Mitotic Cell Studies Based on *in vivo* Observations
III. Biological significance of 9+2 tubloid patterns,
***de novo* appearance of blepharoplasts,**
disappearance of centrioles in higher plant cells
and flagellum formation

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In previous papers (Wada 1966, 1969a, b), I have repeatedly pointed out that the karyokinesis in both plant and animal kingdoms is carried out on common principles based on the attractoplasm theory. This community in mitotic cells is not restricted within the spindle mechanism alone. The centriole in animal cells and the blepharoplast in plant cells are also common as to their fine structures and function (Wada 1969b). However both these organelles behave differently in their ontogenetic cycles.

In the animal kingdom, the centrioles are constantly present in all the somatic as well as gametic cells without distinction in lower and higher animals. In the plant kingdom, however, the constant appearance of centrioles in somatic cells is confined to lower plant groups such as algae and aquatic fungi. The *de novo* appearance of blepharoplasts in Bryophyta, Pteridophyta, Cycadophyta and Ginkgophyta is confined to the male gametic cells, while no blepharoplasts are present in their somatic and female gametic cells. The complete disappearance of the blepharoplasts or the centrioles from all the cells occurs in Phanerogames except the primitive Gymnosperme groups mentioned above.

Without taking this morphological community and the ontogenetic difference between centrioles and blepharoplasts into consideration, no entity of centrioles probably can be elucidated fundamentally. Also, it is inadequate to deal with the centriole as a mere problem of animal cytology. Centrioles might have appeared in primitive unicellular organisms as primordia of locomotive organs for cell movement and might have been inherited by the present multicellular organisms over a long period of evolution (Wada 1969b).

In this paper, at first, the biological significance of 9+2 tubloid patterns, and then, the *de novo* appearance of blepharoplasts in male gametic cells, the disappearance of centrioles in higher plant cells, and the multiplication of basal bodies in fern spermatozoids are all explained by introducing the idea of unit discs as an infinitesimal portion of centrioles. This idea also is

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extended to elucidate the processes for division, the elongation of centrioles, and the formation of sperm-tail filaments, the flagella and the cilia from the centrioles or basal bodies.

Biological significance of 9+2 tubloid patterns in the transverse section of centrioles

Important works on cilia and flagella have been published by Fawcett (1961). His treatises exhaustively cover the structures and function of ciliary apparatus for which his contributions are greatly appreciated. In a concluding comment he states: "The evolutionary and functional significance of the universal nine-plus-two pattern of internal fibers found throughout the plant and animal kingdoms is still an intriguing mystery."

The key to the disclosure of this mystery, I believe, seems to be concealed in the manifold behavior of centrioles and blepharoplasts in the plant kingdom. This diversification might have been acquired in correspondence with the diversification of living modes of organisms during the course of evolution in long geological ages.

The 9+2 tubloid patterns in the transverse section of the centriole indicate a polar view of the unit disc: an infinitesimal portion of centrioles

Before we enter into the explanation of the physical and biological significances of the 9+2 tubloid patterns in the transverse section of the centriole, we should reinvestigate the developmental process of the so-called tubules or microtubules generally used in electron microscope studies.

At the light microscopic level, tubules or tubes in animal tissues are organized by piling up cells in a ring which make the peripheral wall of the tube. Corresponding to the size of tube diameter, the number of cells in a ring differs in the transverse sections of the tube. If the longitudinal rows of cells would indicate a periodicity (Figs. 1a, b), we then assume the group of cell rows in one period to be a unit cell group or a unit length of the tube. Then, the total length of the tube may be expressed by the number of the unit cell groups piled up longitudinally. If the thickness of each unit group is equal to or less than the diameter of the cells in the ring, each unit group makes a disc and we call it a unit disc of the tube (Figs. 1d, e).

Although we know, at present, nothing about the molecular arrangement in tubloids of centrioles, there are many excellent works on the molecule arrangement of bacterial flagella (Lowy and Hanson 1965, Iino 1964, Asakura, Eguchi and Iino 1966 and others). The flagella of *Salmonella* are 150 Å in diameter and 10 μ in length. This diameter is nearly the half of the individual tubloids which form the 9+2 patterns in centrioles. In the model of the bacterial flagellum, 8 or 10 flagellin globules appear in a ring in the transverse sections and indicate a periodicity (Fig. 1a). We assume this globule group in one period to be a unit group of bacterial flagellum. Lowy and Hanson

(1965) reported that the globule rows are lined up touching longitudinally and obliquely the flagellum axis. This model, I imagine, may not differ drastically from the model of the molecule arrangement of individual tubuloids in centrioles (Fig. 1b).

