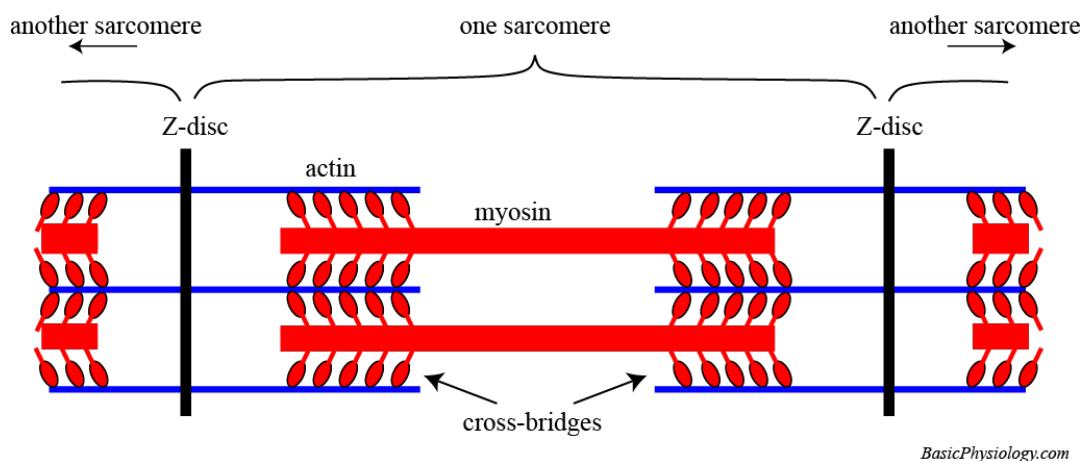
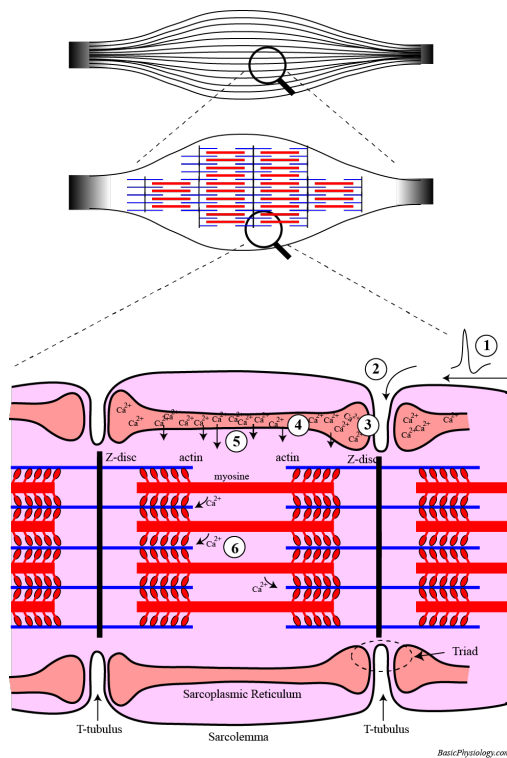


A.4.3. The Sarcomere

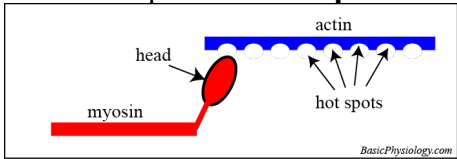
Introduction: The sarcomere is the **fundamental** unit in the skeletal muscle that makes the contraction happen.

A. Definitions and Structural components required:

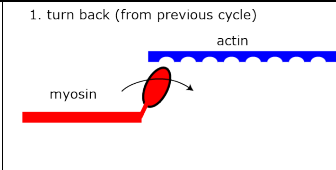
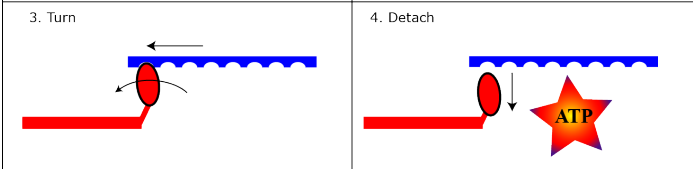
1. The **sarcomere** is the space that runs from one Z-disc to the next Z-disc
2. the sarcomere contains **myosin** and **actin** molecules, which are long and thin molecules
3. the **actin** molecules are attached to the **Z-disc**
4. the **myosin** molecules are arranged in the middle of the sarcomere and between the actin molecules
5. from the myosin molecules, **cross-bridges** extend towards the actin molecules
6. there is also a **sarcoplasmic reticulum** that stores Ca^{2+}
7. and there are **transverse tubuli** (singular: *tubule*). These are invaginations of the cell membrane (= sarcolemma) that come close to the sarcoplasmic reticulum.



