CHAPTER 5: 1.3.1 The neuromuscular system

Question - text book page 65

1) It can be deduced from the information summarised in Table 5.1 above that slow twitch fibres are best suited to aerobic (performed with a full and adequate supply of oxygen) types of exercise. On the other hand, fast twitch fibres are specifically adapted for high intensity and mainly anaerobic (performed without sufficient oxygen to cope with the energy demand) types of exercise. Describe some of the characteristics that support this deduction.

Answer:

- *Slow twitch fibres type 1 are best suited for aerobic types of exercise because they contain large amounts of myoglobin, many mitochondria and blood capillaries.*
- *Type I fibres are red, split ATP at a slow rate, have a slow contraction velocity, very resistant to fatigue and have a high capacity to generate ATP by oxidative metabolic processes.*
- *Such fibres are found in large numbers in the postural muscles of the neck and trunk.*

- *Fast twitch fibres: type IIa, also called fast twitch or fast oxidative fibres and are a hybrid of type I and II fibres.*
- *They contain very large amounts of myoglobin, very many mitochondria and very many blood capillaries.*
- *Type IIa fibres are red, have a very high capacity for generating ATP by oxidative metabolic processes, split ATP at a very rapid rate, have a fast contraction velocity and are resistant to fatigue.*
- *They manufacture and split ATP at a fast rate by utilising both aerobic and anaerobic metabolism and so produce fast, strong muscle contractions, although they are more prone to fatigue than type I fibres.*
- *Resistance training can change type IIb fibres into type IIa due to an increase in the ability to utilise the oxidative cycle.*

- *Fast twitch fibres: type IIb, – also known as type IIx and fast twitch or fast glycolytic fibres (FG).*
- *They contain a low content of myoglobin, relatively few mitochondria, relatively few blood capillaries and large amounts glycogen.*
- *Type IIb fibres are white, geared to generate ATP by anaerobic metabolic processes, not able to supply skeletal muscle fibres continuously with sufficient ATP, fatigue easily, split ATP at a fast rate and have a fast contraction velocity.*
- *Such fibres are found in large numbers in the muscles of the arms and legs.*

Exam style questions - text book page 73 - 74

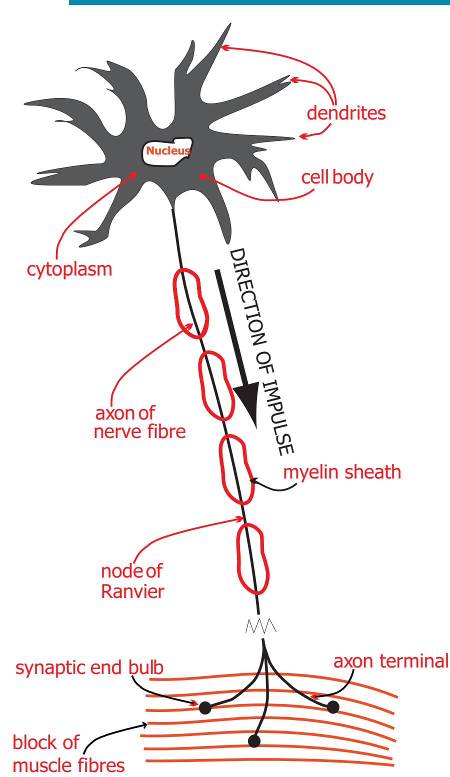
1) Identify and explain the function of the different regions of a motor neurone. 6 marks

Answer:

Note: A diagram, as shown, is good to use when an anatomical structure is required in an answer.

- *Figure 5.3.*
- *Cell body receives stimuli from other neurones.*
- *Via dendrites.*
- *Axon conducts nerve impulses along axon.*
- *At nodes of Ranvier (gaps in myelin sheath) and action potential (depolarisation followed by repolarisation occurs).*
- *As nerve impulse jumps from node to node.*
- *Axon terminal transmits neurotransmitter substances.*
- *Such as acetylcholine.*
- *Which enables nerve impulse to jump across synapse to adjacent cells.*
- *To facilitate action potentials to adjacent cells.*

figure 5.3 – structure of a motor neurone (nerve cell)



2) a) What is a motor unit? 2 marks

Answer:

See figure 5.3.

