

Golgi Complex

Ultrastructure and Functions — Cell Biology Notes

1. Introduction

The **Golgi complex** (Golgi apparatus, Golgi body, dictyosome) is a membrane-bound organelle of the endomembrane system that receives newly synthesised proteins and lipids from the endoplasmic reticulum (ER), **modifies** them (chiefly by glycosylation), **sorts** them and **packages** them into vesicles bound for the plasma membrane, lysosomes or the exterior of the cell. It is often called the 'post office' or 'packaging and dispatch centre' of the cell.

- **Discovery:** Camillo Golgi (1898) observed a reticular structure in nerve cells of the barn owl and cat using the silver-impregnation ('black reaction') technique and named it the *internal reticular apparatus*.
- Its existence was debated for decades (considered a staining artefact) until **electron microscopy** (Dalton & Felix, 1950s) confirmed its stacked membrane structure.
- **Occurrence:** present in all eukaryotic cells except mature mammalian RBCs, sieve tubes of plants and some fungi; absent in prokaryotes. Especially well developed in secretory cells (pancreatic acinar cells, goblet cells, plasma cells, thyroid follicle cells).
- **Position:** in animal cells it is usually a single, juxtanuclear complex near the centrioles (cell centre); in plant cells it exists as many scattered, independent stacks called **dictyosomes** (up to several hundred per cell).

Remember: Golgi is **polar** — it has an entry (**cis**, forming) face towards the ER and an exit (**trans**, maturing) face towards the plasma membrane. Almost every exam question on ultrastructure is built around this polarity.

2. Ultrastructure (Electron Microscopic Structure)

Under the electron microscope the Golgi complex appears as a stack of flattened, membrane-bound sacs surrounded by tubules and vesicles. Four components are recognised: (i) **cisternae**, (ii) **tubules**, (iii) **vesicles** and (iv) **vacuoles**.

2.1 Cisternae

- Flat, disc-shaped, sac-like compartments, usually **4–8 per stack** (can be up to 20–30 in some protists and algae).
- Each cisterna is about **0.5–1.0 µm** in diameter; the lumen is 15–25 nm wide and adjacent cisternae are separated by an intercisternal space of 20–30 nm, often containing parallel fibres or 'intercisternal elements'.
- The membrane is a unit membrane about **6–8 nm** thick. Membrane thickness and staining gradually change from the cis face (ER-like, thinner) to the trans face (plasma-membrane-like, thicker) — a feature called **membrane differentiation**.
- Cisternae are usually **curved**, giving the stack a bow shape: the **convex cis face** faces the ER/nucleus and the **concave trans face** faces the plasma membrane.
- The central region is flat and compact; the **margins are dilated**, fenestrated (perforated) and continuous with tubules.
- Stacks are held together by a proteinaceous matrix including **golgins** and **GRASP** proteins.

