8 μ in diameter) correlated in apparent concentration and arrangement with those organelles in the control choroid plexuses (Fig. 9).

In contrast with choroid plexuses from control dogs, plexuses examined 1 day after shunting possessed polymorphonuclear neutrophils between some choroidal epithelial cells and sparsely scattered throughout the interstitium. Large lipoid inclusions, 1.0 to 6.0 μ in diameter and located under the microvillous border, were present within certain choroidal epithelial cells of dogs examined 1 week after shunting (Fig. 10). Plasma cells, lymphocytes, and macrophages with multiple osmiophilic inclusions were present.

Fig. 5. Photomicrograph of choroidal epithelium of normal structure and thickness (to be compared to Fig. 6). Dark (D) and light (L) choroidal epithelial cells; interstitium (I). Control dog (D8C). Uranyl acetate & lead acetate, ×10,300.
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![Image of photomicrograph](image)

**Fig. 6.** Photomicrograph of flattened choroidal epithelium (E) containing large vacuoles (V) which resemble dilated multivesicular bodies. Interstitium (I); plasma cell (P). Nonshunted hydrocephalic dog (D13H). Uranyl acetate & lead acetate, ×10,300.

in the connective tissue space, and occasional lymphocytes were noted between the choroidal epithelial cells. The ultrastructure of the choroidal vasculature in both groups of shunted hydrocephalic dogs was identical to the vascular ultrastructure in choroid plexuses from the control dogs. Dark and light choroidal epithelial cells were present in all shunted hydrocephalic dogs.

**Discussion**

Dixon and Heller\textsuperscript{11} injected kaolin into the cisterna magna of dogs and described the ensuing development of hydrocephalus. The same method was used to create hydrocephalus in this experiment. All of the canine brains examined 1 month after kaolin injection showed a fibrosis of the cisterna magna and basal cisterns and a fibrous cuff around
the superior cervical spinal cord. Fibrosis of the cisterna magna and basal cisterns apparently inhibited the flow of CSF from the ventricular system to cerebral arachnoid villi, while the fibrosis around the superior cervical spinal cord probably hindered flow of CSF to spinal arachnoid villi. In these short-term hydrocephalic animals, the ventricular system enlarged at the expense of the periventricular white matter, as the cortical thickness remained constant.

Cerebrospinal fluid pressure in the control dogs averaged 35.0 mm H₂O and in the experimental dogs increased to 2 to 14 times the pressure taken before the intracisternal injection of kaolin (P 25.5 vs 110.0 mm H₂O). In normal dogs the distance between the opposing walls of the lateral ventricles was relatively small, rendering precise positioning of the needle difficult; therefore, in all dogs the initial CSF pressure was obtained from the cisterna magna. Ventriculojugular shunt procedures included placement of a low-pressure Holter valve that drained the CSF from the right lateral ventricle and maintained a pressure of 0 to 5 mm H₂O within the ventricular system. Proper placement of the needle during intraventricular CSF pressure determination in shunted hydrocephalic dogs was checked by noting pulsation of the saline column, corresponding to respiration, and confirmed by identification of the needle track at autopsy. Coronal sections of the brains from the shunted hydrocephalic dogs showed a lesser degree of ventricular dilatation as compared to the non-shunted hydrocephalic dogs.

Experiments by Dandy and Blackfan⁸,⁹ and Dandy¹ proved that most of the CSF was formed within the ventricular system and suggested that the principal site of production was the choroid plexus. Later investigators¹,¹⁶,²⁰,⁵³ demonstrated that the choroid plexus had absorptive capabilities. In-
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Fig. 8. Dark and light choroidal epithelial cells showing ovoid nuclei. Interstitium (I); capillary (C). Nonshunted hydrocephalic dog (D18H). Uranyl acetate & lead citrate, ×7300.

deed, studies have shown the choroid plexuses to have a capacity for bidirectional transport. After studying plexectomized dogs, Hassin, et al., suggested that the main function for the choroid plexus was absorption of selected materials from the CSF and that the CSF had its origin elsewhere. Recently, Milhorat produced hydrocephalus in plexectomized and nonplexectomized monkeys but noted the hydrocephalus was less severe in the monkeys without choroid plexuses. Milhorat concluded that the majority of the CSF was not formed by the choroid plexus.

Hochwald, et al., produced hydrocephalus in dogs by injection of kaolin into the interpeduncular cisterns followed by intracisternal kaolin injections. They reported that
Fig. 9. Choroidal epithelial cell from a hydrocephalic dog examined 1 day after shunting. Normal choroidal ultrastructure is illustrated. Tuft of cilia (T); interstitium (I). Shunted hydrocephalic dog (D21S). Uranyl acetate & lead citrate, ×8600.