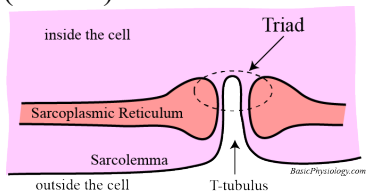
B. Functional Steps:

1. A muscle action potential propagates from the motor end-plate along the cell membrane, thereby activating (=exciting) the whole cell membrane.	2. Because the transversal tubuli are continuations of the cell membrane, the action potential also propagates into these tubuli.
3. The action potential at the end of the transversal tubuli have an effect on the neighbouring sarcoplasmic reticulum .	4. This will open the Ca²⁺ channels that are located in the membrane of the sarcoplasmic reticulum (= SR).
5. Because there is much more Ca ²⁺ inside the SR then in the rest of the sarcomere, there will be Ca ²⁺ diffusion into the cell (along its concentration gradient) and the Ca ²⁺ concentration in the sarcomere will rapidly increase.	6. The Ca ²⁺ ions will influence the actin molecules to open their hot spots . 
7. Once these hot spots are available, the head of the nearest cross-bridge will attach to the hot spot.	8. It is important to note that the cross-bridges are a part of the myosin molecule. So, when the cross-bridges attach to the hot spots, then effectively the myosin molecule is linked to the actin molecule.
9. Once the head is attached to the actin molecule, the head will rotate a little (<i>see animation</i>). The rotation is always towards the centre of the sarcomere.	10. The rotation of the head will therefore pull the actin molecule a little towards the centre of the sarcomere.
11. The head will then de-tach from the actin molecule and rotate back towards its original position. This step requires energy (one ATP molecule).	12. Now repeat the previous steps; the head will attach again to the next hot spot, turn and pull again at the actin molecule.
13. In this manner, step-by-step, the actin molecule is pulled towards the middle of the sarcomere, thereby pulling the Z-discs closer to each other.	14. As the same thing is happening in all the other sarcomere along the muscle fibre, the whole fibre becomes shorter; this is the contraction .

C. The Cross-Bridge Dance:

1. In summary; once Ca^{2+} ions have opened the hot-spots on the surface of the actin molecules, the head of the cross bridges will start, what I call, the “cross-bridge dance” (animation). This dance consists of four steps:	2. These are the four steps of the Cross-Bridge Dance: 1. attach (myosin head to actin hot-spot) 2. turn (towards the middle of the sarcomere) 3. detach (this requires energy in the form of ATP) 4. turn back
	

