Microtubules or actions of microtubule motor protein → polymerization, depolymerization → movement

**MTOC (microtubule-organizing center):** contributing to cell motility; Located near the nucleus, assembly an orientation of microtubules, the direction of vesicle trafficking, and orientation of organelles.

Organelles and vesicles are transported along microtubules, the MTOC becomes responsible for establishing the polarity of cell and direction of cytoplasmic processes in both interphase and mitotic cells.

Kinesin powered movement of a vesicle along a microtubule

---

Microtubule organized around the MTOC and spindle

---Orientation of cellular microtubule

most microtubules have a constant orientation relative to MTOC

(-) end: close to the MTOC

(+) end: distal to the MTOC

---

Cells contain stable and unstable microtubules (MTs).

SEM of the surface of ciliated epithelium of rabbit oviduct

---

Assembly and disassembly cause microtubules → probe →...
Polymer of globular Tubulin $\rightarrow$ arranged $\rightarrow$ microtubule

Two populations of MT:
1. stable, long-lived: nonreplicating cell; cilia, flagella, RBC and platelets pass through small vessel, axon
2. unstable, short-lived; assemble and disassemble quickly, replicating cell

Heterodimeric tubulin subunits compose the wall of a MT.

Tubulin subunit are formed by $\alpha$ and $\beta$.
One subunit bind to two GTP, has GTPase activity.
55kDa monomers in all eukaryotes $\gamma$-tubulin are formed by $\alpha$ and $\beta$.

In mammals at least 6 alpha and 6 beta isoforms have been identified.
The proteins are highly conserved (75% homology between yeast and human).
Most variability is found in the C-terminal region of the molecules and is likely to affect interactions with accessory proteins.
A tubulin homologue, FtsZ, is expressed in prokaryotes.

Irreversibly, does not hydrolyze GTP reversibly.

Arrangement of protofilaments in singlet, doublet, and triplet MTs.

The tubule is a complete microtubule cylinder, made of 13 protofilaments.

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Irreversibly, does not hydrolyze GTP reversibly.

Arrangement of protofilaments in singlet, doublet, and triplet MTs.

The tubule is a complete microtubule cylinder, made of 13 protofilaments.
Temperature affects whether MTs assemble or disassemble.

<table>
<thead>
<tr>
<th>Time</th>
<th>Mass of microtubules</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cool to 4°C</td>
<td>Depolymerization of MTs</td>
<td>High Temp: assembly (need GTP)</td>
</tr>
<tr>
<td>Warm to 37°C</td>
<td>Polymerization of αβ-tubulin</td>
<td>Low Temp: disassembly</td>
</tr>
</tbody>
</table>

Cc: critical concentration
Up: dimers polymerize into microtubules; below: depolymerize

Addition of MT fragments demonstrates polarity of tubulin polymerization. (MT assembly and disassembly take place preferentially at the + end)

Cryoelectron microscopy allows observation of disassembled MTs.

Rate of MT growth in vitro is much slower than shrinkage.

Disassembly quick (7 μm/min)
Assembly slowly (1 μm/min)

Fluorescence microscopy reveals in vivo growth and shrinkage of individual MTs.

Fluorescently-labeled tubulin microinjection into fibroblasts.
Microtubule is dynamic instability.

Two factors influence the stability of MT:
1. Cc (critical concentration): > or = Cc → growth; < Cc → shrinkage
2. β subunit bind to GTP or GDP.
Dynamic instability model of MT growth and shrinkage ($\beta$ subunit bind to GTP/GDP).

+ end is most important for MT growth and shrinkage

Dissociation of GDP-tubulin dimer $\Rightarrow$ GTP-tubulin dimer

When GDP-tubulin $\rightarrow$ depolymerizes and unstabilized

When GTP-tubulin add to $+$ end $\Rightarrow$ rescued shortening MT.

Two factor influence stability of MT:
1. $C_c$
2. GTP or GDP $-\beta$ subunit

Numerous proteins regulate MT dynamics and cross-linkage to other structures.

MAPs: microtubule-associated protein, influence the assembly and stability of microtubule and their related structure.

