PROFESSIONAL DEVELOPMENT

AP® Biology

Cell-to-Cell Communication— Cell Signaling

Special Focus

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Contents

Introduction

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Cell-to-cell communication, or signaling, is an important part of understanding cell functions as well as system functions. There are several types of signaling, such as neurotransmitters that are recognized in the synapse, antigens triggering antibody responses, and target cells responding to specific hormones. This project provides more information about the signaling process using integrins as the mechanism.

The document opens with a very effective introductory lab focused on cell-to-cell communication. Following this lab, author Elizabeth Cowles elaborates on cell linkages and integrins in an attempt to offer students and teachers additional background information and practical applications.

These materials also include appropriate AP Biology Exam free-response questions and their rubrics from previous years, as well as informative and interactive Web sites. These resources provide teachers with additional information regarding cell communication as well as animated examples of other types of signaling. If access allows, teachers may use the activities and information presented on these Web sites to introduce, develop, and reinforce concepts associated with cell communication. Likewise, teachers may use the free-response questions to not only reinforce the concepts embedded within cell communication, but also to aid in the understanding of this communication. These questions also serve to test students' analytical and reasoning skills while reflecting appropriate lab experiences they should possess.

Introductory Lab: Cell-to-Cell

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Is there an exchange of chemical information between cells?

Purpose

To determine if one cell has an effect on the conditions in an adjacent cell. This is a simple representation of cell-to-cell transfer of information with diffusion through two cell membranes.

Materials

- One eight-inch by four-inch plastic disposable storage box with a lid (clear or translucent without color)
- Four pieces of one-inch by eight-inch dialysis tubing that have been soaked overnight
- 1 percent starch solution
- Diluted Lugol's solution (4 ml per 200 ml of distilled water)
- String or dialysis tubing clamps
- Distilled water

Procedure

- Clamp or tie off one end of each of the dialysis tubing.
- Place enough distilled water in the plastic storage box to cover the bottom.
- Fill two pieces of the dialysis tubing with 1 percent starch solution and seal the open ends.

- Fill the remaining two pieces of dialysis tubing with the diluted Lugol's solution and seal the open ends.
- Place the completed tubing into the plastic storage box, alternating first with Lugol's-filled tubing and then a starched-filled tube, then another Lugol's-filled tube, and finally the last starch-filled tube. The tubes should fit snugly into the box so the sides of the tubing are in complete contact.
- Place the lid on the plastic storage box to help keep the tubing moist, just as cells are moist at all times.
- Make observations every five minutes to observe any changes in the tubes. Are there any color changes?

Analysis

1) Explain why it was important to keep the system moist.
2) Were there color changes in any of the tubes? If so, what do these changes indicate?
3) Compare and contrast the dialysis tubing bags in contact with each other to cells that are in contact with each other.
4) The dialysis tubing bags serve as a model for a community of living cells. In what ways is the model an accurate portrayal of cell systems and in what ways is it flawed?
5) Describe two specific examples of cell-to-cell communication, naming the type of cell and what chemical message is passed.

Lab Questions Answer Key

Question 1:

The system must be kept moist for the solutions to diffuse across the dialysis tubing (membranes) just as the cell membranes are moist for the same defusing actions to take place.

Question 2:

The starch tube will initially appear clear to milky white, depending on the amount of starch; the iodine tube will initially be copper colored. The starch tube will turn dark

as the iodine diffuses into it. The iodine tube will become lighter in color as the iodine leaves.

Question 3:

The dialysis tubes lying side by side are similar to cell membranes because they are moist and they allow small particles to diffuse. They are different because the only method of material passage is diffusion.

Question 4:

Cell membranes have protein channels and allow materials to be moved by endocytosis and exocytosis, and they are moist to allow for diffusion. The dialysis tubing is a model for the diffusion portion of the cell activity, and it also demonstrates the need for the system to be moist.

Question 5:

Examples include neurotransmitters in the synapse, antigens triggering antibody response, target cells responding to specific hormones, and many others.

Cell Linkages: Integrins

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Introduction

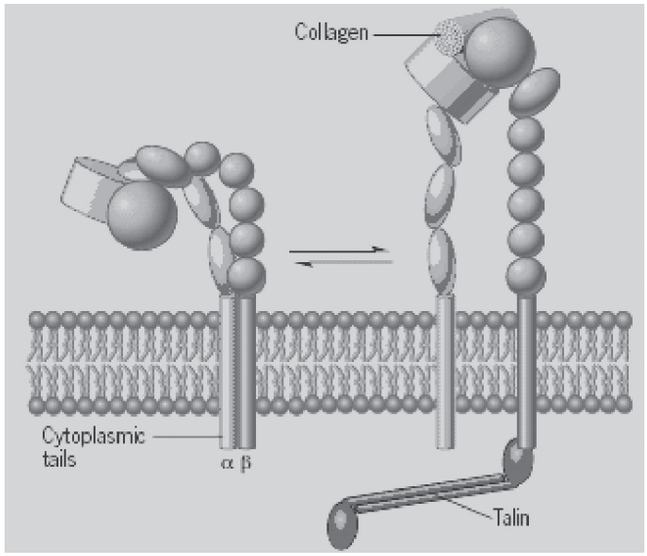
Communication is the name of the game, especially in cells; specialized receptors called integrins provide vital communication links between the interior and exterior of the cell. Integrins are transmembrane proteins that act as mechanotransducers and signal conductors, providing a physical link between the extracellular matrix (ECM) and the cell's cytoskeleton. Although integrins do not have intrinsic enzymatic activity, they can interact with enzymes such as kinases that have specific signaling functions. Integrins are involved in many cellular processes, such as differentiation, migration, proliferation, ECM protein expression, activation of growth factors, apoptosis, and cell survival. Interestingly, integrins work from either direction: They can bind to extracellular ligands, thus triggering intracellular signal cascades, or they can be activated by factors from within the cell to influence the relationship of the cell with its environment.

Integrins are heterodimers, meaning that they are composed of two distinct subunits termed α and β. Humans produce 18 different alpha chains (the larger subunit weighing 120–180 kDa) and 8 different betas (smaller subunits weighing 90–110 kDa), which combine to form different integrins. So far, 24 human integrins have been identified, each named for their two-component subunits (α2β1, for example). Studies of invertebrate species such as *Drosophila melanogaster* and *Caenorhabditis elegans* have revealed the presence of integrins (though there are fewer varieties), and the basic heterodimer structure is highly conserved among all animals. Proteins very similar to integrins are found in plants, fungi, or prokaryotes; these proteins may be important in touch (thigmo) responses in these organisms

(Jaffe et al. 2001), in gravity perception in plants (Katembe et al. 1997), and in the binding of a pathogenic fungus to fibronectin (Kottom et al. 2008).

Integrins typically span the cell's plasma membrane with the N- or amino-terminus of both subunits extending into the extracellular matrix, providing potential ligand binding sites. The subunits interact with each other and exist in either a low-affinity or a high-affinity conformation depending on external and internal signals (Humphries and Liddington 2002). The integrins are normally bent in the low-affinity state, but "open like a switchblade" upon activation via phosphorylation of the β subunit's cytoplasmic end.

FIGURE 1



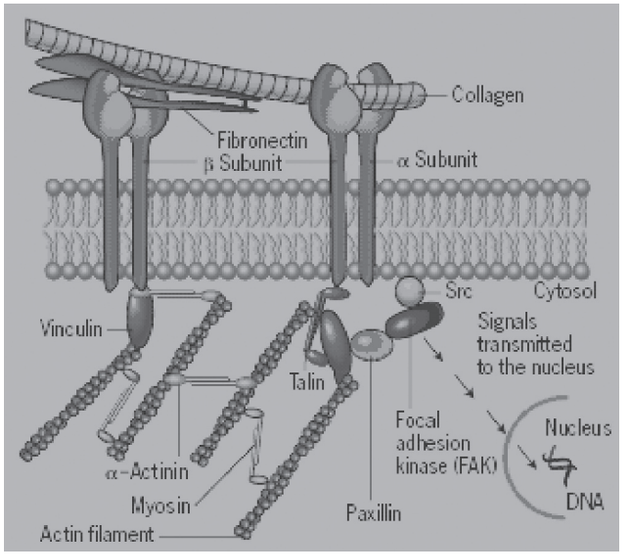
A model of integrin activation. Schematic representation of a heterodimeric integrin molecule in the bent, inactive conformation (left) and the upright, active conformation (right). The switch in conformation is triggered by the binding of a protein, in this case talin, to the small cytoplasmic domain of the β subunit. The binding of talin induces a separation of the two subunits and conversion to the active conformation. Activated integrins typically become clustered as the result of interactions of their cytoplasmic domains with the underlying cytoskeleton. The extracellular ligand, in this case a collagen fiber, binds between the two subunits in the head region of the activated integrin dimer.

Figures 1–4 from *Cell and Molecular Biology: Concepts and Experiments* by Gerald Karp. New York: John Wiley & Sons, Inc., 2007. Used with permission of John Wiley & Sons, Inc.

