2023 Nov P3 answers

Question 1

Mitosis is a key process in the development of a fertlised egg into an adult human. Each mitotic cell division is preceded by DNA replication.

(a)

(i) Explain the significance of mitosis in the development of a fertilised egg into an adult human. [3]

1. mitosis results in increase in number of cells which is essential for biological processes like tissue growth in a multicellular organism;
2. and replacement of cells for tissue repair;
3. mitosis produces 2 genetically identical diploid daughter nuclei, each of which has the same number and same type of chromosomes (2 sets/homologous chromosomes) thereby contributing to genetic stability in all cells of the adult human;

(ii) Name one environmental factor and one lifestyle factor that are associated with increasing the risk of mutations that lead to cancer. [2]

environmental factor: exposure to ultraviolet light / ionising radiation / radioactivity
lifestyle factor: smoking and exposure to carcinogens such as tar in cigarette smoke

(iii) Explain how random errors that occur during the process of DNA replication can result in different types of changes to DNA sequences. [4]

1. Mistakes can occur during the synthesis of new daughter strand catalysed by ***DNA polymerase****, during DNA replication;
   OR
   Mistakes made during DNA replication could have escaped proofreading by DNA polymerase during DNA replication, A: DNA repair enzymes also not correct the mistake.
2. ***Substitution**** mutation where a nucleotide/base is replaced by a different nucleotide;
3. ***Inversion**** – a segment of nucleotide sequences separates from the allele and rejoins at the original position but it is inverted;
4. The length of DNA is unchanged but the sequence will be different;

5. ***Insertion /addition**** – occurs when one or several nucleotides are *inserted* in a sequence
6. ***Deletion**** – occurs when one or several nucleotides are removed from a sequence of base(s)
7. Resulting in a change in both length and sequence of the DNA;

Pt 4 with 2 or 3; Pt 7 with 5 or 6
Must have point 4 or 7 to get full marks.

(iv) Suggest why it is important for doctors to be able to distinguish passenger mutations from driver mutations. [2]

1. passenger mutations do not result any change in the function of the cell and hence are not linked to the development of cancer so doctors will not need to prescribe drugs;
2. driver mutations result in the benign tumour formation and subsequently invasive cancer resulting in uncontrolled cell division and cancer development;
3. Doctors need to distinguish the two in order to make an accurate diagnosis/ suggest appropriate treatment if driver mutations are discovered in patients;

(v) State the name given to the type of mutation in cancer development that results in a dominant driver mutation. [1]

Gain-in-function mutation*

(vi) State the name given to the type of gene that, when mutated, contributes to cancer development as a dominant driver mutation. [1]

proto-oncogene*

(vii) Use Fig. 1.1 to calculate the annual mutation rate (number of mutations per year) in this cell lineage during two periods of time:

Annual mutation rate from formation of the zygote at conception to the start of adulthood = 5 mutations / 21.75 years = **0.23**

21.75 years to include the *gestation period which is the period from formation of the zygote at conception to the start of adulthood*

Annual mutation rate from formation of the zygote at conception to the start of adulthood = ……0.23…. $year^{-1}$

Annual mutation rate from first development of the benign tumour to chemotherapy-resistant recurrence = (18-8)/(70-67) = **3.3**

Annual mutation rate from first development of the benign tumour to chemotherapy-resistant recurrence = ……3.3…. $year^{-1}$

(viii) Within a struggle for existence with surrounding cells, discuss whether the cell lineage that has the mutator phenotype **and** the mutation shown as a black triangle has a selective advantage compared to cell lineages without these features. [5]

1. The cell lineage with both mutator phenotype and black triangle mutation will have a selective advantage;

Mutator phenotype has an increased rate of mutation

2. The mutator phenotype has an increased rate of mutation which resulted in all three types of mutations, passenger, driver, and chemotherapy resistance mutations;
3. Mutator phenotype will also result in a higher rate of mutation giving rise to greater variation;
4. And higher chance of forming favourable alleles/phenotypes for the cell e.g. faster growth, ability to gain resources;

Black triangle represents chemotherapy resistance mutation

5. When exposed to chemotherapy, the cell is able to survive and continue to divide while other cells without this mutation will die;

(b) With reference to Table 1.1, explain how suitable each patient is as a candidate for treatment with 5-fluorouracil. [3]

A: suitable. 5-fluorouracil kills cancer cells who are actively dividing. The absence of mutation in DPYD in normal cells allows for breakdown of 5-fluorouracil in normal cells so it will not accumulate to toxic levels to kill normal cells.
B: not suitable. The mutation in DPYD mutation is present in both normal cells and tumour cells. While this allows for accumulation of 5-fluorouracil to kill cells, both normal cells and cancer cells will be killed.
C: suitable. The mutation in DPYD in cancer cells allow for accumulation of 5-fluorouracil, allowing for more effective killing of cancer cells. At the same time, DPYD is not mutated in normal cells so 5-fluorouracil can be broken down and normal cells are not killed.