Basis of their function has two groups:

<table>
<thead>
<tr>
<th>TABLE 20.1</th>
<th>Proteins That Modulate Microtubule (MT) Dynamics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protein</td>
<td>MW</td>
</tr>
<tr>
<td>MAP1</td>
<td>250,000–300,000</td>
</tr>
<tr>
<td></td>
<td>(neurofilament)</td>
</tr>
<tr>
<td>MAP2</td>
<td>120,000–160,000</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>MAP4</td>
<td>210,000–250,000</td>
</tr>
<tr>
<td>Tau</td>
<td>55,000–62,000</td>
</tr>
<tr>
<td>CLIP1/2</td>
<td>170,000</td>
</tr>
</tbody>
</table>

---

Spacing of MTs depends on length of projection domain in bound MAPs.

MAP2 and Tau can regulate microtubule spacing.

When MT bundles are induced in cells

overexpressing MAP2 (left) and tau (right), the bundles formed by MAP2 have wider spacing between MT than those formed by tau.

MAP2 COOH end binds along the MT lattice while NH2 terminal end projects out from the microtubule.

Tau binds similarly but its projection arm is much shorter than arm of MAP2.
**MAP kinase (MAPK):** A key enzyme for phosphorylating MAPs → phosphorylated MAPs → unable to bind to microtubules

Cyclin-dependent kinase → phosphorylation of MAP4 → controlling the activity of various proteins in the course of the cell cycle.

**MTs can assemble in vitro from purified tubulin, but**
MAPs are found with MTs isolated from cells; most found only in brain tissue; MAP4 has wider distribution

**Have globular head domain that attaches to MT side & filamentous tail protruding from MT surface**

**May interconnect MTs to help form bundles (cross-bridges), increase MT stability, alter MT rigidity, influence MT assembly rate**

---

**Drugs involved in microtubule dynamics**

(1) colchicines/colcemid: mitotic inhibitors

- its effect is reversible
- binds to tubulin dimer
  - blocks the addition or removal of other tubulin subunits to the ends of microtubule
  - disruption of microtubule dynamics

- cells are blocked at “metaphase” after colchicines treatment

  - cytogenetic studies
  - cell synchronization (時間一致)

(2) taxol, vinblastin:

- bind to microtubules and stabilize microtubule by inhibiting the lengthening and shortening of microtubules
- used for cancer treatment
MTOCs orient most MTs and determine cell polarity.

MT (doublets) are found in cilia or flagella that are used for cell movement. MT in axon are plus end out, MT in dendrites are plus and minus ends out. These MT are not attached to any nucleating structure. Cells have stable (half life >1 hr) and unstable/dynamic (half-life = 5-10 min) microtubules. These subsets differ in post-translational modification of tubulin.

The centrosome (MTOC) is usually located near the nucleus during interphase. Microtubules grow out from the MTOC.

Centrosome contains a pair of orthogonal (直角) centrioles in most animal cells.

MTOC = microtubule organizing center. Microtubules assemble from the MTOC. In mammals, the centrosome (中心體) is the MTOC, with the MT minus (-) ends inserted into the centrosome and the plus (+) ends directed towards the cell periphery. Centrosome is a collection of microtubule orienting proteins within a cloud of material termed the pericentriolar or centrosomal matrix. Sometimes, inside will be a pair of centrioles (中心粒) that serve to organize the matrix. The microtubules emanate from γ-tubulin ring complexes inside the centrosome.

Centrioles (C) a pair. C and C'. Pericentriolar (PC) matrix: γ-tubulin & pericentrin; surrounding the centrioles.

The γ-tubulin ring complex (γ-TuRC) nucleates polymerization of tubulin subunits.

MTOC organization: pericentriolar material (including protein and γ-tubulin) → nucleating (以核為中心) microtubule assembly → anchoring γ-TuRC the has 8 polypeptides and 25 nm diameter. Under Cc, γ-TuRC directly nucleate microtubule assembly γ-TuRC Formed only one end (-). Stain with an anti-gamma tubulin antibody. Gamma-tubulin at initiates synthesis at one end (-) (green).
**Microtubules** nucleated by the γ-tubulin ring complex appear **capped** at one end, assumed from other data to be the **minus end**.

γ-Tubulin, which is homologous to α & β tubulins, **nucleates** microtubule assembly within the centrosome. Several (12-14) copies of γ-tubulin associate in a complex with other proteins called "grips" (gamma ring proteins). This **γ-tubulin ring complex** is seen by EM to have an open ring-like structure resembling a **lock washer, capped** on one side.