This physical change modulates both the integrin's affinity for its ligand and also the stability of the attachment. The relatively small 40–70 amino acid subunit ends that extend into the cytoplasm allow interactions with intracellular proteins; the β4 cytoplasmic "tail" is so long, it can even bind to intermediate filaments in the cytoskeleton.

Fibronectin, which has important cell migration and wound healing functions, provides a good example of extracellular protein interaction with integrins. Fibronectin contains an RGD or arginine–glycine–aspartate sequence, which is recognized by the integrin α5β1. The integrin simultaneously interacts with talin, which provides a physical link to actin filaments, thus allowing cells to migrate along the fibronectin.

FIGURE 2



Focal adhesions are sites where cells adhere to their substratum. This drawing of a focal adhesion shows the interactions of integrin molecules with other proteins on both sides of the lipid bilayer. The binding of extracellular ligands, such as collagen and fibronectin, is thought to induce conformational changes in the cytoplasmic domains of the integrins that cause the integrins to become linked to actin filaments in the cytoskeleton. Linkages with the cytoskeleton are mediated by various actin-binding proteins, such as talin and a-actinin, that bind to the β subunit of the integrin. The cytoplasmic domains of integrins are also associated with protein kinases, such as FAK (focal adhesion kianse) and Src. The attachment of the integrin to an extracellular ligand can activate these protein kinases and start a chain reaction that transmits signals throughout the cell. The association of myosin molecules with the actin filaments can generate traction forces that are transmitted to sites of cell–substrate attachment.

Other proteins containing the RGD sequence include vitronectin, bone sialoprotein, von Willebrand factor, fibrillin, fibrinogen, thrombospondin, PECAM (platelet endothelial cell adhesion molecule), tenascin, and LAP-TGFβ (latency associated peptide transforming growth factor-β). The RGD motif is also used for interactions between ECM proteins and integrins αvβ1 and α8β1. Other integrins use a different tripeptide sequence, leucine-aspartate-valine (LDV), to recognize and bind proteins important for intercellular adhesion, such as VCAM (vascular cell adhesion molecule), ICAM (intercellular adhesion molecule), factor X, mucosal adhesion cell adhesion molecule (MadCAM), and E-cadherin. Integrins containing the α1 and α2 subunits have an A domain, similar to von Willebrand factor, a blood glycoprotein important in clotting. These subunits combine with β1 to form receptors for collagen, thrombospondin, and laminin.

Integrins and Cellular Signaling

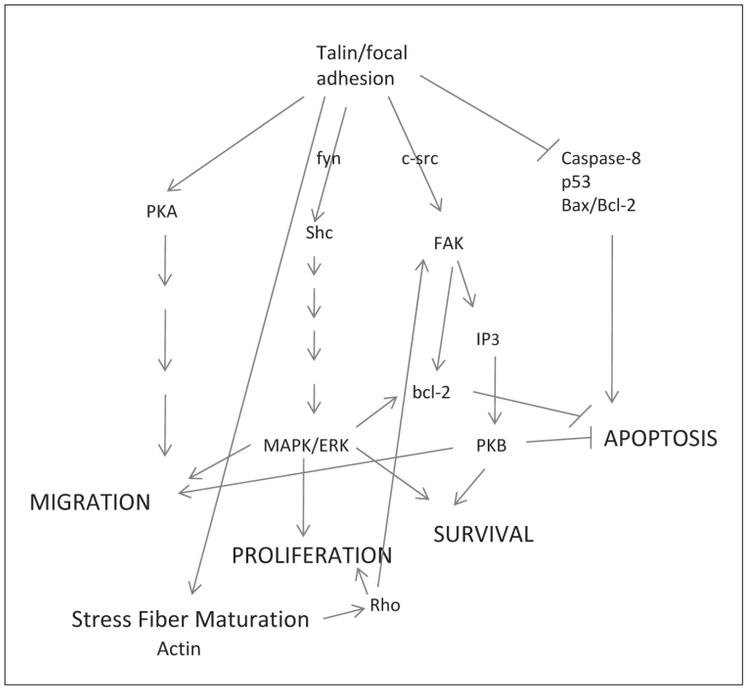
Inactive integrins are dispersed over the cell surface. Upon binding to ECM proteins, integrins migrate within the cell membrane to cluster and form focal adhesion sites in a process called activation.

These sites may then include interactions with several additional proteins such as focal adhesion kinase (FAK), paxillin, talin, and tensin (Tadokoro et al. 2003; Lo 2006). Integrin interactions between talin, vinculin, α-actinin, and paxillin provide a physical linkage between the ECM and the actin cytoskeleton; these links are critical

for cell anchorage and migration. Phosphorylation of the β tail, in the cytoplasm, disrupts the talin–integrin interaction, thus permitting cell movement.

Integrin activation via external factors can set off a cascade of events; this is called outside-in signaling. These interactions can involve several proteins, in which the integrin has a critical mediating role. Outside-in signaling can result in modification of the cytoskeleton, cause cellular proliferation or migration, and determine cell survival or apoptosis. One example is the MAPK/ERK (mitogen-activated protein kinase or extracellular signal-related kinase) signal pathway, which is turned on by integrin-extracellular ligand interactions.

FIGURE 3

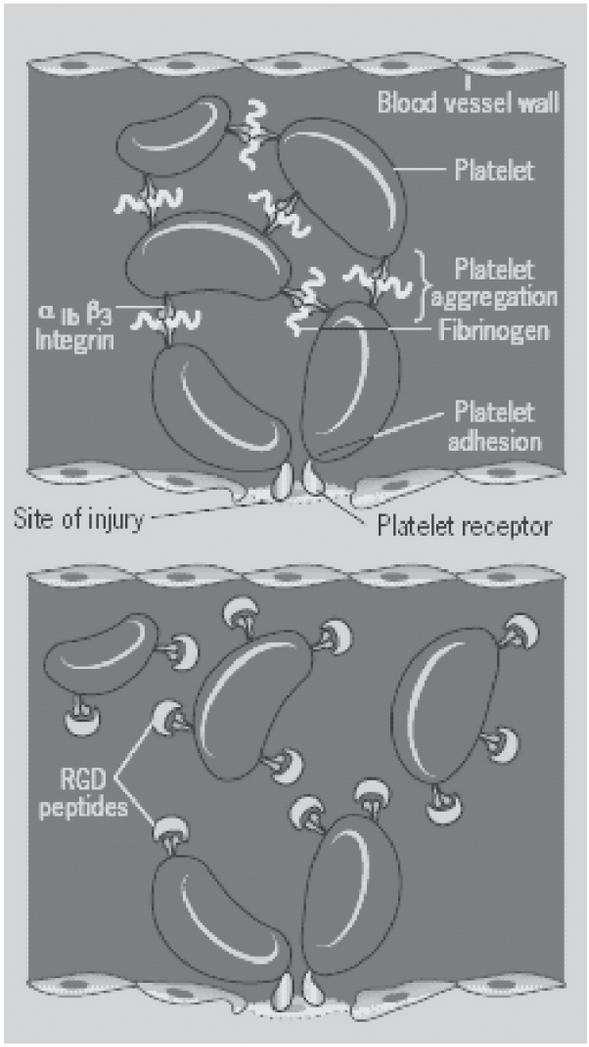


This pathway controls gene expression by increasing the stability of c-jun and increasing transcription of the protein c-fos. C-jun and c-fos combine to form AP-1 (activating protein-1), which binds to specific DNA promoters; therefore, integrins can control gene transcription via the MAPK/ERK signaling kinases. In particular, AP-1 induces expression of integrin α2β1 and its ligand, collagen.

Another example of integrin-mediated control of transcription involves activation of the α5β1 integrin, which increases ERK; this ultimately up-regulates the transcription of the protein Bcl-2, which is an anti-apoptotic signal. High Bcl-2 levels prevent apoptosis, or programmed cell death. Temporary loss of integrin-substrate contact is necessary for migration; however, loss of adhesion may trigger apoptosis. This balance between integrin binding and apoptosis prevents inappropriate cell migration and adhesion; this equilibrium is often aberrant in cancer cells.

Signaling via integrins is not always outside-in, nor is it always unidirectional.

FIGURE 4



Blood clots form when platelets adhere to one another through fibrinogen bridges that bind to platelet integrins. The presence of synthetic RGD peptides can inhibit blood clot formation by competing with fibrinogen molecules for the RGD-binding sites on platelet αIIIβ3 integrins. Nonpeptide RDG analogs and anti-integrin antibodies can act in a similar way to prevent clot formation in high-risk patients.

Recent research has focused on the intracellular Rho family of GTPases. Rho coordinates cell functions such as cell adhesion, cell migration, gene expression, and the cell cycle. Integrins activated by extracellular factors regulate Rho through the MAPK/ERK pathway.

Rho, however, increases integrin avidity ("stickiness") and the numbers of stress fibers, which in turn regulates the formation of integrin focal adhesion sites (Schwartz and Shattil 2000; Lo 2006). Therefore, an internal molecule like Rho can modulate integrin–ECM interactions by changing the integrin conformation to the active form.

