4
Introduction to Volume Conduction

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Summary

The term "volume conduction" refers to the complex effects of measuring electrical potentials a distance from their source generators. Near-field potentials refer to those recorded in relative close proximity to the detector, whereas far-field potentials refer to those recorded at a considerable distance, as is most commonly the case in evoked potentials. A relative straightforward model of volume conduction can be worked through to assist in better understanding how volume conduction effects can impact the shape of a recorded neuronal potential. In fact, all motor and sensory nerve conduction waveforms are substantially impacted by volume conductive effects. The recording setup of sensory studies (i.e., whether they are bipolar or referential) also impacts the size and morphology of the recorded signals. In addition, the compound motor action potential actually represents a composite of both near- and far-field activity. The morphology of both spontaneous discharges and the motor unit potentials themselves evaluated during needle EMG are, in part, caused by the complex effects of volume conduction.

Key Words: Bipolar; far-field; fibrillation potential; near-field; positive sharp wave; source generator; referential; volume conduction.

1. WHAT IS VOLUME CONDUCTION? WHY IS IT RELEVANT?

Volume conduction is the term used to describe the effects of recording electrical potentials at a distance from their source generator. In other words, the recording electrodes are not in direct contact with the nerve or muscle; there is a medium of some sort separating the two. In truth, volume conduction plays a role in almost all clinical neurophysiological recordings, both central and peripheral, because recording electrodes are never placed in direct contact with the nerve cells generating the signal. There are some occasional examples in which volume conduction plays only a minor role because the amount of nonexcitable tissue between the depolarizing neuron and the recording electrodes is quite small. One example of this would be near-nerve nerve conduction studies, in which a needle electrode is placed in very close vicinity to the nerve of interest. Even so, electrical signals can take short cuts through ionic media and, therefore, distant activity can be detected.

Two terms are worth being familiar with immediately: far-field potentials and near-field potentials, and volume conduction theory plays into both. A *near-field potential* is one that is obtained with the recording electrode in relatively close proximity to the source of the signal (the generator), although, again, not in direct contact with it. Bipolar recording arrangements as discussed below in Section 3 are generally used to study exclude these potentials. Examples would include standard needle EMG, digital sensory conduction studies, motor studies, and

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standard electroencephalography. *Far-field potentials*, in contrast, are generated at a distance from the recording electrodes. These potentials are most critical in somatosensory evoked potentials (SSEPs), in which electrodes on the scalp can pick up electrical activity occurring in the brainstem. Referential recordings (again, discussed in Section 3, below) detect these potentials more easily. However, far-field potentials also play a role in other aspects of clinical neurophysiology, and even standard motor studies can be "contaminated" by far-field effects, as described below in Section 4.2.

To become more familiar with the effects of volume conduction, it is helpful to first review several examples. In the sections that follow, we will then deal with the underlying theory and come back to an explanation regarding why the observed phenomena occur.

Example 1: A motor response recorded from the motor point of abductor pollicis brevis produces a negative first phase; however, a motor response recorded off the motor point will produce an initial positive phase followed by a negative phase.
Example 2: An antidromic sensory response recorded from the sural or radial nerve usually has a small positive phase before the main negative phase; antidromic sensory responses from the ulnar and median nerves, on the other hand, have a major negative phase without the preceding positive phase.
Example 3: Fibrillation potentials and positive sharp waves, which are morphologically quite "dissimilar," are both generated by the single muscle fibers.
Example 4: The P9 potential observed on upper extremity SSEPs can be observed simultaneously at multiple recording sites.

2. WORKING MODEL OF VOLUME CONDUCTION

There are two basic models that have been used to explain the observed phenomena of volume conduction. The first involves the use of a waveform moving down a nerve sitting in a medium. The second relies upon the concepts of what is called "solid-angle geometry." Although both models are relatively straightforward, because our goal here is merely to provide a basic understanding of volume conduction, we will omit the discussion on the solid-angle geometry model, which can be obtained in the suggested reading.