Figs. 1a-e. Schematic diagrams of globule arrangement in bacteria flagellum (a), in tubuloid of centriole (b), and in transverse section of centriole (c-d). a, showing globules in a ring and their arrangement in profile. Periodicity of globule rows represented with black globules. This model is drawn after the original paper of Lowy and Hanson (1966). b, inferential globule arrangement of the tubuloid in centriole showing globules in a ring in transverse section, their profile, and globule rows in longitudinal section. Globule rows between the 2 black ones represent a periodicity of globule arrangement and a unit length. ul: unit length. c, transverse section of centriole showing 9+2 tubuloid configuration. Eleven tubuloids embed in a common layer of centriolar substance forming a unit disc. d, profile view of tubuloid arrangements of 4 unit discs. e, longitudinal section of centriole at a plane of X-Y showing piles of unit discs in which globules in a ring appear as rows parallel to the tubuloid axis.

in Fig. 1b. If a number of globule rows in the tubuloid show a periodicity, we regard the globule group in one period as a unit length of the tubuloid (Fig. 1b).

Concerning the discussion on the mechanism of ciliary movement,

oles (Fig. 1b).

In the longitudinal sections of centrioles in the spermatozoa of a frog-lung-fluke, *Haematoloechus medioplexus*, two kinds of linear rows of globules appear in high magnification (Burton 1967). Wound around the innermost tubuloid of the centriole, two globule-chains are arranged in a double helical pattern lined up obliquely to the tubuloid axis. After a comparison of this double helical pattern with the innermost tubuloid, and the nine peripheral ones, the globule rows of the latter show no inclination toward the tubuloid axis. Therefore, the rows of globules in the ring line up in longitudinal sections parallel to, and in the profile views, vertical to the tubuloid axis as shown

importance seems to be put on the outer and internal constructions of completely organized centrioles or flagella (Fawcett 1961); and their origin and developmental process are apt to be disregarded. However, to understand the entity of centrioles and their relations to other organelles, it is important to find out analytically the basic constituents and to integrate these into functional organization. The molecule arrangements of individual globule groups in tubloids, and those in unit discs of centrioles have not been analyzed biophysically at present. And yet by introducing the idea of unit discs, many pending problems on centrioles and blepharoplasts such as division, elongation, the *de novo* appearance of blepharoplasts in fern male gametic cells, the disappearance of centrioles in higher plant cells, the multiplication of basal bodies in spermatozooids of cytasters in sea urchin eggs are all explained basically without any inconsistencies in both plant and animal kingdoms.

Physical significance of 9+2 tubloid configurations

At present, the nine-plus-two patterns found in the transverse sections of centrioles, blepharoplasts, basal bodies, flagella and cilia have attracted the interest of biologists. These latter have discussed the biological significance of this pattern mostly from the standpoint of their research and, their opinions are thus divergent.

In physics, the 9+2 corpuscle configuration is nothing but an example of the corpuscular theory of matter proposed by J. J. Thomson (1907). This theory discussed the constitution of matter which is made up of specified arrangements of charged particles. The object of this idea was to construct a model atom. This theory, however, is classical and is disregarded at present. In spite of this situation, I believe, the corpuscular theory is still valid so long as it is concerned with the construction of matter in living cells.

According to this theory, to make a ring of n corpuscles stable, it is necessary to bring some particles inside the ring, and the number of inside corpuscles increases very rapidly with the number of corpuscles in the ring (Table 1).

Table 1. The ring arrangement of corpuscles in stable equilibrium
(J. J. Thomson 1907)

n	5	6	7	8	9	10	12	13	15	20	30	40
i	0	1	1	1	2	3	8	10	15	39	101	232
Total	5	7	8	9	11	13	20	23	30	59	131	272

n : The number of corpuscles in the ring.

i : The number of corpuscles which must be placed inside the ring to keep it in stable equilibrium.

The corpuscles, when they are confined to one plane, arrange themselves in a series of concentric rings. The ring arrangements of corpuscles in the

stable equilibrium shown in Table 1 were visualized by using small magnetized particles which were floating on water.