The inside-out signaling is exemplified by the blood clotting system. Platelets have inactive integrins, which prevent inappropriate adhesion to vessel walls (Horowitz 1997). Damage to endothelial cells exposes thrombin, which activates platelets that come in direct contact by causing their αIIbβ3 integrin to become more adhesive and to bind fibrinogen. Platelets bind to the thrombin without the assistance of integrins; the thrombin–platelet interaction elicits intracellular signals, which change integrin adhesiveness.

FIGURE 5

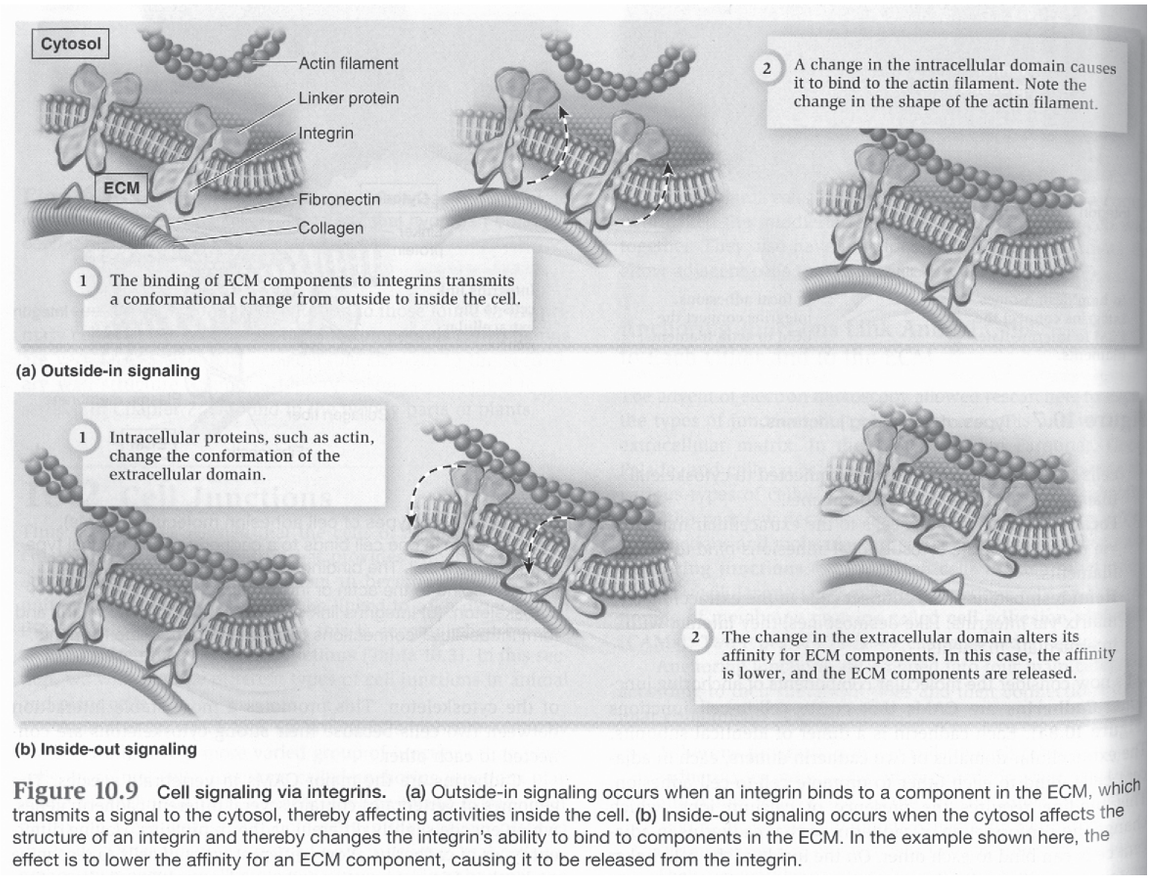


Figure 10.9 **Cell signaling via integrins.** **(a)** Outside-in signaling occurs when an integrin binds to a component in the ECM, which transmits a signal to the cytosol, thereby affecting activities inside the cell. **(b)** Inside-out signaling occurs when the cytosol affects the structure of an integrin and thereby changes the integrin's ability to bind to components in the ECM. In the example shown here, the effect is to lower the affinity for an ECM component, causing it to be released from the integrin.

From *Biology*, by Robert J. Brooker, Eric P. Widmaier, Linda Graham, and Peter Stiling. New York: McGraw-Hill Science, 2007. Used with permission of The McGraw-Hill Companies.

The now-activated integrins on the platelet surfaces capture circulating von Willebrand factor and fibrinogen, which form the blood clot. Glanzmann's thrombasthenia is caused by a mutation in either the αIIb or β3 integrin genes; the disorder is characterized by abnormal bruising and bleeding and is often mistaken for hemophilia. Antagonists (inhibitors) of αIIbβ3 integrin, such as abciximab and xemilofiban, are used to reduce clot formation in patients at high risk for stroke or heart attacks.

Leukocytes infiltrate damaged tissues, but only do so when their αMβ2 or αLβ2 integrins are activated by cytokines via inside-out signaling (Horowitz 1997). Cytokines are small, secreted proteins which regulate immunity and inflammation. The integrins mediate attachment to vascular endothelial ICAMs (intercellular adhesion molecules), and then the leukocyte migrates between the endothelial cells. Leukocyte adhesion deficiency (LAD), a very rare human disorder in which patients lack β2 or make defective β2, occurs when phagocytes cannot attach to endothelial cells. LAD patients often succumb to bacterial infections early in life.

Many integrin signaling events are coupled with growth factor responses; this is because cellular responses, such as migration and mitosis, require integrin-substrate interactions or anchorage (Giancotti and Ruoslahti 1999).

For example, the platelet-derived growth factor (PDGF) receptor responds maximally only when αVβ3 is bound to the ECM and PDGF increases the amount of αVβ3 in the plasma membrane. This synergistic activity between the PDGF receptor and the integrin increases cell migration and wound healing. The interactions between the growth factor and integrin signaling pathways fine-tune the cell's response to its external environment and allow for coordinated regulation.

Integrins in Health and Disease

Angiogenesis, or the production of new blood vessels, is critical not only during development but also during oncogenesis or cancer development; tumors need a ready blood supply for survival. αVβ3 integrin attachment to the ECM is regulated by the vascular endothelial growth factor (VEGF) receptor; impairing the VEGF receptor–integrin interaction reduces angiogenesis (Mahabeleshwar et al. 2006). Drugs that interfere with integrin function during angiogenesis are in clinical trials; Vitaxin, an anti-αVβ3 antibody, shrinks tumors by decreasing blood vessels and Avastin, an anti-VEGF monoclonal antibody, is used for treating colorectal cancers.

Researchers have noted that certain breast cancers metastasized to bone. It appears that αVβ3 expression is elevated in breast cancer tissue, and this integrin recognizes bone sialoprotein, a major bone matrix constituent. Cancer cells migrating from breast tumors bind to bone tissue through αVβ3 and become established (Sloan et al. 2006). Scientists are investigating whether αVβ3 antagonists could prevent metastases (Zhao et al. 2007). Unpublished data from Barbara Susini's laboratory (University of California, San Diego) indicate that an α4β1 antagonist inhibits lymph node blood vessel development; because breast cancer spreads via the lymphatic system, such an antagonist may prevent breast cancer metastases.

Viral and bacterial pathogens take full advantage of integrins. Bacterial pathogens use integrins to maintain contact and prevent removal from the host, and then gain entry (Scibelli et al. 2007). Binding allows the bacteria to be phagocytosed, to inject virulence factors, or to adhere indirectly through fibronectin. The α5β1 integrin that binds fibronectin is recognized by *Shigella*; several *Shigella* protein antigens mediate bacterial-directed endocytosis. *Staphlococcus aureus* and *Streptococcus spp.* express fibronectin-binding proteins, and indirectly attach to cells through the ECM.

Viruses also employ integrins to bind and gain entry into cells (Stewart and Nemerow 2007). Adenovirus is recognized by the αV integrin. The herpes virus outer envelope glycoprotein has a sequence that mimics a metalloprotease; this glycoprotein binds to β1 and αVβ3 integrins. Hantaviruses, which directly affect platelet and endothelial cell functions, have αIIbβ3 and αVβ3 as receptors. Binding not only allows the virus access to the cell's synthetic machinery but also to its signaling pathways. Novel vaccines, therapeutic strategies, and antiviral drugs may be based upon integrin antagonists.

A new area of integrin research is in nanoscale technology and material science (Stevens and George 2005). Implants often fail because cells do not attach and reproduce on the foreign surface. Titanium implants are commonly used in dental and joint replacements, but do not readily support osteogenesis. Implants coated with matrices of calcium carbonate (hydroxylapatite) and RGD-containing proteins, such as fibronectin, collagen or related peptides, bond bone-forming osteoblasts better than uncoated material (Reyes et al. 2007). These coatings promoted α2β1 binding, which triggered the expression of osteoblast-specific genes, which resulted in increased cell differentiation and bone production.