Figure 1 demonstrates the depolarization of an axon moving from left to right and what will be observed depending on the exact location of the recording electrodes, both in terms of distance from the nerve (Levels 1, 2, and 3) and location along the nerve relative to the depolarizing wave front (Ovals A, B, and C). For purposes of discussion, it is easier to envision the waveform remaining stationery and the electrode moving from left to right across the diagram. In A, the waves of depolarization are initially moving *away from* the current source as they fan out in the medium, slightly against the direction of electrode movement (most obvious toward the extreme left side of A). By convention, this will produce a downward deflection on the oscilloscope. As we move through A, however, the current lines begin to move in the same direction as the electrode movement and the tracing on the oscilloscope begins to move upward. At the "O" line (the equipotential point), there is no net current flow across the electrode, and the oscilloscope tracing returns to baseline. In B, current flow is now toward the sink, in the same direction as the moving recording electrode, producing further upward movement of the tracing producing the rising peak of the main negative spike. In C, the current abruptly switches direction as we cross the point of maximal depolarization. Current again now moves in the opposite direction of the electrode and the oscilloscope shows a downward movement (but it now has to start at the apex of the negative peak, not at baseline, so it remains in negative territory). After crossing the equipotential line again, we

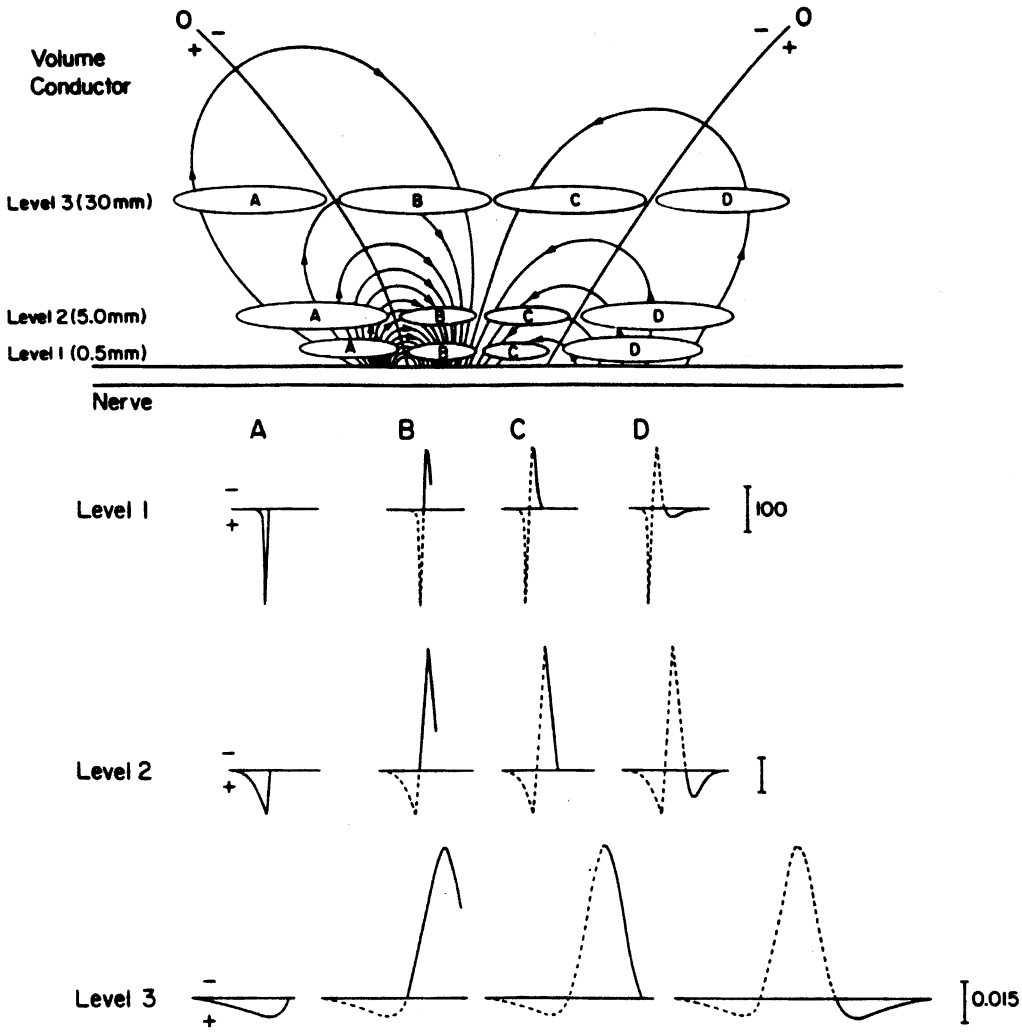

Fig. 1. A model of the effects of volume conduction on a recorded neuron or muscle potential. For discussion purposes, it is simpler to imagine the depolarization frozen in time and the electrode slowly being moved through positions A to D. Levels 1, 2, and 3 simply represent what would be seen depending on the proximity of the recording electrode to the nerve. Focusing on a single level (e.g., level 2) is simplest. By convention, if current lines are traveling opposite the direction of electrode movement, this will produce a downward deflection on the oscilloscope; if traveling in the same direction, it will produce a upward deflection. In A, the lines of current fanning out beyond the electrode source are initially traveling opposite the electrode movement, producing a downward (positive deflection), but then gradually start to travel in the same direction as the electrode, returning the deflection back to