Biological significance of 9+2 tubloid configurations

On the macroscopic level, eleven holes are found in the transverse sections of the rhizome in *Nelumbo nucifera*. Nine of the eleven holes are arranged in a ring and two are in the center (Satô 1960). In the initial state of the rhizome, I imagine, a number of free-moveable primordia of vascular bundles may appear at random in undifferentiated tissues of the rhizome. When eleven of the primordia happen to come together, they would make a 9+2 configuration to keep themselves in stable equilibrium; the other primordia, if any are present, may lie outside the ring.

To elucidate the force acting on the formation of chromosome configurations in metaphase plates, the principle of the corpuscular theory was once taken into consideration by Fujii (1931). In spite of many investigations on the metaphase plates of various plants carried out by many Japanese cytologists, the significant results which demonstrated the correspondence between the configurations of metaphase chromosomes and those of corpuscles were not obtained. However in some plants, e.g. *Hemerocallis* and *Lycoris*, which have eleven short bivalent chromosomes of similar sizes, the 9+2 configurations were frequently observed on their metaphase plates (Satô 1960).

On the electron microscopic level, the 9+2 tubloid configuration in the transverse sections of centrioles and flagella give another example of eleven particles kept in stable equilibrium. Based on the principle of the corpuscular theory and the idea of unit discs, the *de novo* appearance of blepharoplasts in male gametic cells will be explained in the next chapter.

Reciprocal movement of stigma-granules in the mitosis of Euglena

Prior to the interpretation about the *de novo* appearance and disappearance of centrioles in cells, other preliminary knowledge is needed about the disappearance of intracellular organelles or granules. According to electron microscope studies, the stigma of *Euglena* consists of a curved plate of many orange-red granules lying in the cytoplasm (Gibbs 1960). The individual granules of the stigma are very loosely packed in one or two plates. I was reminded of the interesting reciprocal movement of stigma-granules observed in the mitosis of living *Euglena* (Wada unpublished). At the beginning of the *Euglena* mitosis, the stigma-granules become loose, then disperse one by one and migrate to distant regions. In a few minutes, the stigma completely disappears from its original position (Figs. 2a-c). After the disappearance of the stigma, the prophase nucleus transforms into a metaphase spindle. When the cell enters into late anaphase, the scattered stigma-granules in the cytoplasm begin to move toward the positions where new stigmas of the daughter individuals will appear (Figs. 2c-e). The separation, migration, reciprocal movement and reaggregation of the stigma-granules in the dividing

Figs. 2a-e. Photomicrographs of reciprocal movement of stigma-granules of *Euglena* observed in a living cell in mitosis; a'-e' are schematic diagrams of the photomicrographs. Arrows indicate the position of stigma-granules and the direction of granule-movement. Numerals in parentheses indicate the time photographed. a and a', all the cells become rounded to enter mitosis. Cell A showing stigma and nucleus is still in a resting state. Cell B showing the beginning of mitosis. Orange-red granules composing the stigma become loose and are separating into two groups (21:51). b and b', beginning of anaphase. Granules scatter and rapidly migrate toward cell periphery (22:00). c and c', granules showing reciprocal movement toward the new positions of stigma (23:00). d and d', telophase showing beginning of cleavage formation and appearance of new stigmas in daughter cells. A few stigma-granules still moving toward the stigmas. Stigma in right cell lying out of microscope focus (23:47). e and e', by finishing cytokinesis, each sister individual shows a stigma. Two stigma-granules remain in the cytoplasm (24:05). In living cells orange-red stigma-granules appear clearly in greenish back ground of chloroplasts. n: nucleus, s: stigma, sp: spindle body.

Euglena will give an important suggestion about the phenomenon namely that the blepharoplast can arise *de novo* in the male gametic cells.

To start the scattered stigma-granules on their way back toward the sites of daughter stigmas, it is assumed that some differentiation takes place, at first in the cytoplasm. Then the scattered granules move, as if they are attracted, toward the new stigma sites presumably by a chemotaxis-like reaction or chemotaxis itself. In the living mitotic cell, the migration of organelles or granules is considered to be caused by chemotaxis or chemotaxis-like reactions (Wada 1966, 1969a, b).