Integrins are involved in many cellular and organismal processes, including tissue remodeling, immunology, and proliferation. These biological activities require coordination between the internal and external cellular environments; integrins provide some of the critical communication links. Insights into these fascinating cell surface receptors will help us design new therapies for cancer, inflammation, and pathogen-related diseases.

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Integrin Definitions

Adenovirus: Double-stranded DNA virus; causes respiratory tract infections.

α-actinin: Actin-crosslinking protein; found in the cytoskeleton.

AP-1: Activator protein-1 transcription factor; dimeric complex of c-jun and c-fos. Binds to TPA (phorbol ester) responsive element in DNA.

Bcl-2: Protein found in mitochondrial, endoplasmic reticulum, and nuclear envelope membranes. Helps protect cell from apoptosis by inhibiting caspase (protease) activity.

Bone sialoprotein: Protein found in mineralized tissue; may help in formation of hydroxylapatite.

c-fos: Cellular proto-oncogene protein product of *c-fos* gene; protein is produced rapidly after growth factor stimulation. Phosphorylation by MAPK stabilizes c-fos.

c-jun: Cellular proto-oncogene protein product of *c-jun* gene; forms AP-1 with c-fos.

c-src: Cellular proto-oncogene protein product of *c-src* gene; is a tyrosine kinase important in transmitting integrin signals; these kinases phosphorylate tyrosine residues. Protein is associated with cytoplasmic face of plasma membrane. The src family of kinases includes Src, Lck, Hck, Fyn, Blk, Lyn, Fgr, Yes, and Yrk.

Cytokine: Small secreted proteins; important in mediating immune system and inflammation.

E-cadherin: Transmembrane protein used in epithelial cell–cell adhesion. Found near focal adhesion sites.

Factor X: Thrombokinase; important in clotting (coagulation) cascade. Requires vitamin K for synthesis.

FAK: Focal adhesion kinase; a protein tyrosine kinase. Localized at focal adhesion sites by C-terminal region; associates with and is phosphorylated by c-src.

Fibrillin: ECM glycoprotein found in microfibrils; important in tissue elasticity.

Fibrinogen: Blood glycoprotein which is cleaved by thrombin to form fibrin, which is found in blood clots.

Fibronectin: ECM glycoprotein; important in cell migration and wound healing.

Hantavirus: Negative-sense, single-stranded RNA virus in Bunyaviridae family; causes infectious respiratory disease.

Herpesvirus: Double-stranded DNA virus (Herpesviridae); includes oral and genital herpes, and Epstein-Barr virus.

ICAM: Intercellular adhesion molecule with structure similar to immunoglobulins (immunoglobulin super family); different forms are tissue related.

Laminin: Basement membrane glycoprotein, which is a heterotrimer of α-, β-, and γ-polypeptides; forms a meshlike network.

LAP-TGFβ: Amino terminal latency associated protein (LAP) fused with cytokine transforming growth factor β; is secreted into ECM.

LDV region: Leucine–aspartate–valine sequence found in integrin ligands such as VCAM.

MadCAM: Cell adhesion molecule found in mucosal cells.

MAPK/ERK: Mitogen-activated protein kinase/extracellular signal-regulated kinase; a family of serine/threonine kinases, which are phosphorylated by other kinases for full activity. Important in gene transcription and regulation. Related proteins include SAPK, JNK, and p38 MAPK.

Paxillin: Protein (signal transduction adaptor) that localizes to focal adhesion sites. Paxillin phosphorylation controls cell migration.

PDGF: Platelet-derived growth factor; a dimeric protein. PDGF receptor is tyrosine kinase. PDGF regulates cell growth, especially angiogenesis.

PECAM: Platelet/endothelial cell adhesion molecule; aids in leuckocyte migration through endothelial cell intercellular junctions.

PKA: Protein kinase A or cyclic AMP-dependent protein kinase; is a serine/threonine kinase. PKA activity is high when cAMP levels are high. Important in glycogen and lipid metabolism.

Rho: Family of GTP-binding proteins (GTPases); members include Rho, Rac, and Cdc42. GTP-bound Rho regulated cell proliferation, actin polymerization, and intercellular adhesion.

***Shigella*:** Gram-negative, rod-shaped bacteria. Agent of shigellosis and dysentery, which are intestinal infections.

***Staphlococcus aureus*:** Gram-positive, spherical bacteria that is found on skin. Agent of pneumonia, toxic-shock syndrome, impetigo, and septicemia.

***Streptococcus*:** Gram-positive, spherical bacteria. Agent of strep throat, scarlet fever, and rheumatic fever.

Talin: Protein found in focal adhesion sites; helps anchor actin to integrins and activates integrin αIIbβ3. Contains binding sites for vinculin.

Tenascin: ECM glycoprotein; found in areas of cell proliferation and cell migration. Tenascin levels are increased by TGF-β.

Tensin: Actin-binding protein present in focal adhesion sites.

Thrombospondin: Family of secreted glycoproteins. Thrombospondin-1 inhibits angiogenesis.

VCAM: Vascular adhesion molecule; member of immunoglobulin super family. Mediates leukocyte-endothelial cell adhesion. Expressed on endothelial cells after cytokine stimulation.

VEGF: Vascular endothelial growth factor/vascular permeability factor; increases endothelial cell proliferation and promotes angiogenesis.

Vinculin: Focal adhesion protein that binds to talin or α-actinin.

Vitronectin: Also called S-protein; found in ECM and blood. Interacts with collagen and important in blood clotting.

Von Willebrand factor: Blood glycoprotein used in blood coagulation; binds to platelets and to collagen.

AP® Biology Free-Response Questions and Scoring Rubrics

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Joplin, Missouri

Question Topic: Plant Reproduction
1985 Exam

Question

Seeds that are randomly positioned when planted in a pot of soil placed on a windowsill produce seedlings with downward growing roots and upward growing shoots. Above ground, the shoots are oriented toward light. Describe the physiological mechanisms that occur to produce:

a) the downward growth of the roots
b) the upward growth of the shoots
c) the bending of the shoots toward light

Reader's Scoring Rubric

Standards: Not More Than 15 Total Points Were Given.
One Point for Each of the Following:

__ The hormone involved is auxin.
In vertical roots or stems, auxin is uniformly distributed.
__ In horizontally placed roots, auxin accumulates on the lower side.
__ The accumulation of auxin on the lower side in roots inhibits cell elongation in the area.
__ In horizontally placed stems, auxin accumulates on the lower side.
__ Accumulation of auxin in stems is stimulatory.

- ___ In a laterally illuminated stem, auxin accumulated on the shady side.
- ___ There is lateral transport of auxin from the sunny to the shady side, or from top to bottom in horizontally placed stems and roots.

Two Points for Each of the Following:

- ___ Auxin is produced in the stem apex.
- ___ Auxin causes cell elongation in stems.
- ___ The optimum for root growth is an amount much less than for stem growth.
- ___ In high concentration, auxin is inhibitory in both stems and roots.
- ___ Lateral movement of auxin requires energy.
- ___ Auxin movement is too fast to be explained by diffusion.
- ___ The perception of auxin in stem tips is light promoted (carotenes or flavenes).
- ___ Discussion of the perception of gravity.
- ___ Evidence that the site of perception is the tip.

Five Points for the Following:

The downward growth of roots: The geotropic response of the root is dependent on the production of a growth inhibitor or inhibitors produced in the root cap. The inhibitor(s) move from the cap through the apex to the elongating cells. If the root is horizontal, a large part of the substance is transported laterally to the lower side. The difference in concentration produces unequal growth.... [T]he lower side is more inhibited and the root therefore turns down.

Question Topic: Plant Reproduction
1984 Exam

Question

Define the following plant responses and explain the mechanism of control for each. Cite experimental evidence as part of your discussion.

a) Phototropism
b) Photoperiodism

Reader's Scoring Rubric

Standards:

Phototropism:

Max. = 9 points if experimental evidence is given

Max. = 7 points if experimental evidence is lacking

___ Definition: Movement in response to light (involving growth) – 2 points

___ Possibility of negative response

Mechanism

___ Auxins

___ Distribution (apex -> stem or lateral)

___ Elongation of cells

___ Stem tip or coleoptile

Evidence (2 points for any of the following)

___ Darwin – covered coleoptiles

___ Paal – cut coleoptiles – agar, uneven placement

___ Boysen-Jensen – mica

___ Went – bioassay

Photoperiodism

Max. = 9 points if experimental evidence is given

Max. = 7 points if experimental evidence is lacking

___ Definition – response to light/dark periods

___ Flowering (or other response)

Mechanism

___ Categories of plants (LDP, SDP)

___ Receptor in leaf

___ LDP (if night shorter than minimum)

___ SDP (if night longer than minimum)

___ Night not day

___ Existence of phytochrome in two forms

___ PFR/PR interconvertible

___ PFR active form

___ Ratio (PR/PFR) important

___ Possible hormonal involvement

Evidence

__ Light flash in dark
__ Grafting
__ Ratio of PR/PFR

Question Topic: Reproduction
1985 Exam

Question

Describe the structure of a bean seed and discuss its germination to the seedling stage. Include in your essay hormonal controls, structural changes, and tissue differentiation.