baseline, as the electrode "arrives at" the "zero" or equipotential line. In B, the current continues to travel in the same direction as the electrode movement and the oscilloscope traces an upward (negative) potential. As the electrode crosses the current sink (where the actually depolarization of the neuron is occurring), the lines of current abruptly change direction and the oscilloscope potential begins to move downward in C. This downward movement continues past the equipotential line and into D. However, within D, the fanning out of current lines gradually begins to move in the same direction as the electrode, producing an upward deflection on the oscilloscope and returning the tracing to baseline. Note that the potential is asymmetric, reflecting the fact that neuronal repolarization is a slower process with less dense current lines.

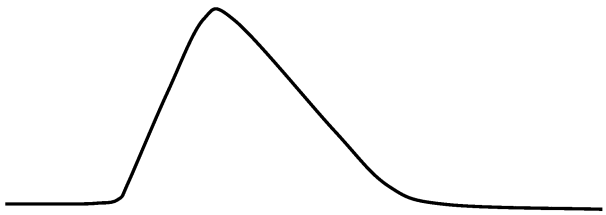

Fig. 2. A monophasic potential produced by a neuronal recording in the complete absence of volume conduction. Because there is no fanning out of current lines observed in Fig. 1, the initial and final positivities do not occur, leaving only the negative, slightly asymmetric monophasic negative potential.

enter D, where the current continues to flow in the direction opposite electrode movement initially, and the oscilloscope traces out the trailing positive peak. However, at some point in D, the fanning out current lines begin to move in relatively the same direction as the electrode, and the tracing moves up and returns to zero as the current reaches undetectable levels. It is also worth noting that the repolarization of the axon is a slower process than the depolarization (note how the lines of current flow are more densely packed on the left side than the right side of the diagram), leading to a sharper initial positive peak as compared with the final positive peak. When closer to the axon (the different levels), the peaks appear sharper than when further away from it.

It is worth considering what a potential would look like in the absence of a volume conductor. Using the same model, the major difference would be that no initial positivity nor final positivity would be identified, because the current would not fan out from the source generator. This would leave a monophasic negative spike (Fig. 2). This spike would have some asymmetry, however, given the fact that repolarization is slower than depolarization. In summary, the middle negative phase of a recorded potential will be present with or without volume conduction, but the end positivities are purely a consequence of volume conduction.