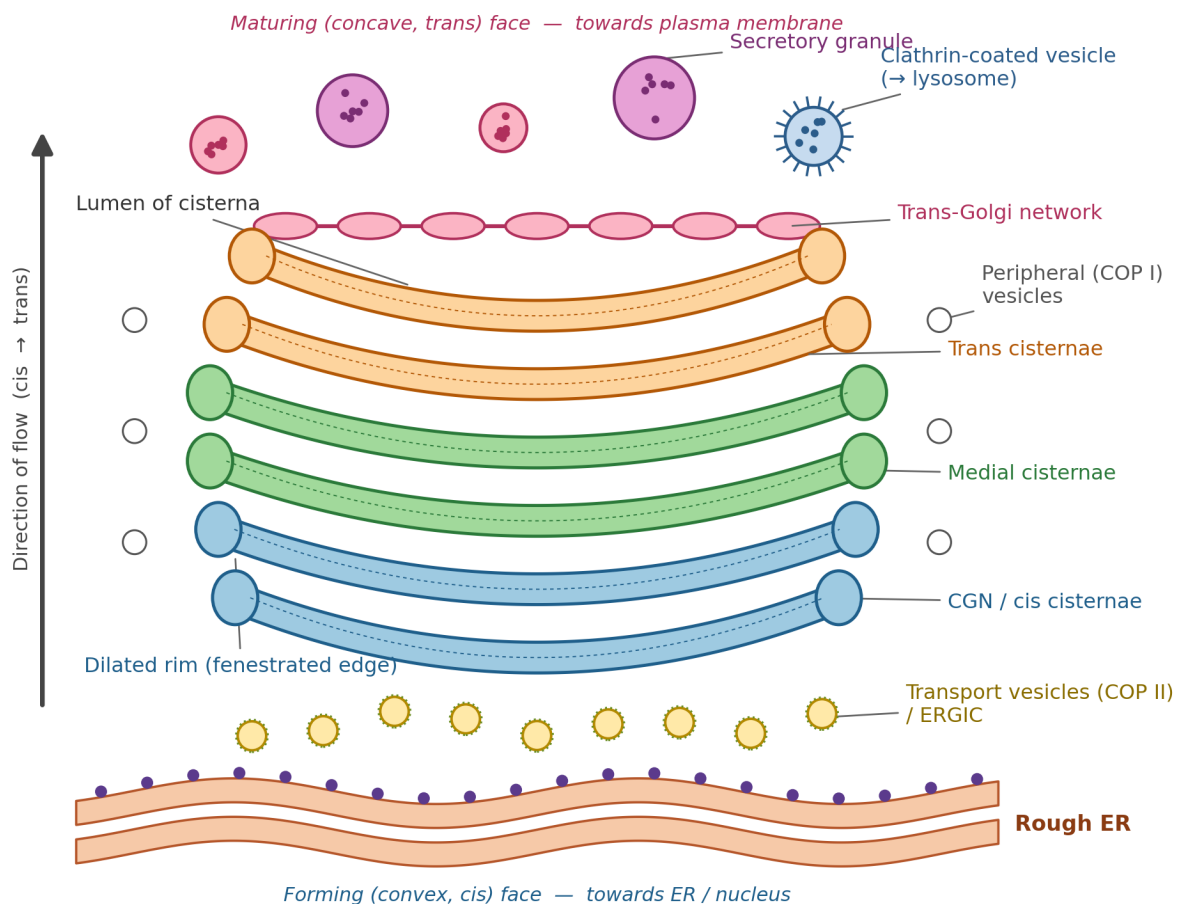


Fig. 1. Ultrastructure of the Golgi complex (vertical section) showing polarity from the cis face (towards rough ER) to the trans face and trans-Golgi network, with transport, peripheral, secretory and clathrin-coated vesicles.

2.2 Tubules

A complex network of branching and anastomosing tubules, **30–50 nm** in diameter, arises from the fenestrated periphery of cisternae. They interconnect cisternae of the same stack and adjacent stacks (forming the *Golgi ribbon* in animal cells). At the trans side they form the **trans-Golgi network (TGN)**.

2.3 Vesicles

- **Transport / transition vesicles** (40–80 nm): small, smooth vesicles budding from transitional ER with a **COP II** coat; they fuse to form the ERGIC and deliver cargo to the cis face.
- **Peripheral COP I-coated vesicles** (~50 nm): bud from cisternal rims; mediate **retrograde** transport (Golgi → ER, and trans → cis) and possibly intra-Golgi transport.
- **Clathrin-coated vesicles** (~50–100 nm): bud from the TGN, carry lysosomal hydrolases bound to mannose-6-phosphate receptors; show a bristle-like coat in EM.
- **Secretory vesicles / granules** (100–1000 nm, smooth, often electron-dense): bud from the trans face and store secretory products (zymogen granules, hormone granules).

2.4 Vacuoles (Golgian vacuoles)

Large, spherical, smooth-surfaced vacuoles formed by expansion of the terminal ends of trans cisternae. They contain amorphous or granular secretory material and later become condensing vacuoles, secretory granules or primary lysosomes.