(c) (i) Identify **two** types of biomolecule in food that a person may eat from 12 to 6 hours before the scan. [1]

proteins and fats

(i) Suggest why people should **not** eat carbohydrates for 12 hours before the scan. [2]

1. Carbohydrates would be broken down into glucose in the digestive system and taken up into the bloodstream;
2. The presence of glucose in the bloodstream could lead to cancer cells taking up glucose instead of FDG, preventing the building of FDG in cancer cells;

(ii) Table 1.2 compares ATP production in mammalian muscle cells at different stages of the respiration of glucose under aerobic conditions and under anaerobic conditions.

Table 1.2

stage of respiration	ATP production	
	aerobic conditions	anaerobic conditions
glucose → pyruvate	✓	✓
pyruvate → lactate	✗	✗
pyruvate → acetate (acetyl)	✗	✗
acetate → CO_2 + H_2O	✓	✗

(iii) Use Table 1.3 to explain why cancer cells use significantly more glucose than normal cells. [4]

1. Mutation in AKT increases number of glucose transporters, resulting in an increased uptake of glucose into cancer cells;
2. Mutation in AKT also stimulates the activity of enzyme that phosphorylates glucose, committing glucose to the glycolytic pathway;
3. Mutations in MYC and ras activates directly and indirectly the expression of genes coding for glycolysis enzymes, increasing the concentration of enzymes and the rate of glycolysis;
4. Mutation in ras inhibits the action of pyruvate dehydrogenase, preventing the conversion of pyruvate to acetyl-coA;
5. p53 prevents the expression of gene coding for final electron transport protein, preventing the transport of electrons down the electron transport chain and the generation of a proton gradient / proton motive force;
6. Link reaction, Krebs cycle and oxidative phosphorylation which produce the bulk of ATP in aerobic respiration is unable to happen, hence glycolysis occurs at a faster rate to meet the ATP demands of the cancer cell;

[Total: 32]

Question 2

(a) (i) Compare the biochemical composition of the outer structure of a bacteriophage and the outer structure of the host cell. [2]

1. The outer structure of a bacteriophage is the capsid which is made up of a protein coat that encloses the viral genome
2. The outer structure of bacteria, the host of bacteriophage, is the cell wall, which is mainly composed of peptidoglycan, a polymer consisting of sugars and amino acids. It provides structural support and rigidity.

(ii) Compare the structure and organization of genetic material of a bacteriophage and the host cell. [2]

1. Bacteriophages can have either DNA or RNA genomes, while bacteria have only DNA.
2. Bacteriophage genomes can be linear or circular, and their DNA or RNA may be single- or double-stranded. Bacterial genomes are typically circular and double-stranded.
3. Phage genetic material is packaged within the capsid. In bacteria, DNA is organized in the nucleoid region and can be further associated with various proteins but is not enclosed in a membrane-bound compartment.
4. Phage genome is small with no other extrachromosomal structures but bacteria has plasmids, which are extrachromosomal

(b) After infecting a host cell, the bacteriophages shown in Fig. 2.1 cause the host cell to break open (lysis). The antibiotic penicillin can cause lysis of this type of host cell.

Outline how the antibiotic penicillin can cause lysis of this type of host cell. [3]

1. During growth of bacteria, the bacterium remodels the peptidoglycan cell wall by breaking down the cross-links between peptidoglycan chains. An enzyme, ***transpeptidase**** reforms the cross-links between new peptidoglycan chains and existing peptidoglycan chains.
2. Penicillin acts as a ***competitive inhibitor**** and binds to the active site of transpeptidase
3. As a result, there is inhibition to the formation of cross-links between adjacent chains.
4. Bacterial cell wall becomes weakened. When bacteria takes in water by osmosis, the increased turgor pressure against the weakened cell wall causes the bacteria to swell and lyse.