Reader's Scoring Rubric

Standards:

Structure: Max. = 8 points

__ Seed coat (protection)
__ Embryo (new plant)
__ Cotyledons (store food)
__ Epicotyl (new shoot)
__ Hypocotyl (new stem/root)
__ Radicle (1st root)
__ Plumule (1st leaves)
__ Hilum scar (attachment)
__ Micropyle (pollen tube entry)

Germination Discussion: Max. = 12 points

__ Imbibition of water (increases metabolism)
__ Correct temperature (enzymes)
__ Oxygen (for respiration)
__ Radicle emerges first (establishes root)
__ Subsequent shoot (photosynthesis when stored food gone)
__ Formation of hook/arch (pulls epicotyl)
__ Epigeal germination

a. Hormonal Control
   __ Auxin in geotropism (+ or -)

___ More auxin, lower 1/2 axis
___ Stem/root affected differently
___ Gibberellins stimulate length growth
___ Cytokinins stimulate cell division
___ Abscisic acid inhibits root cell elongation

b. Structural Changes (Note: Some germination discussion is structural change.)
___ Formation of root cap
___ Dropping spent cotyledons
___ Change, dark-to-light growth
___ Branch root production
___ Leaf primordia
___ Two different foliage leaves

c. Tissue differentiation
___ Cell division, elongation, maturation
___ Xylem, phloem (elaboration)
___ Apical meristem
___ Protoderm, ground meristem, procambium
___ Several vascular strands, stem; one, roots
___ Collenchyma, sclerenchyma
___ Mesophyll, epidermis, guard cells
___ Endodermis pericycle
___ Root hair formation

Question Topic: Flight or Flight Response
1992 Exam

Question
Survival depends on the ability of an organism to respond to changes in its environment. Some plants flower in response to changes in day length. Some mammals may run or fight when frightened. For both of these examples, describe the physiological mechanisms involved in the response.

Reader's Scoring Rubric

Adaptive

Turn on needed systems/turn off those not needed; understanding of acute versus chronic response, above and beyond statements in the question.

Mechanism

- ___ Description of nerve pathway (sensory–associative–motor)
- ___ Sympathetic nervous system (autonomic) – activation
- ___ Sympathetic system innervates adrenal medulla
- ___ Inhibition of parasympathetic by sympathetic
- ___ Parasympathetic – counters sympathetic, return to normal homeostasis; acetylcholine = neurotransmitter
- ___ Epinephrine – adrenalin (cause and effect)
- ___ Norepinephrine – noradrenalin (cause and effect)
- ___ Source – adrenalin from adrenal medulla (gland)
- ___ Source – noradrenalin from adrenal medulla and/or sympathetic nerve endings
- ___ Receptor molecules on cell membranes
- ___ Use of cAMP (second messenger) to elicit intracellular response
- ___ Brief versus sustained – contrasted (initial = sympathetic versus long = adrenal)
- ___ Chemical structure of adrenalin/noradrenalin

Effect: Max. = 7 points

- ___ a. target tissues and effects (2 points)
- ___ b. pupillary muscles of eye – dilates pupils
- ___ c. inhibits salivation
- ___ d. bronchi of lungs – relaxes
- ___ e. increases respiratory rate
- ___ f. heart muscle – accelerates pulse, strengthens contraction
- ___ g. piloerection – muscles attached to hair follicles
- ___ h. liver – breaks down glycogen, stimulates release of glucose
- ___ i. digestive tract – decreases digestive activities – peristalsis
- ___ j. stomach, small intestine, pancreas – inhibits secretion of digestive enzymes
- ___ k. stimulates release of fatty acids from fat cells

__ l. peripheral circulation – vessels constrict
__ m. inhibit sex structures
__ n. relax bladder/bowels
__ o. decreased sensation of pain
__ p. "superhuman"

Question Topic: Biological Recognition
1992 Exam

Question

Biological recognition is important in many processes at the molecular, cellular, and organismal levels. Select three of the following, and for each of the three that you have chosen, explain how the process of recognition occurs and give an example.

a. Organisms recognize others as members of their own species.
b. Neurotransmitters are recognized in the synapse.
c. Antigens trigger antibody responses.
d. Nucleic acids are complementary.
e. Target cells respond to specific hormones.

Reader's Scoring Rubric

Standards*:*
Four points maximum for each of the following

a. *Organisms recognize others as members of their own species.*

- Definition (1 point)
- Importance of species recognition/definition of species/reproductive isolation prezygotic (3 points)
- Mechanisms (2 points)
- Visual/auditory/chemical/tactile/(multiple/ritual/behavioral)
- Recognition is innate or learned (imprinting) (1 point)
- Example (1 point)
  - __ Visual–birds, fruit flies
  - __ Auditory–birds, whales, frogs, insects
  - __ Chemical–moths, voles
  - __ Tactile–fruit flies, octopods
  - __ Multiple–albatross, butterflies, fruit flies, people, dove
  - __ Imprinting–ducks, goats

b. *Neurotransmitters are recognized in the synapse.*

- Definition (1 point)
  - ___ Neurotransmitter is a chemical messenger
  - ___ Synapse definition
- Mechanisms (1 point each)
  - ___ Neurotransmitter binds to receptor on postsynaptic membrane
  - ___ Receptor is a protein
- "Lock and Key" Concept (3 points)
  - ___ Enzymatic recognition and degradation of Neurotransmitter
  - ___ Reabsorption of Neurotransmitter by presynaptic membrane
  - ___ Presynaptic/Postsynaptic Events (1 point for any one)
- Stimulus (impulse, depolarization, signal, action potential) travels from presynaptic membrane (axon terminus, synaptic knob)
  - ___ Membrane channels opened (calcium channels, ion channels, calcium goes in)
  - ___ Neurotransmitter released from presynaptic neuron (synaptic vesicle)
  - ___ Neurotransmitter diffuses across synapse/synaptic cleft
  - ___ Neurotransmitter binding alters permeability
  - ___ Depolarizes and/or hyperpolarizes postsynaptic membrane (creates EPSP [excitatory postsynaptic potential]/creates IPSP [inhibitory postsynaptic potential])
  - ___ Change membrane potential (toward or away from threshold)
  - ___ Opening ion channels
  - ___ Alter metabolism inside postsynaptic cell (2nd messenger, cAMP)
  - ___ Reversible binding of Neurotransmitter
- Examples (1 point)
  - ___ Acetylcholine (ACh)—Synapse Types
  - ___ GABA—Acetylcholinesterase (AChE)
  - ___ Norepinephrine—Catecholamines, L-dopa
  - ___ Dopamine and Serotonin—Biogenic Amines
  - ___ Endorphins/Enkephalins—Neuropeptides

c. *Antigens trigger antibody response*

- Definitions (1 point for either)
  - ___ Antigen (Ag)—foreign substance/nonself

- ___ Antibody (Ab)—defensive protein produced in response to Ag—structure (two heavy and two light polypeptide chains)

- Processes (1 point for each)
  - ___ Selection of B cell highly specific
  - ___ B cell surface Ab binds Ag to activate B cell—plasma cell and memory cell clones
  - ___ Secondary response description
  - ___ Ag-Ab complex—amino acid sequence of light and heavy chains of hypervariable regions at N-terminus
  - ___ Specific site of Ag binding with Ab (Ab binding with Ag)
  - ___ Receptors on B cells and capping
  - ___ Free Ag with Ab
  - ___ T-cell dependent activation of B cells—Macrophage (Ag presenting cell) activates Interleukins to activate Helper T cells and B cells
  - ___ Generation of Ab diversity
  - ___ Examples of Antigens or Resultant Antibodies (1 point)

- IgG, IgM, IgA, IgD, IgE
  - ___ Bacterial cells, viruses, fungi, protozoa, allergens (pollen, dust, dander), grafts
  - ___ (HLA), Heterologous Ag (RBCs), Self Antigens

d. *Nucleic acids are complementary.*

- Definitions (1 point)
  - ___ DNA and RNA are nucleic acids
  - ___ Nucleic acids are polymers of nucleotides
  - ___ Nucleotide = sugar (deoxyribose and ribose), phosphate, nitrogenous base

- Mechanisms (1 point for each)
  - ___ A with T or U, C with G or Chargaff's Rules
  - ___ Pyrimidine with Purine or Single ring with Double ring
  - ___ 2 Hydrogen Bonds with A+T/U and 3 Hydrogen Bonds with G+C or H bonds
  - ___ Antiparallel orientation 5'---3'/3'---5'
  - ___ Template requirement or semiconservative replication mechanism
  - ___ Primers

__ DNA/RNA polymerase requirements
__ Elongation/Initiation Factors
__ Divalent Cations

- Examples (1 point)
  __ Replication of DNA (2 strands of dsDNA are complementary)
  __ Transcription of DNA into mRNA, tRNA, rRNA
  __ Translation - mRNA-tRNA (codon/anticodon complementarity)
  __ Hybridization - DNA-DNA/DNA-RNA/Probes

e. *Target cells respond to specific hormones.*

- Definition (1 point for each)
  __ Hormone—chemical messenger released to travel to cause specific biological response within organism, effective at low concentration
  __ Protein hormone/receptor at cell surface (doesn't get in)
  __ Steroid hormone/receptor inside cell (does get in)
  __ Recognition of hormone is to specific receptor (specific proteins)
  __ Protein hormone involves second messenger (cAMP, etc.)
  __ Steroid hormone affects transcription

- Examples (1 point each)
  __ Any hormone/target or effect (no pheromones, allomones, attractants)

Question Topic: Membranes
1993 Exam

Question

Membranes are important structural features of cells.