De novo appearance of blepharoplasts in male gametic cells

Figs. 3a-f. Schematic diagrams of appearance and disappearance of blepharoplast in the male gametic cells and in the somatic ones in the Pteridophyta. Granules drawn in cytoplasm represent inferential scattered individual tuboids arising through disintegration of the unit discs in the blepharoplast or basal bodies. The size of granules, therefore, belongs to the electron microscopic level. Other cell organelles drawn at the light microscopic level. a-c, appearance of blepharoplast and basal bodies during spermatogenesis. d-f, disappearance of blepharoplast and basal bodies in somatic cells after fertilization. a, immature spermatid cell. b, appearance of 9+2 tubloid patterns in maturing spermatid cell. c, mature spermatozoid. Flagella grow forth from basal bodies. d, spermatozoid enters into the egg nucleus leaving flagella parts in cytoplasm. e, spermatozoid nucleus disappears by fusing with egg nucleus. Basal bodies begin to disintegrate and individual tuboids scatter into cytoplasm. f, showing complete disappearance of 9+2 tubloid patterns of basal bodies in somatic cells. n: nucleus in spermatid cell. b: blepharoplast, a: basal body, f: flagellum, en: egg cell nucleus, t: scattered tuboid of disintegrated basal bodies, sn: somatic cell nucleus.

In the case of blepharoplast-bearing plants, it is a well known fact that after fertilization the blepharoplast disappears from all the cells of new born plants (Figs. 3d-f). However, no explanation of this disappearance of the blepharoplasts has been attempted. Classical cytology had not been blessed with biological phenomena which are available to interpret the behavior of centrioles, such as the fine structure of 9+2 tubloid patterns in both plants and animals and the *raison d'être* of centrioles as primordia of locomotive organelle for cell movement (Wada 1969b). Based on

the idea that the blepharoplast (centriole) is constructed of a stack of unit discs, I imagine, that the blepharoplast would, at first, disintegrate into

individual unit discs. Then the eleven tubloids composed each unit disc disjoin one by one and scatter as minute tubloids in the cytoplasm, similar to the stigma-granules of *Euglena* at the beginning of the mitosis as mentioned above.

In the case of blepharoplasts, which is different from the stigma-granules in *Euglena*, the scattered individual tubloids remain in the cytoplasm and get distributed to thousands of sporophytic cells by replication and separation (Fig. 3f). When the differentiation of male gametic cells takes place in the adult plants, the scattered tubloids in the cytoplasm may migrate at first toward the site where a new blepharoplast would appear (Figs. 3a-b). This tubloid movement is considered to be caused by a chemotaxis reaction between the tubloids and the differentiated site of the blepharoplast in the cytoplasm. At this point eleven of the scattered tubloids gather and form the 9+2 configuration keeping themselves in a stable equilibrium presumably according to the principle of the corpuscular theory. In this way the 9+2 tubloid configuration of the initial unit disc of blepharoplast may become organized (Fig. 3b). Starting from this initial unit disc, a blepharoplast may grow forth by replication of unit discs and by pilling up them (Fig. 3).

Disappearance of centrioles in higher plant cells

The principle used to explain the disappearance of blepharoplasts from the sporophytic cells is also available for conjecturing the process by which the centrioles completely disappear from cells in higher plants. In the latter case, we can assume that there are two processes. One of these is due to a decrease in that power which organized scattered individual tubloids into a blepharoplast. The other process may be due to the disintegration of scattered individual tubloids in the cytoplasm. It is also possible to conjecture that both processes may occur simultaneously in the cells. However, this problem is highly difficult to demonstrate at present. It is practically impossible to detect and distinguish the scattered tubloids from other cytoplasmic granules under the electron microscope.

In the animal kingdom, the centriole is transmitted from cell to cell by divisions. No disintegration of centrioles into unit discs and then further into individual tubloids would occur. Consequently, animal centrioles are generally dealing with self-perpetuating organelles. There are various modified patterns of 9+2 tubloids: the degeneration of two tubloids in the center; the appearance of a cartwheel-like structure; doublet or triplet tubloids with or without short arms. The diversification of centrioles might have been induced by the adaptation of themselves to the change in living modes during the course of their evolution.

On the contrary, the blepharoplasts which appear *de novo* in plant male gametic cells show always the typical 9+2 tubloid configurations. This fact may imply that the initial unit disc of blepharoplasts would be formed by renewing 9+2 tubloid configurations presumably according to the principle

of the corpuscular theory.