- *A motor unit consists of a block of muscle fibres connected to a single motor neurone.*
- *Which in turn connects to the brain via the nervous system.*

b) Explain how a motor unit transfers a neural impulse into muscular contraction. 8 marks

Answer:

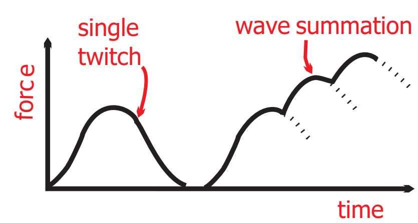
- *Dendrites receive electrical impulses from other neurones via cell body to axon.*
- *Axon transmits neural impulse away from the cell body towards other neurones or effector cells such as muscle fibres.*
- *Achieved via depolarisation of axon membrane to produce action potential.*
- *An action potential travels down axon via saltatory conduction.*
- *Acetylcholine enables the electrical impulse to jump across the synaptic cleft of neuromuscular junction.*
- *To create a muscle action potential in a block of muscle fibres.*
- *Ca^{++} is released from 'T' vesicles and binds to troponin molecules on actin filament.*
- *Exposing actin-myosin cross bridge binding sites.*
- *Mitochondria produce ATP which provides energy for muscle contraction.*
- *ATP attaches itself to a binding site releasing energy:*
    - $ATP \xrightarrow{ATPase} ADP + P_i + \text{energy.}$
- *Myosin cross bridges swivel towards the centre of the sarcomere (power stroke).*
- *Drawing actin filaments past myosin filaments.*
- *This is the ratchet mechanism (attach, detach, reattach of cross bridges).*
- *To create muscle contraction.*

c) The result of an electric impulse reaching the muscle fibres is a maximal contraction of those fibres. Explain this statement and describe how the force exerted by the muscle can vary significantly. 3 marks

Answer:

- *This is the All-or-none law:*
- *The stimulus has to be sufficiently strong enough to make all the muscle fibres within a muscle fibre block (attached to a motor neurone) contract.*

figure 5.9 – force produced by a single fibre twitch



- *The force exerted by the muscle can vary as a result of wave summation:*
- *If the frequency of stimulus increases, there would be no time for the muscle fibre block to relax.*
- *So the force does not drop to zero at the end of a contraction, and the next impulse sends the force up higher (adding on to the force already in the fibres as the next contraction started), then again the force does not drop to zero, and the next contraction sends the force up even higher, until the force reaches maximum.*
- *Hence the force of contraction of this muscle fibre block would increase (see figure 5.9).*

- *Gradation of contraction:*
- *This depends on the number of motor units stimulated at any one time.*
- *The more motor units involved, the more muscle fibres activated and the greater the force exerted by the muscle.*

2) d) Why is it that all the muscle fibres attached to a motor neurone will not necessarily contract at the same time?
3 marks

Answer:

- *Motor nerve fibres have different lengths, hence the impulse takes less time down a shorter one, which will cause its muscle fibre to contract earlier (than others connected to longer nerve fibres).*
- *Hence if the shorter of the two motor units is stimulated all the muscle fibres connected to that motor unit will contract - this is the 'all-or-none law'.*
- *But at the same time the longer of the two motor units could be resting and so those muscle fibres connected to that motor neurone would be in a state of relaxation.*
- *It is not necessary for both motor units to be stimulated at the same time = spatial summation.*

3) Analyse how the characteristics of different skeletal muscle fibres help contribute to success in different sports. 12 marks

Answer:

- *There are 2 main types of skeletal muscle fibre - slow twitch (ST) and fast twitch (FT – type 11a, type 11b, also known as type 11x).*
- *Exercise may produce transitions between FT and ST fibres to create FT-type 11a.*

- *Fibre type distribution varies between individuals.*
- *Endurance-based athletes have a higher percentage of slow twitch muscle fibres in their leg muscles.*
- *Whereas anaerobic-based athletes such as explosive elite sprinters and throwers have a greater percentage of fast twitch muscle fibres in their leg muscles.*

- *These proportions are genetically determined.*
- *And to a degree could account for specialisms of individuals.*
- *Such as whether a person becomes good at marathon running or weight lifting.*
- *ST fibres contain large amounts of myoglobin, mitochondria and blood capillaries.*
- *Mitochondrial proteins and oxidative enzymes are important determinants of the duration during submaximal exercise.*
- *High capillary density and myoglobin content ensure a continuous supply of oxygen to mitochondria (the powerhouse of tissue respiration) which have a high capacity to generate ATP by oxidative metabolic processes.*
- *Supported by high glycogen stores.*

- *Slow twitch fibres split ATP at a slow rate and so have a slow contraction velocity.*
- *Are very resistant to fatigue.*