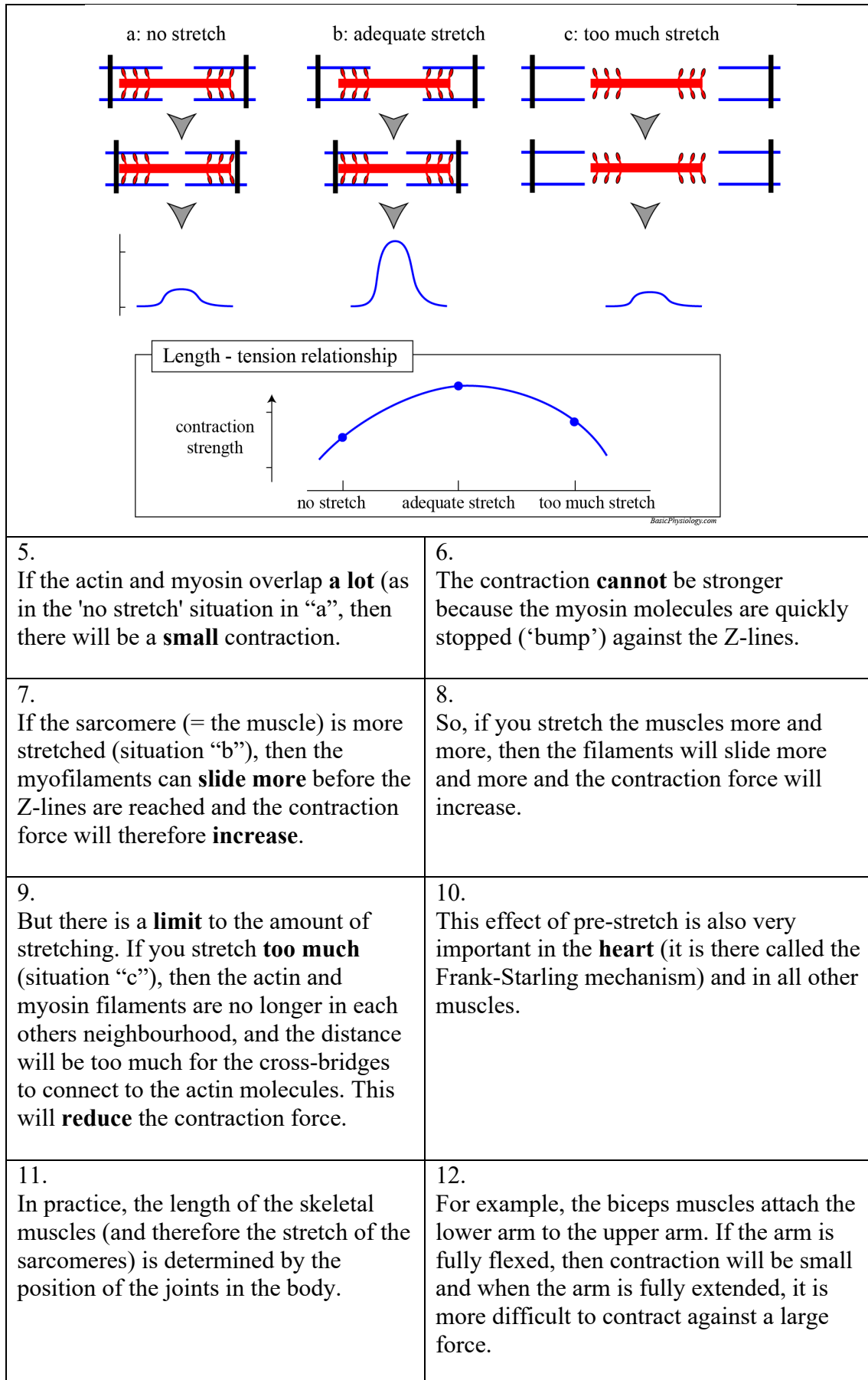
D. Additional Notes:

1. Triad: this is the name of the structure at the end of the transversal tubules. There, the cell membrane is close to the membranes of two sarcoplasmic reticula (plural of reticulum). The proximity of three membranes together is called a Triad (= three). 	2. Actin hot-spots: Ca^{2+} ions have a complicated effect on the actin molecule. There is actually an interplay between three molecules: actin, troponin and tropomyosin. For more (technical) information, go to your Physiology textbook (<i>not very important</i>)
3. Head rotation is a bit of an exaggeration. In reality, the head movement is more like a “tilting” towards the middle of the sarcomere and, during the fourth step of the dance; the head tilts back to its starting position. It is more like the wipers on your car windshield that swipe back and forth.	4. Million repeats: During a typical contraction, this cross-bridge tilting will happen millions of times, at all the thousands of cross bridges in the sarcomere, and in all the thousands of sarcomere strung along a muscle fibre.

	
5. End of contraction: the cross-bridge dance continues as long as Ca^{2+} keeps the hot-spots on the actin molecule open. But, at the same time that the contraction takes place, Ca^{2+} is being pumped back into the sarcoplasmic reticulum (active transport).	6. This pumping back will decrease the calcium-concentration in the neighbourhood of the sarcomere. As soon as the Ca^{2+} concentration is low enough, the hot spots will be closed and no longer available for the cross bridges. This will stop the contraction.
7. Sliding Filament Theory: This process of the cross-bridge heads pulling the actin along the myosin molecules, makes the actin slide along the myosin molecule (= filaments).	8. In the early days of this research, no one could actually see these cross bridges work and the idea of this mechanism was based on indirect evidence. But that evidence was enough to deduce the 'sliding' of the actin along the myosine molecule; hence the term "sliding filament theory".

E. The Stretch-Contraction relationship. Also called the Force-Length relation.

1. This is an important phenomenon in physiology	2. If the muscle is stretched before the muscle is stimulated (by pulling at the tendons for example), then the contraction will be stronger.
3. But if you stretch too much, then the contraction will become weaker!	4. The explanation of this phenomenon is shown in the diagram and in the following steps:



13.

The optimal length of the biceps is at an angle of the elbow joint of about ninety degrees. This is the angle that most sportsman will use when having to lift heavy weights for examples (weight lifters).