**Grip** proteins of the cap may be involved in mediating binding to the centrosome.

**Phosphorylation** of a conserved tyrosine residue of γ-tubulin has been shown to regulate microtubule nucleation in yeast cells.

**Cytoplasmic organelles and vesicles are organized by MTs.**

Colocalization of endoplasmic reticulum membranes and cytosolic MTs. Others organelles also colocalized.

The alignment of the ER network and microtubules in many but not all regions of the cytoplasm is evident because the cell has sparse microtubules.

**Kinesin and dynein powered movements**

Progression of organelles along axons requires microtubules and the motor proteins: **kinesin and dynein**.

Also dependent on motor proteins:

- Transport of vesicles for exocytosis/endocytosis or between the endoplasmic reticulum and Golgi
- Extension of the endoplasmic reticulum
- Integrity and reassembly of the Golgi apparatus
The rate of axonal transport in vivo can be determined by radiolabeling and gel electrophoresis.

**Anterograde transport** goes towards the axon terminal (cell body → synaptic terminals), such as vesicles.

**Retrograde transport** goes towards the axon hillock (synaptic terminal → cell body), such as old membrane.

Fast: membrane-limited vesicles, ~250 mm/day.
Slow: tubulin subunits, neurofilaments.
Intermediate: mitochondria.

DIC microscopy demonstrates MT-based vesicle transport in vitro.

Squid axon

*Motors carrying different cargoes in different directions*
Kinesin and Dynein-powered movement

Melanosomes in fish pigment cells aggregate or disperse by moving along a network of MTs.

Two major mediator for transport along microtubules:
1. Kinesins (驅動蛋白) and dyneins (動力蛋白)
2. Cilia and flagella

Mucus secretion sperms

Transport of GFP-tagged neurofilaments down axons exhibits periodic pauses.

Every 5 sec Gap 15μm

Speed down

Microtubule based motor protein

<table>
<thead>
<tr>
<th>Class</th>
<th>Common Members</th>
<th>Cargo</th>
<th>Direction of Movement*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cytoskeletal</td>
<td>Kinesins (KIFs, KIFs)</td>
<td>Cytoskeletal microtubules</td>
<td>(-)</td>
</tr>
<tr>
<td>Cytoskeletal</td>
<td>Dyneins</td>
<td>Cytoskeletal microtubules</td>
<td>(-)</td>
</tr>
<tr>
<td>Motor proteins</td>
<td>Kinesin II</td>
<td>Spindle and axon MTs</td>
<td>(+)</td>
</tr>
<tr>
<td>Motor proteins</td>
<td>Podocyte kinesins</td>
<td>Chromosomes (arms)</td>
<td>(+)</td>
</tr>
<tr>
<td>Motor proteins</td>
<td>Microtubule kinesins</td>
<td>Microtubule kinesins</td>
<td>(+)</td>
</tr>
<tr>
<td>Motor proteins</td>
<td>CORTK</td>
<td>Kinesines</td>
<td>(-)</td>
</tr>
<tr>
<td>Motor proteins</td>
<td>C11P-1</td>
<td>Kinesines</td>
<td>(-)</td>
</tr>
<tr>
<td>Motor proteins</td>
<td>Kinesin</td>
<td>Spindle and axon MTs</td>
<td>(+)</td>
</tr>
<tr>
<td>Motor proteins</td>
<td>Dynein</td>
<td>Spindle and axon MTs</td>
<td>(+)</td>
</tr>
<tr>
<td>Motor proteins</td>
<td>Dynein</td>
<td>Kinesoles</td>
<td>(-)</td>
</tr>
<tr>
<td>Motor proteins</td>
<td>Dynein</td>
<td>Wave-like motion of flagella and cilia</td>
<td>(+)</td>
</tr>
</tbody>
</table>

Movement of motor proteins toward the (+) end (+1) end of microtubules.

*Orientation and type of movements:
- (+) toward the plus end (+1) end of microtubules
- (-) toward the minus end (-1) end of microtubules

MT associated motor proteins:
kinesins: towards + end (anterograde transport) Golgi to ER traffic
dyneins: towards - end (retrograde transport) ER to Golgi traffic
wave-like motion of flagella and cilia
Kinesin I powers anterograde transport of vesicles in axons.