Fig. 10. Large lipoid inclusion (L) within the cytoplasm of a choroidal epithelial cell from a dog examined 1 week following shunting. Nucleus (N). Shunted hydrocephalic dog (D19S). Uranyl acetate & lead citrate, ×15,300.
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the rate of CSF formation, determined by ventriculocisternal perfusion at constant pressure, in hydrocephalic dogs was 70% of the rate of CSF production in normal dogs.

The ultrastructure of the choroid plexus has been reported in man and various other mammals, and the embryology, structure, function, and pathology of the choroid plexus has been reviewed by Dohrmann. The electron microscopic structure of the choroid plexuses from control dogs conformed to that described in the choroid plexuses of other animals. The dark and light cell phenomenon in choroidal epithelium has been ascribed to differences in cellular hydration at the time of fixation.

Certain morphological features of the canine choroid plexus may be correlated with possible functional capabilities: microvilli (absorption and secretion); infolded basal and lateral plasma membranes (water transport); high mitochondrial concentration (high metabolic activity); pinocytotic vesicles (transport of high molecular weight substances); and attenuated fenestrated capillaries (active fluid transport). From morphological evidence the choroid plexus could function in secretion and/or absorption.

Choroid plexuses from the hydrocephalic dogs had a flattened epithelium and a concentration of the cytoplasm. These phenomena were probably related to the high intraventricular pressures, which ranged from 2 to 14 times the cisternal CSF pressures prior to kaolin administration. The large vacuoles contained fluid and small, rounded, membrane-bound structures of undetermined origin. As the vacuolar fluid did not react with osmium tetroxide to give an electron dense deposit, it probably contained little or no protein or lipid. With the increasing intraventricular volume of CSF, formation of the large vacuoles might represent degenerative change secondary to the pressure increase or might represent an uptake of the CSF along with any intraventricular particulate matter contained therein. These large vacuolar structures may represent dilated multivesicular bodies. Becker and Almazon injected horseradish peroxidase into the lateral ventricle of rats and noted pinocytotic uptake of the peroxidase by the choroidal epithelium followed by deposition of the peroxidase within the multivesicular bodies. If choroidal multivesicular bodies function in resorption of substances from the ventricle, hydrocephalus may be a condition of increased uptake of CSF by the choroid plexus, thereby giving rise to dilated multivesicular bodies.

Hydrocephalic dogs killed 1 day after shunting possessed choroid plexuses closely resembling those of the control dogs; however, occasional polymorphonuclear neutrophils were noted in the interstitium and between some epithelial cells. The presence of these acute inflammatory cells might be attributed to mechanical or chemical irritation during the shunting procedure involving the other lateral ventricle or might be indicative of a low-grade infection, although the left lateral ventricle and its contents appeared normal at craniotomy.

In general the choroid plexuses from hydrocephalic dogs examined 1 week after shunting corresponded closely with the choroidal ultrastructure of the control dogs, although large, intracytoplasmic membrane-bound inclusions, measuring 1.0 to 6.0 μ in diameter, were located near the apical surface of certain epithelial cells. Since these inclusions reacted with osmium tetroxide, they were presumably lipid in nature. The genesis of the inclusions is unclear; however, they may represent uptake of the products of intraventricular hemorrhage by the choroid plexus during placement of the ventricular catheter into the opposite lateral ventricle. On the other hand, the lipid material may have been synthesized by the respective choroidal epithelial cells. Askanazy and Flather demonstrated cytoplasmic inclusions in the choroidal epithelial cells in patients and experimental animals with intraventricular hemorrhage. One week after the implantation of a cannula into the lateral ventricle of rabbits, Weindl, et al., examined the choroid plexuses with an electron microscope and noted similar, intracytoplasmic, large lipid inclusions within the epithelium. These authors injected ferritin intraventricularly into the same rabbits and described an initial uptake of the ferritin by pinocytotic vesicles and later storage of the ferritin within the lipid inclusions. As the lipid inclusions were present only in the hydrocephalic dogs shunted for 1 week, the lipid inclusions...
within the choroidal epithelium may well be remnants of the small intraventricular hemorrhage that occurred 1 week earlier.

Acknowledgments

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References

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45. Pease DC: Infolded basal plasma membranes found in epithelia noted for their water transport. J Biophys Biochem Cytol 2(Suppl):203–208, 1956


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