(a) Describe how membrane structure is related to the transport of materials across a membrane.
(b) Describe the role of membranes in the synthesis of ATP in either respiration or photosynthesis.

Reader's Scoring Rubric

Membranes serve diverse functions in eukaryotic and prokaryotic cells. One important role is to regulate the movement of materials into and out of cells. The phospholipid bilayer structure (fluid mosaic model) with specific membrane proteins accounts for the selective permeability of the membrane and passive and active transport

mechanisms. In addition, membranes in prokaryotes and in the mitochondria and chloroplasts of eukaryotes facilitate the synthesis of ATP through chemiosmosis.
Part A. (6 Maximum)

Membrane Structure (3 Internal Maximum)

- Phospholipid structure—hydrophilic, hydrophobic, amphipathic
- Phospholipid bilayer/fluid mosaic description
- Proteins embedded in the membrane
- Sterols embedded in the membrane
- Well-labeled diagram may replace one of the above.

Membrane Transport (3 Internal Maximum)

- Use of the term "selectively permeable," a good definition of selective permeability, or an explanation of the role of phospholipids or proteins, including nuclear pore proteins, in determining selective permeability.
- Description of the effect of size, charge, polarity, lipid solubility on membrane permeability.

Mechanisms + Description Related to Structure:

- Passive transport: diffusion/osmosis + reference to membrane gradient
- Ion channel: transport as a mechanism for a change in permeability
- Facilitated diffusion: description (symport, antiport, uniport)
- Active transport: description
- Exocytosis, endocytosis, phagocytosis, pinocytosis: description

(1 additional point) A good example of one of the above mechanisms

PART B. Role of the Membrane in the Production of ATP in Photosynthesis or Respiration (6 Maximum)

Chemiosmosis:

- Involved molecules are embedded in the membrane.
- Electron carriers are sequentially organized.
- The energy comes from the flow of electrons.
- H+ / Proton / pH gradient established

__ Movement through the membrane generates ATP.

__ A specific protein makes ATP.

RESPIRATION or PHOTOSYNTHESIS

- ___ Site is the mitochondrion
- ___ Inner mitochondrial membrane (cristae) are involved in ejkaryotes
- ___ Folded membrane present
- ___ Cell membrane is involved in membranes prokaryotes
- ___ Correct direction of H+ flow

- ___ Site is the chloroplast
- ___ Thylakoid/grana are involved in eukaryotes
- ___ Folded membrane present
- ___ Thylakoid/grana involved in prokaryotes
- ___ Correct direction of H+ flow

Question Topic: Cellular Communication
1999 Exam

Question

Communication occurs among the cells in a multicellular organism. Choose THREE of the following examples of cell-to-cell communication, and for each example, describe the communication that occurs and the types of responses that result from this communication.

- Communication between two plant cells
- Communication between two immune-system cells
- Communication **either** between a neuron and another neuron **or** between a neuron and a muscle cell
- Communication between a specific endocrine-gland cell and its target cell

Reader's Scoring Rubric

Overview of point distribution:
Communication between two plant cells (Max. = 4 points)

- Source (Max. = 1 point)
  - ___ Hormone-producing cell (generic)
  - ___ Plasmodesmata (elab. pt. for good description)
- Signal (Max. = 1 point)
  - ___ A specific plant hormone
- Responses/Elab. (Max. = 2 points)
  - ___ Various physiological changes
  - ___ Ion movement; H_20 movement; RNA movement

Communication between two immune system cells (Max. = 4 points)

- Source (Max. = 1 point)
  - ___ Any two immune system cells interacting or
  - ___ An immune system cell interacting with the product of another immune system cell
- Signal (Max. = 1 point)
  - ___ Tc/APC docking
  - ___ Antibody
  - ___ Histamine
  - ___ Interferon
- Responses/Elaboration (Max. = 2 points)
  - ___ Discharge of perform; phagocytosis of pathogen; inflammatory response; phagocyte activation; Ab secretion; clonal selection

Communication between two neurons or between a neuron and a muscle cell (*Max. = 4 points*)

- Source (Max. = 1 point)
  - ___ Sending neuron
- Signal (Max. = 1 point)
  - ___ Neurotransmitter
- Responses/Elaboration (Max. = 2 points)
  - ___ Neuron-neuron: Chemical gating; depolarization of postsynaptic membrane; EPSP, IPSP, or both
  - ___ Neuron-muscle: Action potential to T tubules; Ca ++ release from sarcoplasmic reticulum; Ca ++ binding to troponin; cross-bridge formation

Communication between a specific endocrine-gland cell and its target cell (Max. = 4 points)

- Source (Max. = 1 point)
  - ___ Specific gland (elaboration point for peptide vs. steroid hormone pathways)
- Signal (Max. = 1 point)
  - ___ Specific hormone
- Responses/Elaboration (Max. = 2 points)
  - ___ Specific effect

Question Topic: Proteins
2001 Exam

Question

Proteins—large complex molecules—are major building blocks of all living organisms. Discuss the following in relation to proteins.

a. The chemical composition and levels of structure of proteins
b. The roles of DNA and RNA in protein synthesis
c. The roles of proteins in membrane structure and transport of molecules across the membrane

Reader's Scoring Rubric

a. *Chemical composition (Max. = 2 points)*

__ Amino acids are the basic building blocks of proteins (Max. = 1 point)
__ Amino acids contain amino, carboxyl, and R groups or correct structural formula showing amino, carboxyl, and R group attached to central carbon or proteins are composed of carbon, hydrogen, oxygen, and nitrogen (Max. = 1 point)
__ R group determines the identity/properties of the amino acid (Max. = 1 point)

Elaboration (Max. = 1 point)

- Describe addition of lipids, carbohydrates, and/or prosthetic group

Levels of structure (Max. = 3 points)
(Note: To obtain any points, response must name level or list in correct order.)

Primary structure (Max. = 1 point)

- sequence (chain, string) of amino acids or the number and order of amino acids
- amino acids linked by peptide bonds
- amino acids bonded through dehydration synthesis

Secondary structure (Max. = 1 point)

- helix and/or pleated sheet
- hydrogen bonds (between carboxyl and amino groups)

Tertiary structure (Max. = 1 point)

- single polypeptide chain forms globular shape
- hydrogen, ionic, disulfide, and van der Waals bonds, and/or hydrophobic interactions (if hydrogen must have more than one)
- interaction between R groups

Quaternary structure (Max. = 1 point)

- more than one polypeptide or subunit
- hydrogen, ionic, disulfide, and van der Waals bonds, and/or hydrophobic interactions (if hydrogen must have more than one)
- interaction between R groups

Elaboration (Max. = 1 point)

- explanation of domains
- explanation of chaperones

(b) *Global understanding of information flow (Max. = 1 point)*

__ Information in DNA is transcribed to mRNA, which is translated into protein.
__ DNA contains the information that ultimately determines the sequence of amino acids in the protein.

Roles

DNA (Max. = 1 point)

- codes for RNA, mRNA, tRNA, or rRNA

mRNA (Max. = 1 point)

- codes for amino acid sequence

tRNA (Max. = 1 point)

- brings the correct amino acid to the ribosome/mRNA
- contains anticodon complementary to codon

rRNA (Max. = 1 point)

- forms part of ribosome

Elaboration (Max. = 1 point)

- intron removal by RNA/snRNP/snRNA
- alternative splicing provides protein diversity
- acts as ribozyme/involved in formation of peptide bond
- rRNA finds and binds start AUG of mRNA (in prokaryotes)

(c) *Role in membrane structure (Max. = 2 points)*

__ Description of integral and/or peripheral proteins
__ Membrane synthesis
__ Defines membrane sidedness

Membrane function other than transport (Max. = 1 point)

- Receptors
- Enzymes
- Cell-to-cell communication
- Anchoring of cytoskeleton or extracellular matrix
- Spatial configuration of reaction pathways (e.g., electron transport system)
- Cell recognition
- Cell junctions

Role in transport (Max. = 3 points)

- transport proteins may be specific
- process may require direct input of energy (e.g., use of ATP)
- description of transport mechanisms (bind molecule, conformational change, release molecule) or description of how proteins form channels and move molecules through them

Elaboration (Max. = 1 point)

- description of a specific transport system (e.g., ATP synthase, Na~/K~ pump, receptor-mediated endocytosis)
- description of chemiosmosis
- more than one molecule transported (e.g., symport, antiport)
- may be regulated by electrical or chemical stimuli (gated channels)

Question Topic: Immune Systems
2005 Exam

Question

An important defense against diseases in vertebrate animals is the ability to eliminate, inactivate, or destroy foreign substances and organisms.