Most common structure comprised of two heavy chains and two light chains; and processive + end directed motor protein (most) MT bind to the helix region in the head; binding is regulated by ATP hydrolysis

Plastic bead coated with kinesin will slide along a microtubule towards an end

10 families identified - mainly 2 types, cytosolic and mitotic kinesins;

Some structural similarity to myosin

Not all kinesins have the same subunit structure but all have the globular head domain

Structure of kinesin: two heavy chain and two light chain

Most kinesins are processive + end-directed motor proteins

Dimer of a heavy chain complexed to a light chain

Mr= 380kD

Three domains:

1) Large globular head Binds microtubules and ATP
2) Stalk
3) Small globular head Binds to vesicles

ATP hydrolysis coupled to movement

EM data suggests binding primarily to β-tubulin

Binding sites

Model of kinesin-catalyzed vesicle transport.

How does kinesin move?

Adapted from: Figure 1 in Vale & Milligan (2000) Science, Vol 288, Issue 5463, 88-95

Cytosolic dyneins are (-) end-directed motor proteins that bind cargo through dynactin.

Very large multimeric complex

Dynein also has heavy chains like kinesin but it mediates transport towards the (-) end of the microtubule;

Its light chain associates dynamin, that is part of a large protein complex called dynactin, which is responsible for interacting with the organelles, vesicles, or chromosomes that are being transported.

Transport require dynactin, to links vesicles and chromosomes to dynein light chain

Arp1 actin related protein, interact with spectrin

Dynactin interact with light chains of dynein
Dynactin is complex: Besides dynamin, dynactin contains
- a filament made of Arp1 that is actin-like and binds with spectrin
- Spectrin binds ankyrin which associates with the vesicle/organelle
- p150 Glued binds microtubules and vesicles
- ankyrin, spectrin, and Arp1 are thought
to form a planar cytoskeletal array.

Dynactin complex

Dynein needs dynactin to link vesicles and chromosomes to the dynein light chain

Cooperation of myosin and kinesin at the cell cortex.

Multiple motor proteins sometimes move the same cargo
Multiple motor proteins are associated with membrane vesicles

General model of kinesin and dynein mediated transport in a typical cell
**Motor proteins** are enzymes that couple the hydrolysis of ATP to a conformational change

Kinesin and dynein: Motor proteins that 'walk' along microfilaments

Myosins: Motor proteins that 'walk' along actin filaments

Organelle transport uses motor proteins

RER to Golgi vesicle → Golgi to RER vesicle

Cytoplasm

Dynein → Kinesin

Freeze-etching reveals structure of axonemal dynein.

Structure of an axoneme (軸絲)

Eukaryotic cilia and flagella contain a core of doublet MTs studded with axonemal dyneins.

Video microscopy shows flagellar movements that propel sperm and chlamydomonas forward.
Ciliary and flagellar beating are produced by controlled sliding of outer double MTs.

In vitro dynein-mediated sliding of doublet MTs requires ATP.

Comparison of the mechanochemical cycles of kinesin and myosin II.

Microtubule dynamics and motor protein in mitosis

<table>
<thead>
<tr>
<th>Class</th>
<th>Common Members</th>
<th>Cargo</th>
<th>Direction of Movement*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cytosolic motors</td>
<td>Kinesin (K, KIF)</td>
<td>Cytosolic vesicles/secretions                                      (+)</td>
<td></td>
</tr>
<tr>
<td>Cytosolic motors</td>
<td>Dynein</td>
<td>Cytosolic vesicles/secretions                                      (-)</td>
<td></td>
</tr>
<tr>
<td>Mitotic motors</td>
<td>Kinesin Run (tubular)</td>
<td>Spindle and astral MTs                                                    (+)</td>
<td></td>
</tr>
<tr>
<td>Mitotic motors</td>
<td>Chromatokinesin</td>
<td>Chromatokinesin (mitotic)                                             (+)</td>
<td></td>
</tr>
<tr>
<td>Mitotic motors</td>
<td>NCKA</td>
<td>Kinetochore                                                          (+)</td>
<td></td>
</tr>
<tr>
<td>Mitotic motors</td>
<td>CENP-E</td>
<td>Kinetochore                                                          (+)</td>
<td></td>
</tr>
<tr>
<td>Mitotic motors</td>
<td>Kinetos Nud</td>
<td>Spindle and astral MTs                                                    (+)</td>
<td></td>
</tr>
<tr>
<td>Cytosolic motors</td>
<td>Kinesin</td>
<td>Kinetochore, cytoskeleton, cell                                       (+)</td>
<td></td>
</tr>
<tr>
<td>Axonemal motors</td>
<td>Outer-arm and inner-arm dynein</td>
<td>Doublet microtubules in axon and flagella                            (-)</td>
<td></td>
</tr>
</tbody>
</table>