No common features are found between the kinetochore and centriole

In current cytology books, the interpretation viz. "kinetochore may in fact be transformed into centrioles", (Mazia 1961), is described based on the observations by Pollister and Pollister (1943). They studied both the typical and atypical spermatogenesis in the snail, *Viviparus malleatus*. However, several difficulties in this account have been pointed out by Went (1966). We also refute the kinetochore origin of centriole because of the following evidence (Wada 1969b).

First, it is a self-evident fact that the centrioles are morphologically and functionally different from those of kinetochores demonstrated by electron microscope studies (Gall 1966, Brinkley and Stubblefield 1966). In the period of the Pollisters', this decisive morphological difference was utterly unknown. Gall especially studied the snail, *Viviparus*, and reported that in the atypical meiosis, centriole clusters give rise to the basis of multi-flagellated sperms. A second disproof is based on the erroneous idea that the intranuclear organelles would be able to migrate freely in the cytoplasm and *vice versa* due to the disappearance of the nuclear membrane (Wada 1966, 1969a). At present, an interpretation on the homology between the centriole and the kinetochore has only a historical meaning and is apparently beyond dispute.

Problems on cytasters and centrioles in sea urchin eggs

In animal cytology, the long pending problem—the *de novo* arising of cytasters in the sea urchin egg is discussed. An interpretation of classical cytology is that the cytasters appear *de novo* from granules in the cytoplasm of parthenogenetic cells after the disappearance of centrioles in the egg cell. In the electron microscope study of Dirksen (1961), the presence of typical centriolar structures were demonstrated in each of the cytasters in parthenogenetically activated sea urchin eggs. Taking these findings into consideration, the solution of the origin and the entity of cytasters may be reduced to the following two items; 1) whether the centrioles in the parthenogenetic egg cell can multiply themselves or not; 2) whether the multiplied centrioles can scatter in the cytoplasm as individual ones or not.

The disappearance of centrioles in the sea urchin eggs, I imagine, may be induced by the disintegration of centrioles into unit discs which scatter in the cytoplasm. No further disintegration of each unit disc into individual tubloid would occur in this case. Each separated unit disc would grow by replication and by pilling up unit discs to appear as a cytaster. Accordingly, there is no intrinsic difference between centrioles and cytasters. The appearance of astral rays around each cytaster may be due to the ordinary process as known in the case of centrioles (Wada 1969b).

Different from the multiplication of centrioles in the snail atypical spermatogenesis, no flagellum formation takes place in the cytasters because

the appearance of cytasters is an event in the female gametic cells in which the centrioles remain in an inactive state (Wada 1969b). The disintegration or the multiplication of centrioles may be caused by alterations of physico-chemical changes in cytoplasmic, nuclear or centriolar colloidal states, although molecular biological details of these important life phenomena are very little known.

Multiplication of centrioles into basal bodies and the growing of flagella from centrioles

In the animal kingdom, it is a well known fact that the division of centrioles is repeated in mitotic cells. However, no explanation seems to be given for the process of this phenomenon. Thanks to the recent advances in electron microscope studies, it is revealed that the centriole is not a mere granule but a short rod-shaped body. By analyzing the infinitesimal portions of centrioles based on their transverse and longitudinal sections, I have reached the conclusion that the centriole is made up of a stack of unit discs as explained in the foregoing chapter.

Division of centrioles, their multiplication and basal body formation

The division of the centriole in the mitosis of animal cells is a case in which the stack of unit discs separates at its middle and becomes two pieces of short centrioles. Then each piece can elongate to the original size by replication of unit discs at their terminals. In the case of the basal body formation, it is assumed that the separation of unit discs simultaneously takes place at several parts of the centriole or that the separations occur successively at the terminal portion of the centriole. In the case of spermatozooids in Bryophyta and Pteridophyta, the separated pieces of blepharoplast are presumably lined up on the cilia-bearing band (Yuasa 1936), where they grow to individual basal bodies and form the cilia. In the atypical spermatogenesis of *Viviparus malleatus*, the separated centrioles may scatter, at first within the cytoplasm and later arrange themselves close to the cell periphery. In the case of cytasters, the separated centrioles scatter at random in the cytoplasm and are arrested from moving by the radiating astral rays around them.