(c)(i) Suggest **one** reason why there is increased interest in finding alternative treatments for bacterial infections. [1]

Any one:

- Rise in antibiotic resistant bacteria as many bacteria have mechanisms to evade the effects of commonly used antibiotics.
- Bacteriophages can specifically infect and kill bacteria. They can be tailored to target specific bacterial strains, potentially minimising damage to beneficial bacteria and reducing side effects compared to broad-spectrum antibiotics.
- Phages are generally considered to be safe for humans because they are highly specific to bacteria and do not infect human cells.

(i) Describe **two** possible disadvantages of using phagotherapy to treat bacterial infections. [2]

1. Phages are highly specific to their bacterial hosts. This specificity means that phages designed to target one strain of bacteria may not be effective against other strains or different species of bacteria. This can be a limitation if the bacterial infection is caused by multiple strains or species.
2. Potential for Immune Response and Side Effects: The human immune system can recognize and attack phages as foreign invaders. This immune response can reduce the efficacy of phage therapy by neutralizing the phages before they have a chance to act on the bacteria

[Total: 10]

Question 3

(a) Outline how scientists could obtain and analyse the data needed to deduce Fig. 3.2. [3]

1. Obtain fresh plant specimen from all the populations of the species and extract mitochondrial DNA.

(FYI: Mitochondrial DNA has faster mutation rate compared to nuclear DNA and hence it is useful for comparing individuals within a species that are closely related.)

2. Obtain the DNA sequence of a ***homologous**** gene on the mitochondrial DNA.
3. Quantify the number of differences in the nucleotides (of the gene) between the populations.
4. The more closely related the populations, the smaller the numerical genetic difference.

(b) Suggest how the history of the Criollo population could account for the lower yield compared to all of the other wild populations. [2]

1. Deliberately crossing genetically similar trees with better-tasting beans is a form of artificial selection.
2. Unmasking deleterious recessive alleles that are expressed in the homozygous condition results in reduced growth, whereas the wild populations remain genetically diverse and deleterious alleles remain hidden in the diploid state.

(c) Suggest how knowledge of the genetic diversity and evolutionary history of *T. cacao* could be useful in the future. [3]

1. Future challenges could be related to climate change with more extreme temperatures and flood or drought conditions.
2. For populations to survive better in extreme conditions, interbreed a population with one that is genetically different to introduce new alleles into the population that could result in favourable phenotypes
3. Knowledge of the mechanism and rate of evolutionary change of the different populations to climate change can allow prediction of adaptability of the population to future changes or improves mitigation strategies to protect the species.

[Total: 8]

Section B

4 (a) Compare the normal functions of totipotent, pluripotent and multipotent human stem cells. [13]

Similarities:

1. Stem cells are a group of ***undifferentiated* and unspecialized* cells***;
2. They have the ability to ***differentiate**** into specialized cells when appropriate molecular signals are present;
3. Stem cells are capable of ***self renewal**** to ensure a constant pool of stem cells with the same development potential;
4. Stem cells divide by ***mitosis**** to produce genetically identical daughter cells ;

Differences:

Point of comparison	**Totipotent stem cells**	**Pluripotent stem cells**	**Multipotent stem cells**
Examples	1a. ***Zygotic stem cells**** are totipotent;	1b. ***Embryonic stem cells**** are pluripotent;	1c. ***Blood stem cells (myeloid and lymphoid stem cells)**** are multipotent;
Differentiation potential	2a. They have ability to ***differentiate**** **into all cell types** that make up an organism **including *extra-embryonic tissue**** such as ***placenta****, which nourishes embryo;	2b. They have ability to ***differentiate**** **into all cell types** that make up an organism **except *extraembryonic tissue**** such as ***placenta****;	2c. They are adult stem cells which have the ability to ***differentiate**** **into limited range of related cell types** - all type of blood cells - but far **fewer types** than the pluripotent embryonic stem cell;
Functions	3a. They are able to form entire organism;	3b. They **cannot form entire organism** as extraembryonic tissues such as placenta is required for foetal nourishment and development;	3b. They also **cannot form entire organism** but they replace cells that are lost due to wear and tear, or cell death and injury, e.g. myeloid stem cells differentiate to form red blood cells and macrophages, while lymphoid

			stem cells differentiate to form B lymphocyte and T lymphocyte
Examples and sources	4a. They are derived from a fertilised egg which forms the zygote. Cells that are **produced within first 3 division (*8 cell stage**)** after egg is fertilized;	4b. They are derived from **cells of *inner cell mass of blastocyst**** at about 4 to 5 days post fertilization;	4c. **Blood/ haematopoietic stem cells**, such as **myeloid and lymphoid stem cells** are found primarily in **bone marrow;**

(b) Discuss why and how societies should regulate this technology. [12]

(A) Why societies should regulate this technology

Benefits of using embryonic stem cells

1. Embryonic stem cells are ***pluripotent**** and have the potential to treat a wide range of diseases as they have the potential to grow indefinitely in a laboratory environment and can differentiate into almost all types of bodily tissue.
2. Treatments using ES cells could potentially be developed due to their ability to repair extensive tissue damage and develop organs to replace those lost in injury or disease.
E.g. Treatments for physical trauma, degenerative conditions (e.g. Parkinson's disease), and genetic diseases (in combination with gene therapy).