- *ST fibres have greater triglyceride stores when compared with FT fibres.*
- *And may account for over 50% of the total lipid oxidised during endurance-based exercise.*
- *Thus supporting endurance-based activities such as marathon running.*
- *Type IIb fibres – also known as type 11x.*
- *These fibres, also called fast twitch or fast glycolytic fibres, contain a low content of myoglobin, relatively few mitochondria, relatively few blood capillaries and large amounts glycogen.*
- *Type IIb fibres are white and are geared to generate ATP by anaerobic metabolic processes.*
- *Because type IIb fibres are unable to supply skeletal muscle fibres continuously with sufficient ATP they fatigue easily.*
- *Type IIb fibres split ATP at a fast rate and have a fast contraction speed.*
- *Elite sprinters and throwers are found to have a greater percentage of fast twitch muscle fibres in their leg muscle, when compared with sedentary or endurance-based athletes.*
- *These characteristics help contribute to the success of high, explosive activity such as sprinting and shot putting where speed and power components of physical fitness of required.*
- *Fast twitch type IIa fibres are red, have a very high capacity for generating ATP by oxidative metabolic processes, split ATP at a very rapid rate, have a fast contraction velocity and are resistant to fatigue.*
- *They manufacture and split ATP at a fast rate by utilising both aerobic and anaerobic metabolism and so produce fast, strong muscle contractions, although they are more prone to fatigue than type I fibres.*
- *Resistance training can change type IIb fibres into type IIa due to an increase in the ability to utilise the oxidative cycle.*
- *This physiological training adaptation contributes to the success in sports that require a mixed contribution of energy supply from aerobic and anaerobic pathways.*
- *For example, a tennis match or football game where both speed, power and endurance are important physical fitness components.*

4) Table 5.4 shows the percentage of slow twitch muscle fibres in three muscle groups of elite male (M) and female (F) athletes and non-athletes. The percentage of fast twitch muscle fibre is calculated as the difference between 100% and the percentage of slow twitch fibres.
(Data from research literature – source – 'Essentials of Exercise Physiology' 2e, McArdle, Katch and Katch)

Table 5.4 – percentage of slow twitch muscle fibres

athletic group	shoulder (deltoid)	calf (gastrocnemius)	thigh (vastus lateralis)
long distance runners		79% (M) 69% (F)	
canoeists	71% (M)		
triathletes	60% (M)	59% (M)	63% (M)
swimmers	67% (M) 69% (F)		
sprinters		24% (M) 27% (F)	
cyclists			57% (M) 51% (F)
weight lifters	53% (M)	44% (M)	
shot putters		38% (M)	
non-athletes			47% (M) 46% (F)

a) Compare and account for the differences in percentage distribution of slow twitch muscle fibres with respect to long distance runners and sprinters. 3 marks

Answer:

- *Male long distance 79% to male sprinter 24% in calf muscle = difference of 55%.*
- *Female long distance 69% to male sprinter 27% in calf muscle = difference of 42%.*
- *Expected trend, could be the effects of aerobic and anaerobic training.*
- *And/or genetic potential.*

b) Calculate the percentage of fast twitch muscle fibres for the long distance runners and sprinters. 2 marks

Answer:

- *Long distance runner: males 21%, females 31%.*
- *Sprinters: males 76%, females 73%.*

c) Data collected for male triathletes shows a fairly even distribution of slow twitch muscle fibres across all three muscle groups. Discuss two possible reasons for this trend. 3 marks

Answer:

- *Male triathletes would be expected to have a fairly high even distribution of ST fibres in all three muscle groups.*
- *This trend could be explained due to aerobically stressing all three muscle groups during the swimming, cycling and running parts of this event, both in training and competition.*
- *On the other hand, it is not fully proved whether fibre type changes in response to training or whether these fibre type distributions are genetically determined.*
- *And so the performances of these elite athletes may be a consequence of abnormal fibre type distribution.*

d) For shot putters, only the calf muscle is given a value in table 5.4, What percentage distribution of slow twitch muscle fibres would you expect in the deltoid muscle for shot putters? Give a reason to support your answer. 2 marks

Answer:

Expected percentage:

- *Less than 30% of ST fibres.*

Reason:

- *Because shot putting is an anaerobic power event it relies on flat-out explosive action.*
- *Stressing the predominant use of FT fibres in the deltoid muscle.*

5) Briefly describe the structure of a skeletal muscle fibre, and explain how it contracts when stimulated. 7 marks

Answer:

2 marks for 2 of:

Structure of a skeletal muscle fibre:

- *Skeletal muscle fibre consists of a string of sarcomere (joined end to end) that run from the origin to the insertion of the muscle.*
- *Each sarcomere consists of thin filaments of actin and thick filaments of myosin.*

5 marks for 5 of:

How it contracts when stimulated:

- *A nervous impulse causes calcium (Ca^{++}) to be released from the sarcoplasmic reticulum. This process is called excitation.*
- *Ca^{++} binds to troponin on the actin filament, exposing actin's active sites. Myosin filaments can now attach to the actin filaments to form a cross-bridges.*
- *The breakdown of ATP releases energy which enables the myosin filaments to pull the actin filaments inwards towards the centre of the sarcomere (called the 'power stroke') so shortening the muscle.*
- *This occurs along the entire length of every myofibril in the muscle cell to create a muscle contraction.*
- *This attach, detach, reattach of cross-bridges is called the ratchet mechanism.*

6) Identify the physiological adaptations that occur within sleletal muscle tissue as a result of anaerobic training. 7 marks

Answer:

7 marks for 7 of:

- *Hypertrophy of the muscle/increased muscle mass.*
- *Increased stores of ATP.*
- *Increased PC stores.*
- *Greater levels of enzymes present:*
- *For example, lactate dehydrogenase (LDH).*
- *Increased rate of glycolysis.*
- *Extended energy production via the alactic energy pathway.*
- *Delayed OBLA/increased lactate threshold/increased anaerobic capacity.*
- *Greater tolerance of lactic acid through buffering.*
- *Reduced tendency to experience DOMS.*
- *Increased strength of skeletal muscle/connective tissue.*
- *Increased thickness of myocardium.*
- *Type IIa fibres adopting type IIb characteristics.*
- *Increased SV and $\dot{Q}$.*
- *Decreased end systolic volume.*
- *More effective use of lung capacity.*
- *More effective use of respiratory muscles.*

7) Describe three changes that occur in muscle cells as a result of endurance training. 3 marks

Answer:

3 marks for 3 of:

- *Increase in muscle size/hypertrophy.*
- *Increase in myoglobin content.*
- *Increases number and size of mitochondria.*
- *Increases in oxidative enzymes.*
- *Therefore increase in activity of Kreb's cycle.*
- *Increase in $a\text{-}\bar{v}O_{2diff}$.*
- *Increase in glycogen/triglyceride stores.*
- *Fat stores more mobilised = glycogen sparing.*

8) Describe some of the factors which determine muscle speed and tension characteristics. 4 marks

Answer:

Note: You will be expected identify three from the possible answers below:

2 marks for each selected factor.

- *Muscle shape, cross sectional area and fibre type will determine speed of contraction and tension.*
- *Bulkier muscles such as the biceps brachii will contract quicker and produce more tension than longer, thinner muscles such as sartorius.*

- *Percentage type of motor units ie fast twitch/slow twitch motor units - a greater percentage of ST motor units means decreased muscle tension and speed of movement.*

- *Motor unit recruitment - strength and frequency of stimulus.*
- *The greater strength and frequency of stimulus, the greater the muscle tension and speed of contraction.*
- *By varying the strength of the stimulus from very light to maximal force a muscle can exert forces of graded strengths or gradation of contraction.*

- *Larger diameter motor neurones and myelinated axons conduct action potentials faster therefore giving increased muscle speed.*

- *The use of proprioceptors which provide sensory information which can be used to regulate speed and tension.*

- *Length-tension relationship with muscle tissue is created when the cross bridges on the actin and myosin hook up and energy is released.*
- *And the cross bridges pull actin filaments over the myosin filaments to shorten the length of the sarcomere.*
- *The greater the overlap of actin and myosin filaments, the stronger the contraction or tension.*

- *Type of muscle contraction: isotonic, isokinetic and isometric mc.*
- *During an isotonic muscle contraction (concentrically or eccentrically) the rate of length change is significantly related to the amount of force potential.*
- *When contracting concentrically against a light resistance muscle is able to contract at high speed.*
- *Slight increases in load results in a reduction in muscle speed.*
- *Muscle tension is greater during an eccentric muscle contraction when compared with a concentric muscle contraction.*

- *During an isokinetic muscle contraction there is a constant speed and tension developed over the full range of motion.*
- *This occurs when using hydraulic weights machines such as the Lido.*
- *During an isometric muscle contraction the muscle stays the same length and under great tension.*