More complicated circular arrangements of numeral basal bodies are reported in the apical portion of *Oedogonium cardianum* zoospores (Hoffman and Manton 1963). In the spermatozooids of Cycadophyta and Ginkgophyta, the multiplied basal bodies are arranged on a cilia-bearing band which extends from the initial position of blepharoplast to the middle of the spermatozoid body forming a well known helical arrangement of cilia.

The explanation for the centriole replication in the spermatozooids of *Marsilea* and the cycad, *Zamia* has been reported by Mizukami and Gall (1966). Their detailed descriptions on the centriole behavior started with the youngest spermatids of *Marsilea*; they state: "blepharoplasts are also found

in the preceding cell generation, but their ultimate origin is obscure." If it would be granted to state an alternative interpretation based on their descriptions and figures in the text (Mizukami and Gall 1966), the following interpretation may become possible for the origin and the multiplication process of centrioles in the spermatozooids of *Marsilea*.

Presumably in the sporophytic cells, the centrioles may be kept in the cytoplasm as innumerable scattered individual tubloids. When the male gametic cells differentiate, the scattered tubloids in the male gametic cells may gather at the sites of the blepharoplasts and form numeral unit discs. According to Mizukami and Gall (1966), the solid blepharoplasts appear before the last mitosis. This solid blepharoplast (See Fig. 7 of their paper) becomes large and transformed into a hollow blepharoplast. The wall of the hollow sphere is composed of immature centrioles (procentrioles). Although the pattern of eleven tubloids in each unit disc is imperfect; I assume, the replication may be going on at each tubloid. When the spermatid cell grows and increases its cell size, the procentrioles occupy enough space and they show the perfect 9+2 tubloid patterns to keep themselves in stable equilibrium.

Elongation of centrioles and flagellum formation

In the separation of a centriole into two pieces at the animal cell mitosis, or into several pieces at the basal body formation in fern spermatozooids, the replication of unit discs would take place at each terminal plane of the separated centrioles. By the replication of unit discs and by their piling up, the divided short pieces of centrioles can grow longitudinally to the original length of centrioles or blepharoplasts.

In the formation of flagellum, cilium or sperm-tail filaments from centrioles, blepharoplasts or basal bodies, the initial unit discs of these organelles innumerable repeat the replications and pile up the unit discs longitudinally. Finally, the stack of unit discs, whose size is at the electron microscopic level, becomes visible as a flagellum or cilium under the light microscope. In the animal kingdom, in the growing of sperm-tail filaments from centrioles it is generally known that the cytoplasmic components play important roles for the completion of sperm-tails.

Concluding remarks

1. To understand the entity of the microtubules and also the tubules generally found in the transverse sections of centrioles and flagella, it is most important to distinguish the so-called microtubules from the tubes, the tubules or fibers found at the light microscopic level. The growth of the microtubules is exclusively attained by replication of molecular constituents at their terminal positions, while that of the latter viz. the tubes or tubules by cell divisions occurring at random in the cells of the tube-wall. From this point of view and for some other reasons, I have proposed the expression "tubloid" instead of "tubule" since "microtubules" is confined to the constitutional element or

the nine-plus-two pattern revealed by electron microscope studies (Wada 1969b).

2. Taking the results of molecule arrangement in bacterial flagella into consideration, I have conjectured the possible molecule arrangement of tubloids in centrioles and introduced the idea of unit discs as the infinitesimal portions of the centriole. I assume that centrioles and flagella also are constructed of a stack of unit discs. Although the molecule arrangement of the tubloid is still in an inferential state and remains to be elucidated molecular-biologically, I venture to take this idea as an example of the relationship between the classic and the modern cytomorphology and which should be dealt with in future cell biology.

3. Concerning the division and growth of centrioles, there must be a minimum number of unit discs which can keep the ability to replicate themselves and to grow into independent centrioles or basal bodies, just as the minimum length of the tobacco mosaic virus is known to be necessary for replication and growth.

4. At present the reason why the eleven tubloids appear in the transvers section of centrioles is utterly unknown, unless the 9+2 tubloid configuration is physically in a stable equilibrium state. The centriole as primordium of locomotive organelle for cell movement might have been spontaneously created by increasing the number of tubloids from simple bacterial flagella during the course of evolution in organisms.

It is to be desired that young cytologists will have interests not only in the routine cell images of fixed cells described in cytology-text books but also have wide knowledge of the dynamic features of the intracellular organelles, the basic structure of protoplasm and the functions of both in the living cells themselves.

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