Risks of using embryonic stem cells

3. Possibility of unforeseen consequences in treated patients such as possible risks of tumor formation, immunological reactions, unexpected behavior of the cells, and unknown long-term health effects.

Considerations of ethical problems

4. Some people assert that the embryo has the status of a human being as it has the potential to become one. They believe that embryonic stem cell research violates the sanctity of life and is tantamount to murder.
5. Some people object to extracting stem cells from an embryo to make replacement body cells by treating the embryo as just a source of spare parts. Embryonic stem cell research takes a purely utilitarian view of the embryo.
6. Justice and equity:
- Adult stem cell treatment is established and there are fewer ethical issues involved. Thus adult stem cell research may be able to make greater advances if more money and resources were channeled into it instead of embryonic stem cell research.
- As embryonic stem cell research is expensive, funds can be channeled to treat other more treatable diseases.

7. Claims of the benefits of embryonic stem cell research are over-rated / few (if any) examples of success in medical applications.
8. Current benign applications may lead to abuse in the future. Once human status is denied to embryos, this precedent may extend to other categories of human beings such as the profoundly disabled or the elderly infirm.

(B) How societies should regulate this technology
9. Enforce legislation on the period when ES cells can be extracted.
E.g.: Current UK legislation does not allow use of embryos that are more than 14 days old. In fact, ES cells are obtained earlier from blastocyst (between 3-8 days after fertilisation).
10. Researchers to consider using alternative techniques such as adult stem cells, from sources such as umbilical cord blood, have already produced some results.
11. Institutionalise protocols for donation and consent - For those people involved in donating eggs, embryos or tissues, ensure protocols allowing for informed consent, understanding of research aims and privacy.
12. Offer induced pluripotent stem cells (iPSCs) as alternative source of stem cells proposed for therapy and research.

Governmental research fundings to support use of iPSCs offers several advantages:
12a. Since iPSCs can be derived directly from adult tissues, it does not generate or destroy any human embryos;
12b. iPSCs can be easily procured from any type of adult/specialised somatic cell (e.g. skin cell) without risk to the donor;
12c. In contrast to ES cells extracted from human embryos, iPSCs derived from a patient's own cells would open the possibility of generating lots of patient-specific cells, which will not be rejected by the immune system upon transplantation;
12d. Further, it also allows the generation of pluripotent stem cell lines from patients with inherited diseases, in order to better understand why the diseases develop and use in personalised drug discovery efforts;
12e. An additional reproductive technology that may be enabled by iPSCs is the generation of sex cells (sperm and eggs) for treating infertility;

5 (a) Describe how plants convert light energy into chemical energy. [13]

Light dependent reaction
1. ***Light energy**** from the sun is absorbed by accessory pigments molecules in light harvesting complex of ***photosystems (PS) I and II**;
2. The electrons in these pigment molecules become excited and, when returning to their ground states, pass on the released energy to the next pigment molecule and excite the electrons present in them, as a result. This resonance transfer of energy occurs until it reaches one of the two special chlorophyll a molecules (P700 in PS I & P680 in PS II) in the reaction centre;
3. When the special chlorophyll a molecule absorbs the energy, an excited electron is displaced (Chl a➔chl $a^+ + e^-$) leaving an electron hole in PS I and II. This electron is captured by a primary electron acceptor molecule in the reaction centre;
4. The electron hole in PS II is replaced with electrons from the photolysis of water to give H^+ ions, electrons and O_2.
5. As the excited electrons flow down a chain of carriers of ETC with progressively lower energy levels

6. energy lost is coupled to **pumping H^+ ions** across the membrane into the thylakoid space.
7. **H^+** accumulates in the thylakoid space which serves as the H^+ reservoir. In this way, the electron transport chain transforms redox energy to a ***proton-motive force****.
8. As protons / H^+ diffuse down the concentration gradient back into the stroma via the ***ATP synthase complex****.
9. ADP is phosphorylated to ***ATP**** in the process via ***chemiosmosis****.
10. In non-cyclic photophosphorylation, the ***final electron acceptor**** is ***NADP**** which is a coenzyme.
11. Reduced NADP (NADPH) carries the electrons which are used in the Calvin cycle in the stroma of the choloroplast.