*Movement of motor protein toward the (+) or (-) end of microtubules.
+ Outer-arm dynein has heavy chains, and inner-arm dynein has two heavy chains.
The stages of mitosis and cytokinesis in an animal cell.

Fluorescence microscopy reveals changes in the organization of chromosomes and MTs at four mitotic stages.

Mitotic apparatus is a microtubule machine for separating chromosomes.

Electron microscopy visualizes components of the mitotic apparatus in a metaphase mammalian cell.

Kinetochore is a centromere-based protein complex that mediates attachment of chromosomes to MTs.

Prophase signals must convert interphase array to mitotic apparatus - increase in short dynamic microtubules - mitotic MT turnover 5-10 fold faster than interphase MT - less polymer and more monomer tubulin during M phase than at other times.

All eukaryotes, three components participate in attaching chromosomes to microtubules:
1. Centromere
2. Kinetochore and spindle proteins
3. Cell cycle machinery

MACK: plus ends of spindle microtubules attach to chromosomes
CENP-E: keeps the kinetochore tethered to the kinetochore microtubule
Kinesins
Dynein
A common sort of model for the kinetochore and its MT attachment: the action is in a sleeve

Model for participation of MT motor proteins in centrosome movements at prophase.

Duplicated centrosomes align and begin separating in prophase.

Relation of centrosome duplication to the cell cycle.

TABLE 20.1 Functional Classes of Microtubule Motor Proteins

<table>
<thead>
<tr>
<th>Class</th>
<th>Common Name(s)</th>
<th>Range</th>
<th>Direction of Movement*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cytosolic motors</td>
<td>Kinesin (KIFs, KIF1s, KIF14)</td>
<td>Cytosolic, soluble/tubulogliding</td>
<td>(−)</td>
</tr>
<tr>
<td>Cytosolic dynein</td>
<td>Cytosolic dynein</td>
<td>Cytosolic, soluble/tubulogliding</td>
<td>(−)</td>
</tr>
<tr>
<td>Kinesin I</td>
<td>Cytosolic kinesin</td>
<td>Cytosolic, soluble/tubulogliding</td>
<td>(+)</td>
</tr>
<tr>
<td>Microtubule motors</td>
<td>Kinesin Westgastic</td>
<td>Cytosolic, soluble/tubulogliding</td>
<td>(−)</td>
</tr>
<tr>
<td>Kinesin Nedd</td>
<td>Cytosolic kinesin</td>
<td>Cytosolic, soluble/tubulogliding</td>
<td>(+)</td>
</tr>
<tr>
<td>Amyloid motors</td>
<td>Outer arm and inner arm dynein</td>
<td>Cytosolic, soluble/tubulogliding</td>
<td>(−)</td>
</tr>
</tbody>
</table>

*Direction of motor protein toward the (+) end or (+) end of microtubule.
† Amyloid motors have three heavy chains, and inner arm dyneins have two heavy chains.

G1 Phase → 1st growth phase
S Phase → DNA duplicated
G2 Phase → Final growth phase
Mitosis
Cytokinesis

A common sort of model for the kinetochore and its MT attachment: the action is in a sleeve
Model for participation of microtubule motor proteins in centrosome movements at prophase

Cytosolic dynein participates in the formation and stabilization of mitotic spindle poles.

Capture of chromosomes by MTs in prometaphase.