Explain how the immune system achieves THREE of the following:

- Provides an immediate nonspecific immune response
- Activates T and B cells in response to an infection
- Responds to a later exposure to the same infectious agent
- Distinguishes self from nonself

Reader's Scoring Rubric

NOTE: One point is awarded for each bulleted item; maximum of 4 points for each section.

Provides an immediate nonspecific immune response (Max. = 4 points)

- Physical barrier (e.g., skin or mucous membranes [or blood clot]) with explanation that barrier prevents pathogens and parasites from entering the body. Resident microflora prevents pathogen attachment. Saliva, mucus, or tears wash away harmful entities; also, vomiting/diarrhea purge harmful agents.
- Chemical barriers (low pH, salt, fatty acids of skin inhibit microbial growth, antimicrobial agents [e.g., lysozyme kills bacteria by digesting bacterial wall]).
- Inflammatory response: Blood vessels dilate (precapillary arterioles dilate and postcapillary venules constrict), producing redness, edema, heat (fever), pain, and leading to an increase in white blood cells and clotting factors.
- Chemical agents:
  i. Interferons from cells infected with viruses stimulate nearby cells to produce chemicals that inhibit viral reproduction, OR chemokines activate monocytes to develop into macrophages.
  ii. Histamines cause increase in permeability of capillaries with an increased blood flow that results in more clotting and more white blood cells, OR histamines secreted by mast cells, OR prostaglandins increase blood flow.

iii. Pyrogens induce fever that inhibits pathogen.

- Phagocytosis: ingestion by white blood cells (e.g., neutrophils, macrophages, or monocytes)
- Lysis of cells: Eosinophils or natural killer cells
- Complement system: leads to the lysis of microbes, or aids in recruitment of white blood cells
- Elaboration of any one of the above (e.g., a second physical or chemical barrier)

Activates T and B cells in response to an infection (primary immune response) (Max. = 4 points)

- Macrophages/white blood cells engulf and/or display antigens (may say: epitope) from infection.
- Antigen-presenting cell binds helper T cells to activate or stimulate helper T cells.
- Antigen-presenting cell activates or stimulates cytotoxic T cells.
- Antigen binding to B cell activates B cell.
- Helper T cell activates/stimulates B cell and/or cytotoxic T cell.
- Interleukin—1 (from macrophages) activates helper T cells.
- Interleukin—2 and/or cytokines (from helper T cells) activate B cells or cytotoxic T cells.
- CD4 on helper T cell enhances binding of helper T with antigen-presenting cell; leads to activated T cells.
- CD8 on cytotoxic T cell enhances binding and enhances activation of cytotoxic T cell.
- Elaboration point for explaining one of the following:
  i. MHC in primary immune response.
  ii. B (or plasma) cells produce/secrete antibody.
  iii. Cytotoxic T cells destroy infected cells.
  iv. Antibody mechanism of action (i.e., neutralization/agglutination/precipitation).

Responds to a later exposure to the same infectious agent (secondary immune response) (Max. = 4 points)

- Mediated by memory cells (T and/or B).
- Memory cells are specific for the same antigen encountered previously.

- Memory cells receptors/antibodies have greater affinity for the antigen.
- Production of antibodies/response is faster and/or to a greater extent.
- Origin of memory cells:
  i. Helper T cell —* Memory Helper T —~ Memory B and T cells
  ii. Activated B cell —* Memory B cell
  iii. Activated Cytotoxic T cell —> Memory T cell
- Role of major histocompatibility complex (MHC), cytokines, IL-I, or IL-2 as related to secondary immune response.
- Memory cells are more numerous (or antibody concentration is higher).
- Memory cells are long lived.
- Elaboration of why measles, mumps, or chicken pox do not recur (vaccines), or common cold/flu do recur.

Distinguishes self from nonself (Max. = 4 points)

- All cells have unique ID tags (flags, markers, proteins, glycoproteins, MHC, etc.).
- Origin of self-markers of MHC by multiple alleles (polymorphic antigen receptors).
- Developmental selection in bone marrow and/or thymus where antigen receptors are tested (self-antigen receptors are eliminated, or inactivated/ clonal selection).
- Mechanism of recognition (binding elicits immune response).
- Illustrate self/nonself incompatibilities (e.g., autoimmune disease such as MS, transplant incompatibility, blood types, and pathogens mimicking MHC molecules, or cloaking with host cell membrane).
- Elaboration of:
  i. MHC (or human leukocyte antigens)
  ii. Distinguish between MHC I and II (e.g., MHC I—all nucleated cells; MHC JI—dendritic cells, macrophages, B cells).

Question Topic: Relationship of Structure to Function
2006 Exam

Question

The relationship of structure to function is one of the major themes in biology. For three of the following structure/function pairs, describe the structure and then explain how the function is related to the structure.

a. Enzyme structure/catalysis
b. mRNA structure/protein synthesis
c. Cell membrane structure/signal transduction
d. Membrane protein structure/active transport or facilitated diffusion

Reader's Scoring Rubric

The relationship of structure to function is one of the major themes in biology. For three of the following structure/function pairs, describe the structure and then explain how the function is related to the structure.

a. *Enzyme structure/catalysis (Max. = 4 points)*

   Description (2 points)

   - 3-D shape that results from folding of polypeptide chains
   - Folding produces a pocket in which substrate may bind
   - Levels of protein structure (primary, secondary, tertiary)

   Explanation (2 points)

   - Complementary 3-D shape of enzyme and substrate are required for proper interaction and catalysis in active site—reduction of activation energy; induced fit
   - Allosteric modulation, effect of pH, temperature (or other environmental factors) on enzyme shape
   - Elaboration points: competitive/noncompetitive inhibition—effect on enzyme action; amino acid side groups in active site interact with substrate to stress bonds in substrate and reduce activation energy of reaction

b. *mRNA structure/protein synthesis (Max. = 4 points)*

   Description (2 points)

   - Linear sequence of RNA nucleotides
   - Details: 5 cap; poly-A tail; introns

- Description of origin and/or fate of mRNA (transcription, processing, and translation)
- Fine details of RNA nucleotide structure

Explanation (2 points)

- The linear sequence of RNA nucleotides, read as codons (three at a time; contiguous; nonoverlapping)
- specify the sequence of amino acids incorporated in a new protein being constructed at a ribosome
- start codon and/or stop codon roles

c. *Cell membrane structure/signal transduction (Max. = 4 points)*

Description (2 points)

- A phospholipid bilayer that incorporates malleable (and, often, mobile) integral or membrane-associated proteins
- Membrane-embedded receptor molecules with transmembrane domains

Explanation (2 points)

- Receptor proteins undergo shape changes when proper stimulus is present—signal is communicated through membrane by allosteric shape change.
- The altered proteins may then influence other cellular events or states: activation of G-proteins and/or tyrosine-kinase receptor protein auto- and heterophosphorylations leading to cellular response.

Question Topic: Membranes
2007 Exam

Question

Membranes are essential components of all cells.

a. Identify THREE macromolecules that are components of the plasma membrane in a eukaryotic cell and discuss the structure and function of each.

b. Explain how membranes participate in THREE of the following biological processes:

- Muscle contraction
- Fertilization of an egg

- Chemiosmotic production of ATP
- Intercellular signaling

Reader's Scoring Rubric

Membranes are essential components of all cells.

a. *Identify THREE macromolecules that are components of the plasma membrane in a eukaryotic cell and discuss the structure and function of each. (Max. = 6 points; 1 point for each macromolecule + structure, 1 point for each macromolecule + function)*

NOTE: Only the first three molecules mentioned will be scored.

Macromolecule	Structure	Function (must match selected macromolecule)
Phospholipids OR Lipid with phosphate	• Glycerol, two fatty acids, and polar head group w/ phosphate • Amphipathic • Hydrophilic or polar (head) and hydrophobic or nonpolar (tails) • Forms a lipid bilayer	• Selectively permeable • Fluidity • Creates compartment! separates cell from environment; barrier • Signals, inositol pathway (1P3) diacylglycerol (IJAG)
Cholesterol	• Ring structure • Steroid • Amphipathic • Embedded in bilayer	• Moderates fluidity • Stabilizes membrane
Proteins Integral Peripheral Pump Receptor Transport Recognition Tight junction Desmosomes Gap junctions Integrins Enzyme Channel	General Structure • Polypeptides; amino acids • 2°, 30, 40 structure description Specific Structure • Integral, transmembrane, embedded; forms a channel • Peripheral, on surface • Structure fit to substrate or ligand	• Transport • Enzyme, catalysis • Signal transduction • Attachment: extracellular matrix (ECM)—cytoskeleton • Recognition • Cell junction
Glycolipid—Glycoprotein	• Carbohydrate (chains) linked to lipid protein	• Cell recognition • Attachment to external molecule or another cell

b. *Explain how membranes participate in THREE of the following biological processes: (Max. = 6 points; 2 points per section)*

