Module:
Biological Foundations of Mental Health

Week 3
Synaptic transmission & neurotransmitter systems

Topic 1
Action potentials and synaptic transmission – part 4 of 5

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Lecture transcript

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In this section, we're now going to look at how the action potential is conducted along the axon. So we started now with understanding how the signal is integrated the dendrites and the cell body, how this then has triggered the action potential at the axon initial segment. And now we're going to look athow both myelinated and unmyelinated fibres transmit this action potential along the length of their axon to the terminal field, where it can then have an effect on the postsynaptic neuron in this case or, for example, on muscle tissue to engage movement.

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Now, if you think back to the basic principles what we spoke about, here is the axon initial segment, the dotted circle at the start of the axon, and we have the normal distribution, whereby the inside of the cell is more negative with respect to the extracellular space here, denoted as a positive response. And the incoming graded potential, if you remember we spoke about this component-- this rapidly decaying electrotonic signal. It reaches the axon initial segment, and if it's above the threshold, which, again, we will suggest is minus 55 millivolts in this case.

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This triggers the opening of the voltage gated sodium channels, and sodium rapidly enters the neuron, depolarising the intracellular space. Therefore, the intracellular space now becomes more positive around this area of the membrane, and the extracellular space more negative. If you remember, we also said that the axon initial segment is uniquely designed for that. It has a very high concentration of voltage gated sodium channels, for example, and voltage gated potassium channels. So it's uniquely excitable, in the context of the axon, to trigger these responses. So if you imagine it's got a high concentration of voltage gated sodium channels, so as they trigger and open, they will further open more sodium channels and really cause a rapid influx or rapid depolarising phase.

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Now, as the sodium influxes into the cell, this will further depolarise the membrane in front of it. So we start to get the spread of the depolarisation along the membrane because it's opening more voltage gated-dependent channels along the membrane.

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Now, this will continue to spread. This depolarisation will spread along the axon, as you can see here. So we're now starting to move electrotonically along the axon, the signal is progressing. And behind that, if you remember, now, the slower voltage gated potassium channels will now begin to open. There's a half a millisecond delay in their response. They will begin to open, and potassium will begin to leave the cell, making-- because potassium now wants to get away from this positively charged environment and wants to flow down its concentration gradient.

Now, at the same point, if you remember, the sodium channels-- this is when they become inactive. So because they're inactivated now, behind this potential change, as seen in number four, the charge can only move along in that one direction towards a terminal field and can't propagate back towards the cell body. And this is important because in certain pain states, this can become abnormal, causing an action potential to travel in both directions.

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Now, in the context of an unmyelinated fibre, if we look at that and how that conveys, this is a relatively slow process. So we have this influx of sodium, which then depolarises the membrane, moves this charge across, further opening more voltage gated sodium channels and causing further influx of sodium as we move along the axon.

Behind this, the potassium is now starting to leave and the sodium channels are inactivated. So we're starting to get a reversal of the membrane potential back to its resting state, that is, more positive on the outside and more negative on the inside. And this continues on the entire length of the axon. Now, it's a relatively slow process because sequential voltage dependent channels have to respond along the entire length of the axon. So this is a slightly slower process causing this electrotonic spread each time the cycle has to refresh itself along entire length the axon.

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Now, in myelinated fibres, this is different. If you think, now-- and think that the myelinated fibres are surrounded by myelin generated by Schwann cells in the peripheral nervous system, or oligodendrocytes in the central nervous system. And this myelin is an insulating fatty layer. Much like the rubber cable around the wire in your house, it insulates that cable and prevents the current, or the conductance, the charge, from leaking across into the environment. For example, if you had a bare wire, you might get a shock from that. That's what this is here to do. It's here to prevent that.

Now, in a myelinated fibre, the conduction is classically known as saltatory conduction, and that's where the potential appears to jump from one node to the other node. And these nodes of Ranvier here are these little bare, uninsulated sections between the different oligodendrocytes in this case, because we're talking about a central nervous system neuron, that are exposed to the extracellular space.

And much like the axon initial segment, which we previously spoke about, these are very specialised compartments that have a high density of voltage gated sodium channels in the node and surrounding the node are high density, for example, voltage gated potassium channels. So again, they're uniquely excitable compared to the insulated membrane along which the oligodendrocytes are ensheathing the axon.

Now, in this case, the incoming signal causes influx of sodium at the axon initial segment. That causes then a depolarisation, so a more positive charge within the neuron. And this positive charge spreads electrotonically along the axon to the next node of Ranvier-- to the next bare component-- where it can then flux ions across the membrane.

This then happens again at this node of Ranvier. The sodium channels are triggered, sodium fluxes into the cell, and this is propagated along to the next node of Ranvier. And the same potassium mechanism is happening behind this, where at each node of Ranvier sequentially along the axon, potassium is then leaving the cell, reestablishing the resting membrane potential of the cell. And, of course, the sodium potassium ATPase pumps, you remember, are very important here as well to reestablish these membrane potentials.

Now, by this mechanism, myelin, in this case, can really increase the speed of propagation because we don't have to have sequential activation of ion channels across the entire length of the axon. We get this apparent jumping in the saltatory conduction from one node to the next. And you can really rapidly increase the conduction velocity-- the speed at which we can transmit these signals. And if you think of the brain, it's very important because in some axons, for example, if you've got a motor neuron in your leg travelling up to the CNS, of course, or a higher spinal neuron, this can really be over a distance of metres. So we can really see quite a long process, where we have to get signals to the target zone very rapidly.

And this is where a problem can arise, because myelination is such a specialised event, and it can really help with propagation. But in the case of disorders such as multiple sclerosis, demyelinating diseases, where we get a breakdown of this insulating sheath, the new signal, which is now conducting, can pass to this first node of Ranvier here from the axon initial segment. But if the myelin is disrupted, this charge can now leak out across the membrane potential and can now dissipate across the membrane because the membrane resistance is decreased.

And in doing so, the ongoing charge that's passed along the axon is significantly reduced. And if this potential is no longer strong enough to reach the adjacent node of Ranvier-- much like a graded potential decaying back in the cell body, if you remember that section-- then the action potential will be lost, and we will lose the ability to fire an action potential. And that is what happens in, for example, multiple sclerosis or diseases such as Guillain-Barre syndrome, where we get total loss or breakdown of the insulating myelin sheath and a loss of signal.