Model of the forces stabilizing metaphase chromosomes at the equatorial plate.
Chromosome alignment

1. rapid polymerization/depolymerization at the (+) end of kinetochore microtubule
2. motor proteins pull chromosomes towards pole
   - (+) end-directed motor protein at spindle pole
   - (-) end-directed motor protein at kinetochore (dynein)
3. polar microtubule polymerization push chromosomes away from pole

Chromokinesin, a non-kinetochore (+) end-directed motor on the chromatid arm:
- (+) end-directed motor protein at spindle pole
- (-) end-directed motor protein at kinetochore (dynein)
- CENP-E: tethers the kinetochore the shrinking microtubule

Poleward flux of tubulin subunits during metaphase is visualized by fluorescence speckle microscopy.

Anaphase chromosomes separate and spindle elongates
Anaphase A (early): shortening of kinetochore at +, pulls chromosomes toward poles
Anaphase B (late): two poles move farther apart, bringing attached chromosomes with them into two daughter

Shortening at the (+) end of kinetochore MTs moves chromosomes poleward in anaphase A

Shortening at + end (attach kinetochores) of microtubule by disassembly.
In vivo fluorescent-tagging experiment
Kinetochore associated kinesin, MCAK promotes disassembly at the + end, CENP-E (also at kinetochore) binds to progressively shortening end.
Chromosome moves toward “-.”

Shortening at the + end of kinetochore microtubules moves chromosomes poleward in anaphase A
Model of spindle elongation and movement of poles during anaphase B.

Three processes of anaphase B for separation of chromosomes:
1. Pushing force by kinesin-mediated (BimC, attach microtubule) sliding of polar microtubules (move toward +)
2. Pulling force by cortex-associated cytosolic dynein (move toward -)
3. Lengthening of polar microtubules at + end

Micromanipulation experiments can determine whether the spindle or the asters control location of the cleavage plane during cytokinesis.

Asters determine two cell separate
Two asters determines where cleavage occurs in fertilized sand dollar eggs, whereas the spindle determines the cleavage plane in animal cells

CDK1 (cyclin-dependent kinase) → entry into mitosis, by phosphorylation of the regulatory light chain in myosin II.

The latter stages of anaphase usually include significant spindle elongation: anaphase B

Regulation of myosin light chain by mitosis-promoting factor (MPF).

MPF: CDK1 and mitotic cyclin protein

Figure 18-29. Molecular Biology of the Cell, 4th Edition.
Plant cells reorganize their MTs & build a new cell wall in mitosis.

Interphase plant cells: lack a single perinuclear microtubule-organizing center
Similar to animal:
Prophase: Bundle their cortical microtubules and reorganize, without centrosomes
Metaphase: golgi-derived vesicles are transported into the mitotic apparatus along microtubules
Telophase: vesicles line up near the center of the dividing cell to form the phragmoplast, a membrane structure similar to animal cell contractile ring → become the plasma membrane of daughter cells; vesicles contain cellulose pectin for cell wall

Chapter 20 summary

I. Microtubule structure
   1. tubulins and microtubule structure
   2. Microtubule-organizing center (MTOC)

II. Microtubule dynamics & associated proteins
   1. Assembly/disassembly of microtubule
   2. Dynamic instability
   3. Temperature influences microtubule stability
   4. Drugs involved in microtubule dynamics
   5. Microtubule associated protein (MAP)

III. Motor proteins and intracellular transport
   1. Motor proteins
      --microtubule motor proteins: Kinesin family, Dynein family
   2. Multiple motor proteins are associated with membrane vesicles

IV. Microtubules & motor proteins during mitosis
   1. Mitotic apparatus
   2. Centromere and kinetochore
   3. Centrosome duplication
   4. Microtubule dynamics during mitosis
   5. Centrosome movement during mitosis
   6. Formation of spindle poles and capture of chromosomes
   7. Chromosome separation & spindle elongation
   8. Cytokinesis
各位同學實在是辛苦了
再撐完下週的考試，就功德圓滿。
一分努力一分收穫，相信自己也相信老師
一切都會是值得的
想想，人生就是一直創造不可能，
老師很幸運，有這麼多的修課同學陪我又創造一次不可能

各位同學，細胞生物學這門課，
可能是您這輩子從頭考到尾的一門課
這個紀錄就在人生求學生涯中——最美麗的中山大學裡
創造出來
敬祝大四同學鵬程萬里
大三同學立足中山放眼未來
大二同學福樂智慧