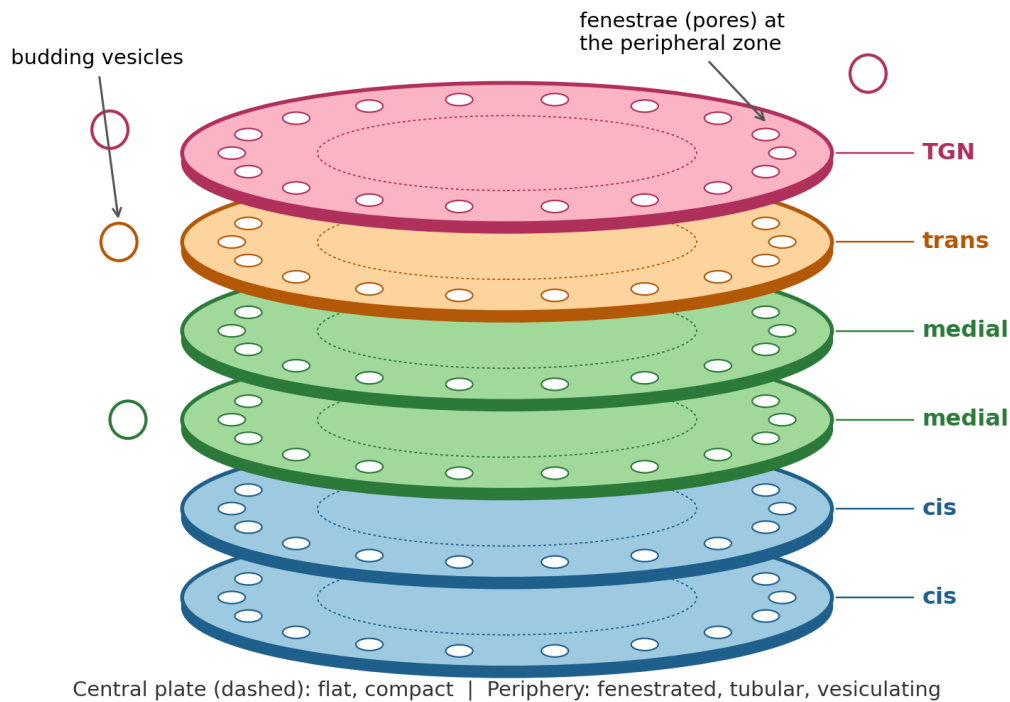


Fig. 2. Three-dimensional view of a dictyosome: stacked cisternae with a compact central plate and a fenestrated, vesiculating periphery.

2.5 Functional compartments (polarity)

Compartment	Location / structure	Key enzymes & events
ERGIC / cis-Golgi network (CGN)	Tubulo-vesicular network facing transitional ER	Receives COP II cargo; retrieves ER-resident proteins with KDEL signal via KDEL receptor + COP I
cis cisternae	First 1–2 flattened sacs	Phosphorylation of lysosomal enzymes (M6P formation); mannosidase I trims mannose
Medial cisternae	Middle sacs	Mannosidase II; N-acetylglucosamine (GlcNAc) transferases — conversion to complex oligosaccharides
trans cisternae	Last 1–2 sacs	Galactosyl-, sialyl- and fucosyltransferases; sulfation of tyrosine and sugars
Trans-Golgi network (TGN)	Tubular network at exit face	Sorting into constitutive, regulated and lysosomal pathways; proteolytic processing begins

Cytochemical markers confirm this polarity: the cis face is stained by **osmium tetroxide** (prolonged impregnation), medial cisternae show **NADPase** activity, and trans cisternae/TGN show **thiamine pyrophosphatase (TPPase)** and **acid phosphatase** activity.

3. Chemical Composition

- **Proteins ~60%, lipids ~40%** (on dry-weight basis in rat liver Golgi).
- Lipid composition is intermediate between ER and plasma membrane: phospholipids (phosphatidylcholine), increasing cholesterol and sphingolipids from cis to trans.
- Enzymes: glycosyltransferases, glycosidases (mannosidases), sulfotransferases, kinases, phosphatases (TPPase, NADPase, acid phosphatase), and phospholipid-synthesising enzymes.

- Matrix/structural proteins: golgins (GM130, giantin), GRASP65/55, coat proteins (COP I, clathrin, adaptor proteins), ARF and Rab GTPases, SNAREs.

4. Origin and Models of Transport

The Golgi arises from the ER: membranes and cargo arrive continuously through COP II vesicles, so the Golgi is constantly renewed (**membrane flow hypothesis**, Morré). Two models explain how cargo moves through the stack:

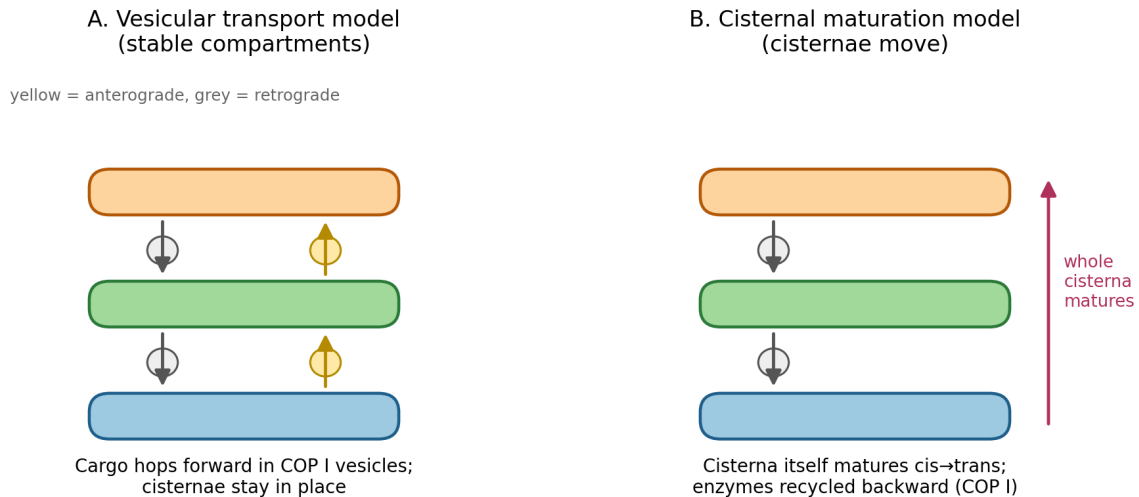


Fig. 3. Models of intra-Golgi transport: (A) vesicular transport between stable compartments; (B) cisternal maturation, now the more widely accepted view.

- Vesicular transport model:** cisternae are stable; cargo moves forward from one cisterna to the next in COP I vesicles.
- Cisternal maturation (progression) model:** new cisternae form at the cis face and mature progressively into trans cisternae; resident enzymes are recycled backward in COP I vesicles. Explains transport of large cargo like procollagen and algal scales that cannot fit in small vesicles.

5. Functions of the Golgi Complex

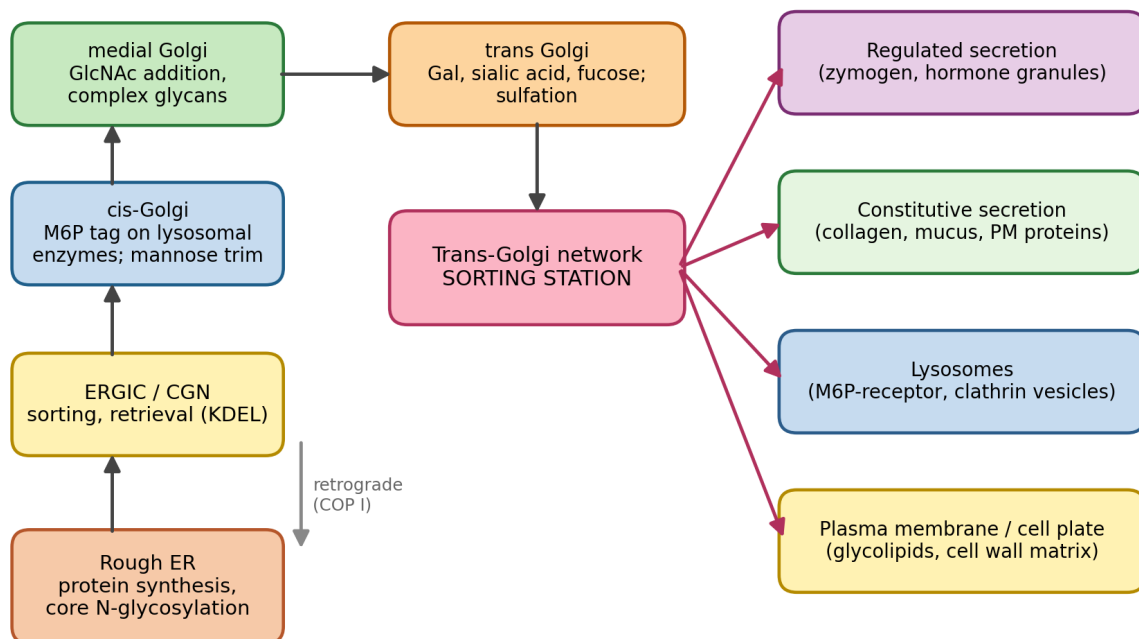


Fig. 4. Flow of cargo through Golgi compartments and sorting at the trans-Golgi network.

1. Glycosylation of proteins. N-linked oligosaccharides added in the ER are trimmed and remodelled into **complex** or **high-mannose** glycans. **O-linked glycosylation** (sugar attached to -OH of serine/threonine) occurs mainly in the Golgi, e.g. mucins. Glycosylation aids folding, stability, sorting and cell recognition.