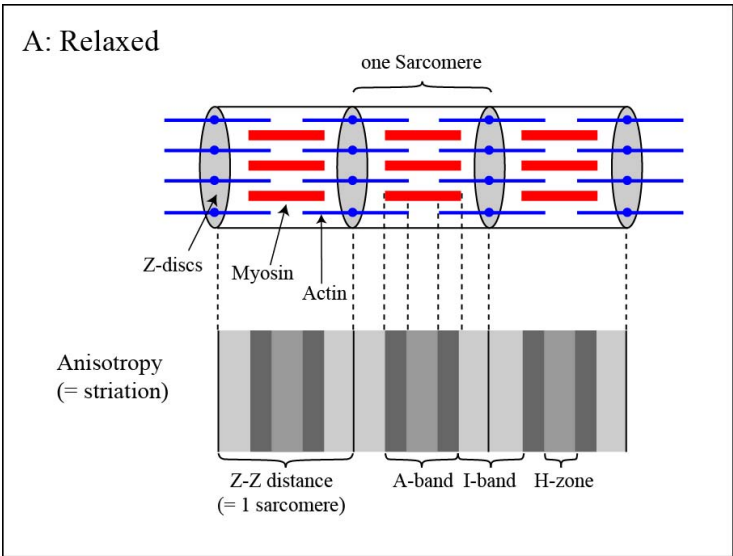
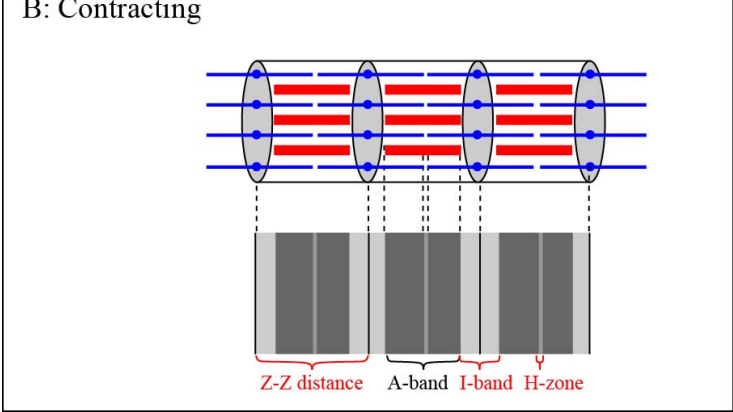
F. Rigor Mortis ("stiffness in death"):

Question: When a person dies, the body, after a few hours, will become **stiff**. Why?

1. Contraction requires energy (ATP). Specifically, the ATP is required to de-tach the cross-bridge head from the actin molecule (step 4 in the “cross-bridge dance”!)	2. But, when a person dies, the normal repair mechanisms of the cells have stopped functioning. This means that the cells will start to deteriorate. One of the first signs of this deterioration is that membranes will start to fall apart.
3. Therefore, the membrane of the sarcoplasmic reticulum, which contains a lot of calcium ions, will break open and holes will appear in the membrane.	4. This will lead to a flow of Ca^{2+} ions from the sarcoplasmic reticulum into the sarcomere, and this will open the hotspots on the actin molecules.
5. Once the hotspots are open, the heads of the cross-bridges will automatically attach to the actin molecules.	6. But; because there is no ATP (<i>the person is dead remember?</i>), the heads will no longer be able to detach from the actin.
7. Therefore, the myosin and the actin molecules are now locked together forever.	8. Because this process happens in all skeletal muscles at more or less the same time, the corpse becomes very stiff .
9. What happens next? <i>(Will the body remain stiff forever?)</i>	

No. After some time, more membranes and filaments will break down in the body. Therefore, in time, the long actin and the long myosin molecules will also start to break down, thereby terminating the bonding between the two filament types. Therefore the muscles will again become less stiff and rigor mortis will disappear.

G. Behaviour of the striation pattern (= anisotropy) during contraction:

A: Relaxed 	
B: Contracting 	
1. When the muscle contracts, this means that the actin and myosin molecules slide into each other (= sliding filament theory)	2. Therefore the Z-disks (Z-lines) will move towards each other.
3. The A-band however will remain the same, as the myosin molecules do not shorten.	4. The H-zone (if visible) will become shorter and may even disappear as the actin molecules move towards the centre of the sarcomere.
5. Summary: When a muscle contract, then the Z-Z distance becomes shorter, the I-band shorter, the H-zone shorter, but the A-band does not change its length.	