9) Skeletal muscle contains both slow and fast twitch muscle fibres but the proportion of each depends upon the function of a muscle as a whole. Table 5.1, page 65 of the text book lists some of the differences between slow and fast twitch muscle fibres.

a) Suggest why the muscles concerned in maintaining the trunk posture of the body of the sprinter might be expected to have a larger percentage of slow twitch muscle fibres.
Using table 5.1 explain why fast twitch muscle fibres may build up an oxygen debt during a 400m sprint. 5 marks

Answer:

Postural muscles in the trunk would have more slow twitch fibres because:

2 marks for 2 of:

- *They maintain posture for long periods of time.*
- *It is important for postural muscles not to get fatigues easlity.*
- *No need for fast, powerful contraction.*

Why fast twitch fibres build up an oxygen debt during a 400m sprint:

3 marks for 3 of:

- *Low capillary density.*
- *Few mitochondria.*
- *Therefore less O_2 supplied because they contain fewer oxidative enzymes.*

9) b) Account for the difference in the speed of contraction between slow and fast twitch muscle fibre types.
Fast twitch muscle fibres are divided into two types, IIa and IIb. Identify the major functional characteristic between these sub groups.
In what sporting activities would the adaptation of fast twitch type IIb to type IIa fibres be relevant to a sportsperson? 6 marks

Answer:

The two types of fibre contract at different speeds because of:

- *High glycogen content of fast twitch muscle fibres (low in slow twitch muscle fibres).*
- *High levels of phosphocreatine (PC) stores in fast twitch muscle fibres (low levels in slow twitch muscle fibres).*
- *Fast twitch muscle fibres have well-developed sarcoplasmic reticulum, which means more Ca^{++} available and improved transportation system for nutrients (e.g. glucose) compared to slow twitch fibres.*
- *Fast twitch muscle fibres are attached to large motor neurones with fast conductive velocity (small contractile time), compared to smaller motor neurones for slow twitch muscle fibres.*

The two types, IIa and IIb, major functional characteristics between these subgroups:

- *Type IIb fibres have a high capacity for glycolytic release of energy (known as FG).*
- *Type IIa fibres utilise both aerobic and anaerobic energy sources (known as FOG).*

Conversion of type IIb to type IIa:

- *Endurance-based events, such as middle distance running.*

10) An understanding of the functional structure of muscle cells is an important basis for an understanding of physical activity. Discuss this statement. 12 marks for AS
15 marks for A level

Answer:

Note that the 15 mark A level questions requires more depth/detail.

- *The functional structure of muscle cells involves an understanding of how muscle cells work to create movement.*
- *Skeletal muscle tissue is responsible for movement and activity.*
- *Within skeletal muscle are bundles of muscle fibres called fasciculi.*
- *Within a muscle fibre are muscle cells containing myofibrils which are long and thin running lengthways down the muscle.*
- *Muscle cells are supplied with nuclei, mitochondria and fat/glycogen stores, myoglobin, phosphocreatine (PC) and adenosine triphosphate (ATP) supplying fuel and energy for muscle contraction.*
- *A myofibril consists of a chain of actin and myosin contractile filaments.*
- *A sarcomere is the functional contractile unit of the muscle fibre.*

How does the sarcomere product movement?

- *A nerve impulse travels via a motor neurone to the motor end plate to create a muscle action potential with a block of muscle tissue- collectively known as a motor unit.*
- *This muscle action potential triggers the release of calcium ions from the 'T' vesicles (located with the sarcoplasmic reticulum).*
- *Calcium ions bind to the troponin molecule on the actin filament.*
- *Causing it to change shape by neutralising the tropomysin and exposing the myosin cross-bridge binding sites on the actin molecules.*
- *Mitochondria enable aerobic ATP regeneration, fuel supplied from muscle fat/glycogen stores.*
- *ATP attaches itself to the binding site on the cross–bridge releasing energy.*
- *Myosin cross-bridges swivel towards the centre of the sarcomere – called the power stroke.*
- *This draws the actin filaments past the myosin filaments as they attached, detach, reattached – called the ratchet mechanism.*
- *The contractile strength is dependent on the number of cross-bridges formed.*
- *Repeated stimulation of muscle cells builds up tension in single muscle fibres.*
- *As there is little time for relaxation and so tension within the muscle cell rises – known as wave summation.*
- *Neural activation of motor units in succession produces graded muscle strength from weak to strong – known as gradation of contraction.*
- *This cycle repeats itself as long as ATP is available.*
- *Thus supporting sustained aerobic activity and explosive anaerobic activity.*