2. Formation of glycolipids and sphingomyelin. Ceramide from the ER is converted into sphingomyelin and glycosphingolipids (cerebrosides, gangliosides) which are delivered to the outer leaflet of the plasma membrane.

3. Secretion (packaging & exocytosis). The classic function. Proteins are concentrated and packed into secretory vesicles: **constitutive secretion** (continuous; e.g. collagen, serum albumin, mucus) and **regulated secretion** (stored until a signal; e.g. insulin, zymogen granules of pancreas, neurotransmitters). Demonstrated by Palade's pulse-chase autoradiography with ^3H -leucine.

4. Formation of lysosomes. In the cis-Golgi, lysosomal hydrolases receive a **mannose-6-phosphate (M6P)** tag. M6P receptors in the TGN sort them into clathrin-coated vesicles that become lysosomes. Defect in this tagging causes **I-cell disease** (mucopolidosis II).

5. Proteolytic processing. Pro-proteins are cleaved into active forms in the TGN and secretory vesicles, e.g. proinsulin $\rightarrow$ insulin, pro-opiomelanocortin $\rightarrow$ ACTH, MSH, endorphins.

6. Sulfation and phosphorylation. Addition of sulfate (from PAPS) to proteoglycans and tyrosine residues, e.g. sulfated glycosaminoglycans of cartilage matrix; phosphorylation of lysosomal enzymes.

7. Membrane transformation and renewal. Golgi membranes are transitional between ER and plasma membrane; vesicle fusion replenishes and remodels the plasma membrane.

8. Formation of acrosome. During spermiogenesis the Golgi forms the proacrosomal granules that fuse to form the **acrosome**, containing hyaluronidase and acrosin for penetrating the egg.

9. Cell plate and cell wall formation (plants). Golgi vesicles carrying pectin and hemicelluloses (matrix polysaccharides) fuse at the equator of dividing plant cells to form the **phragmoplast/cell plate**. Cellulose itself is made at the plasma membrane.

10. Formation of other specialised structures. Yolk and cortical granules of oocytes, melanin granules, mucilage of root-cap cells, scales and cell-coat of algae, contractile vacuoles in protozoa, and formation of the **glycocalyx** (cell coat).

11. Retrieval of ER-resident proteins. Escaped ER proteins with the C-terminal **KDEL** (Lys-Asp-Glu-Leu) signal are bound by KDEL receptors in the CGN and returned to the ER in COP I vesicles.

12. Milk, hormone and enzyme secretion. Lactose is synthesised in the Golgi of mammary cells; thyroglobulin is processed in thyroid cells; digestive enzymes are packaged in pancreatic acinar cells.

6. Golgi Complex in Disease

- **I-cell disease:** deficiency of GlcNAc-phosphotransferase → no M6P tag → lysosomal enzymes secreted outside; lysosomes filled with undigested material.
- **Congenital disorders of glycosylation (CDG):** defective Golgi glycosyltransferases or trafficking proteins.
- **Neurodegenerative diseases** (Alzheimer's, Parkinson's, ALS): Golgi fragmentation is an early feature.

7. Quick Comparison

Feature	Animal cell	Plant cell
Form	Single juxtanuclear complex / Golgi ribbon	Many separate dictyosomes
Location	Near nucleus and centrioles	Scattered throughout cytoplasm
Mobility	Relatively stationary; fragments in mitosis	Mobile along actin filaments; persist through division
Special role	Lysosomes, acrosome, hormone secretion	Cell plate, cell wall matrix, mucilage

8. Exam-Oriented Questions

Long answer

- Describe the ultrastructure of the Golgi complex with a neat labelled diagram. (10)
- Discuss the functions of the Golgi apparatus with special reference to glycosylation and secretion. (10)
- Explain the polarity of the Golgi complex. How is it demonstrated cytochemically? (8)

Short answer / notes

- Trans-Golgi network.
- Cis and trans face of Golgi.
- Role of Golgi in lysosome formation (M6P pathway).
- Dictyosome.
- Cisternal maturation model.

- Golgi in acrosome and cell plate formation.
- I-cell disease.

One-liners

- Who discovered the Golgi complex and in which cells? — *Camillo Golgi, 1898, nerve cells of barn owl.*
- Marker enzyme of trans Golgi? — *Thiamine pyrophosphatase.*
- Coat protein for retrograde Golgi → ER transport? — *COP I.*
- Signal for retention of ER proteins? — *KDEL.*
- Plant Golgi units are called? — *Dictyosomes.*