Light independent reaction/Calvin cycle

Carbon fixation:

12. During carbon fixation stage, CO_2 is combined with ***ribulose bisphosphate (RuBP)**** to form an unstable 6 carbon molecule which;
13. splits up immediately into 2 molecules of glycerate phosphate (GP)*;
14. The enzyme catalysing this reaction is ***RuBP carboxylase (RUBISCO)*;***

Reduction by NADPH:

15. NADPH (from light-dependent reaction) is the reducing power used to ***reduce**** GP to glyceraldehyde-3-phosphate (G3P);
16. ATP (from light-dependent reaction) is the source of energy required;
17. G3P is the first sugar formed in photosynthesis and the end product of Calvin cycle;

Regeneration of RuBP:

18. 5 molecules of G3P are used to ***regenerate**** 3 RuBP so that the cycle of carbon dioxide fixation can continue. This requires 3 ATP (from light-dependent reaction);
19. molecules of G3P may be used to form 1 molecule of glucose (hexose sugar)

(b) Discuss the benefits and risks to society of using these **two** sources of plant chemical energy as fuels. [12]

Benefits of Using Biofuels

1. **Renewability**: Biofuels are produced from crop plants which can be grown repeatedly and relatively quickly, leading to a sustainable energy source. Unlike fossil fuels, which take millions of years to form, biofuels
2. **Carbon Neutrality**: Biofuels are often considered carbon-neutral because the carbon dioxide (CO_2) they release when burned is roughly equal to the CO_2 absorbed by the plants during their growth. This can help reduce ***net**** greenhouse gas emissions, which contribute to global warming.
3. **Energy Security**: Producing biofuels domestically can reduce dependence on imported fossil fuels, enhancing a country's energy security and economic stability.
4. **Waste Reduction**: Some biofuels can be made from agricultural waste or non-food crops, reducing waste and providing a use for by products that would otherwise be discarded.

Risks of Using Biofuels

4. **Food vs. Fuel Debate**: Growing crops for biofuels can compete with food production, potentially driving up food prices and leading to food shortages, especially in developing countries.
5. **Deforestation**: To grow biofuel crops, large areas of forest might be cleared, leading to loss of biodiversity, disruption of ecosystems, and increased CO_2 emissions due to the destruction of carbon-sequestering forests.
6. **Limited Efficiency**: Biofuels generally have a lower energy density compared to fossil fuels like coal, meaning more biofuel is required to produce the same amount of energy, which can be less efficient.

Benefits of Using Coal (Fossil Fuels)

7. **High Energy Density**: Coal has a high energy density, meaning it provides a large amount of energy per unit of weight. This makes it a very efficient fuel for generating electricity and powering industries.
8. **Established Infrastructure**: The infrastructure for mining, transporting, and burning coal is well-established, making it a reliable and accessible energy source in many parts of the world.
9. **Economic Benefits**: In many regions, coal mining is a major industry, providing jobs and contributing to local and national economies.

Risks of Using Coal (Fossil Fuels)

10. **Non-Renewability**: Coal is a finite resource formed over millions of years. Once depleted, it cannot be replaced, making it an unsustainable long-term energy source.
11. **Climate change**: Burning coal releases significant amounts of CO_2, a major greenhouse gas contributing to climate change.
12. The continued use of coal threatens to exacerbate climate change and its associated impacts, such as rising sea levels, extreme weather events, and loss of biodiversity.
13. **Health Risks**: Coal combustion produces other pollutants like sulfur dioxide (SO_2) and nitrogen oxides (NO_x), which contribute to air pollution and acid rain.
14. Coal mining is associated with serious health risks, including respiratory diseases like black lung, as well as environmental health hazards such as air and water pollution.

Note:

Both biofuels and coal have their benefits and risks to society. Biofuels offer a more sustainable and potentially environmentally friendly alternative to coal, but they come with

challenges related to land use, food security, and efficiency. Coal, while energy-dense and economically significant, poses substantial environmental and health risks, particularly in terms of its contribution to climate change. Balancing these factors is crucial for making informed decisions about energy use and transitioning to more sustainable energy systems.