Muscle contraction

- Motor neuron or axon terminal releases neurotransmitter or acetylcholine (ACh).
- ACh binds to receptors

Depolarization, or Na + moves in through membrane channels, or membrane depolarizes

- Action potential propagates along cell membrane (sarcolemma) or T tubules
- Depolarization changes permeability of sarcoplasmic reticulum (SR) or $Ca^{2\sim}$ released from SR
- Ca^{2+} active transport into SR (reuptake of $Ca^{2}\sim$)
- Repolarization or maintenance of membrane potential (Na ~/K + pump)
- Smooth or cardiac muscle gap functions directly transfer membrane potential between cells

Fertilization of an egg

- Part of the acrosomal reaction or sperm acrosome releases hydrolytic enzymes (by exocytosis)
- Sperm binds to receptors on egg
- Fusion of sperm and egg plasma membranes
- Change in membrane electrical charge or fast block (depolarization) to prevent further fertilization (polyspermy)
- Cortical reaction or slow block by exocytosis (prevents polyspermy) or "hardening" of membrane
- Separation of fertilization membrane (envelope)
- Fusion of egg and sperm nuclear membranes or nuclei

Chemiosmotic production of ATP

- Electron transport chain (ETC) in membrane pumps H + across membrane
- H + gradient established across membrane
- H + move through ATP synthase embedded in membrane to produce ATP
- Membrane infolding increases surface area

Intercellular signaling

- Release of chemical signals by exocytosis
- Receptors in membrane bind ligands or chemical signals or chemical signals pass through the membrane (examples: neurotransmitters, hormones, pheromones)
- Ligand-gated ion channels opening/closing
- Cascade of cellular events, including enzymatic reactions and second messengers (examples: G-proteins, cAMP, IP_3, Ca^{2+})
- Antibodies activate immune function
- Descriptions of gap junctions, plasmodesmata (communicating junctions)

Question Topic: Immune Systems
2007 Exam

Question

The defenses of the human body to the entry and establishment of a pathogen (disease-causing organism) can be divided into nonspecific responses and specific responses.

a. Explain how three types of nonspecific defenses can prevent the entry and/or establishment of a pathogen in a person's body.
b. Discuss how the immune system responds to an initial pathogenic exposure, and how this initial exposure can lead to a quicker response following a second exposure to the same pathogen.
c. Explain the biological mechanisms that lead to the rejection of transplanted organs.

Reader's Scoring Rubric

The defenses of the human body to the entry and establishment of a pathogen (disease-causing organism) can be divided into nonspecific responses and specific responses.

a. *Explain how three types of nonspecific defenses can prevent the entry and/or establishment of a pathogen in a person's body.*

One point for each of the following explanations/identifications:

__ Barrier (skin)
__ Traps (mucous membranes, cilia, hair, ear wax)

__ Phagocytosis (white blood cells)
__ Elimination (coughing, sneezing, urination)
__ Unfavorable pH (stomach acid, sweat, saliva, urine)
__ Unfavorable environment (normal flora, fatty acids, enzymes)
__ Cell destruction (complement, natural killer cells)
__ Interference with viral replication (interferon)
__ Lysozyme action (tears, sweat)
__ Inflammatory response (increase in body temperature, capillary permeability, attraction of macrophages, histamine release, vasodilation)

b. *Discuss how the immune system responds to an initial pathogenic exposure, and how this initial exposure can lead to a quicker response following a second exposure to the same pathogen.*

One point for each of the following explanations/identifications:
__ APCs (macrophages, dendritic cells, B cells) present antigen
__ B cells/plasma cells produce/secrete antibodies
__ Helper T cells activate B cells, cytotoxic T cells, and/or macrophages
__ Cytotoxic T cells cause cell death (apoptosis)
__ Ag presented on MI-IC
__ Explanation of how antibodies destroy the pathogen
__ Secretion of cytokines (or interleukins) to signal or activate
__ Memory cells produced in primary response speed up secondary response

c. *Explain the biological mechanisms that lead to the rejection of transplanted organs.*

One point for each of the following explanations/identifications:

__ Cell-mediated response or explanation of cytotoxic T, CD8, killer T cells, or natural killer cells
__ Concept of nonself (foreign) or MHC incompatibility
__ Explanation of the role of cell death or apoptosis or cell lysis

Note: To obtain a score of 10, the student must earn the memory cell point in part b.

Additional Web Resources

Compiled by Carolyn Schofield Bronston

http://bama.ua.edu/~hsmithso/class/bsc_495/signal/signal_web.html: A listing of many cell signaling links, including most of these below.

http://www.signaling-gateway.org/: From the Nature Publishing Group, the Signaling Gateway links to the most recent articles about new signaling findings.

http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/C/CellSignaling.html: From John W. Kimball's online biology textbook, a short introduction to cell signaling.

http://www.biology.arizona.edu/Cell_BIO/problem_sets/signaling/Index.html: From the University of Arizona, a 12-part Cell Signaling Problem Set that covers basic signaling topics with multiple-choice questions and tutorials for students needing more information.

http://www.celanphy.science.ru.nl/Bruce%20web/Flash%20Movies.htm: Twenty-one different animated overviews of cell signaling, from G proteins to cAMP to the effects of toxins on some systems.

http://mama.uchsc.edu/vc/cancer/signal/p3.cfm: Animation from the Biology of Cancer site, which shows how cell divison could be activated.

http://cgmp.blauplanet.com/transd.html: Several animations on general signal transduction.

http://student.ccbcmd.edu/courses/bio141/lecguide/unit4/innate/lpssignal_flash.html: Animation on signaling that produces proinflammatory cytokines.

http://dkc.jhu.edu/~teal/gprotein.html: Two animations showing complex signaling cascades.

http://entochem.tamu.edu/G-Protein/index.html: Texas A&M Protein Hormone Signal Transduction with sound effects.

http://www.grossmont.edu/cmilgrim/Bio220/Outline/ECB2Animations/16.3-cAMP_signaling.mov: QuickTime movie about adenyl cyclase that shows signaling pathway.

http://edissertations.library.swmed.edu/pdf/WableL123004/maps/calcium7.html: Web site on calcium signaling, showing various cell organelles that play a part.

http://www.learner.org/channel/courses/biology/archive/animations/hires/a_cancer1_h.html: Signal transduction video that uses falling dominos to illustrate the multiplicative effect of signal cascades.

http://www.bio.davidson.edu/courses/Immunology/Flash/MAPK.html: Kinase signal transduction with sound effects showing pinball animation and final mRNA transcription.

http://student.ccbcmd.edu/courses/bio141/lecguide/unit4/innate/lpssignal_flash.html: Great "movie" from Dolan DNA Learning Center (Cold Spring Harbor) showing the complex signaling that occurs after an injury. The site takes a tour into a cell and has beautiful graphics.

http://www.cellsignallingbiology.org/: Source for a few excellent PowerPoint slide frames that outline the idea of cell signaling.

http://www.accessexcellence.org/RC/VL/GG/ecb/forms_of_cell_signaling.html: From Access Excellence, a slide showing the four major types of signaling.

http://employees.csbsju.edu/hjakubowski/classes/ch331/signaltrans/olsignalkinases.html: Slide showing five major protein kinases.

http://www.sigmaaldrich.com/Area_of_Interest/Life_Science/PathFinder.html

http://www.genscript.com/phospho_specific_antibody.html?src=google&gclid=CKTaw421yZACFRcdsgodaAIWYA

http://www.cellsignal.com/; http://www.biocarta.com/genes/CellSignaling.asp: Companies selling research materials (Sigma, GenScript, Cell Signaling Technology, and BioCarta) show diagrams of complicated signal transduction pathways.

About the Editor

Julia Kay Christensen Eichman taught high school advanced and AP Biology for 20 years and has been active in AP workshop presentations and AP Biology Exam Readings. Presently she is a student at the University of Arkansas, where she is pursuing a Ph.D., and an adjunct faculty member at Missouri Southern State University.

About the Authors

Elizabeth A. Cowles did two postdoctoral stints. The first was in the entomology department at the University of California, Riverside (1990–1994), where she isolated and characterized the Bacillus thuringiensis (Bt) toxin receptors from insect midguts. The second was in the orthopedic surgery department at the University of Connecticut Health Center, where she researched integrin function and signaling in bone cells (1994–1997).

Liz has been at Eastern Connecticut State University since 1997. She teaches freshman biology, entomology, and biochemistry. She is an AP Biology consultant and has done workshops around New England and at Rice University. Liz has been an AP Biology Reader, Table Leader, and Question Leader for the AP Biology Exam.

Carolyn Schofield Bronston has taught at Memorial High School in Spring Branch, Texas, and Robert E. Lee High School in Tyler, Texas. Traveling as a consultant for the College Board since 1979, she also reads the AP Exam each June, authored the *Teacher's Guide – AP Biology*, created the AP Teacher's Corner, is a member of the Biology Development Committee, and serves as the College Board's AP Biology Advisor. She is a winner of the Presidential Award for Excellence, the Outstanding Biology Teacher Award (OBTA) for Texas, the Tandy Award, and the Texas Excellence Award.


F08BISF129