3. TWO OTHER CONCEPTS RELEVANT TO VOLUME CONDUCTION THEORY

All recordings in clinical neurophysiology are differential recordings, in that the electrical activity under one electrode (the "active" electrode or E1) is compared with that under the other electrode (the "reference" or "inactive" electrode, called E2). The final waveform obtained is a combination of what the E1 and the E2 electrodes are sensing; in mathematical terms, this would be described as E1 – E2. Hence, whatever E2 is "seeing" needs to be subtracted from E1.

Two terms are used to describe the two types of differential recordings: "referential" and "bipolar." Referential recordings refers to E2 being placed on a relatively electrically inactive structure, such as the earlobe in EEG recordings, or a bony prominence in EMG recordings. Bipolar recordings are those in which both E1 and E2 are being placed in relative proximity to electrical tissue, such as an antidromic digital sensory response stimulating the wrist and recording from the finger. For better or worse, although we like to think of E2 as electrically silent in referential recordings, in fact, far-field potentials can be recorded under this electrode, which can contribute substantially to the recorded waveforms. This issue will be discussed in further detail below in Section 4.2.

"Standing waves" (also called "virtual dipoles") may be produced when a depolarization of a nerve traverses from one body segment to another, for example, from arm to shoulder or hand to finger. The mechanism of this is complex, but likely is caused by several different effects, including a change in the anatomic uniformity of the volume conductor, extracellular resistivity, a change in the anatomic orientation of the propagating potential, or the abrupt termination of excitable tissue. Although this plays a role in both nerve conduction studies and all evoked potentials, the issue is most relevant in SSEPs.

4. VOLUME CONDUCTION AND ITS ROLE IN SPECIFIC TESTS

4.1. Sensory Nerve Conduction Studies

Let us begin our discussion by looking at a standard antidromic median sensory study recording from digit 3, a form of "bipolar study," in that both E1 and E2 are in proximity to the potential generators (the digital nerves of the middle finger). Figure 3A shows the standard recorded response. Note that there is an initial negativity and a final positivity. In Fig. 3B, the reference electrode is moved to digit 5, essentially changing the biopolar arrangement to a referential recording arrangement, where E2 is picking up no electrical activity. An initial positivity now appears on the recorded waveform, because of the approaching wave front, as described in Fig. 1. The reason that it was not visible with both electrodes on digit 3 is that both were sensing it simultaneously and, hence, it was subtracted out by the differential recording. With the reference electrode on digit 5, only the active electrode on digit 3 senses it and, thus, it appears. Note also that the amplitude of the negative peak is slightly higher. In Fig. 3C, the contribution of E2 is clarified by keeping it as the reference electrode and placing E1 on digit 5. What is seen is essentially an upside-down version of that seen in Fig. 3B, with an initial negativity and slightly lower amplitude at the now "upside down" negative peak. The amplitude is slightly reduced because the digit 3 electrode is very distal and the underlying electrical potential is smaller. The initial negativity seen here normally counterbalances the positivity of E1 (seen in Fig. 3B) in the bipolar recording (A), producing the flat baseline leading up to the major negativity. In Fig. 3D, the waveforms seen in Fig. 3B and 3C are digitally added, to produce approximately what is observed in Fig. 3A.

Thus, antidromic median and ulnar bipolar sensory studies typically do not demonstrate an initial positivity because they are truly bipolar and the approaching wave front is sensed simultaneously by both electrodes and is cancelled out. However, in standard antidromic radial sensory studies (recording from the snuff box) and antidromic sural sensory studies (recording from the ankle) a small positivity is typically identified. This likely reflects the fact that E1 and E2 are seeing slightly different environments and that the potentials are not truly bipolar with incomplete cancellation of the approaching wave front.

4.2. Motor Studies

In motor studies, there is generally no initial positivity on the compound motor action potential, similar to that observed on bipolar digital sensory studies. However, the reason why this occurs is different. Rather than the wave front being sensed by both electrodes and canceling, in this situation, the depolarization of the muscle fibers is actually originating directly beneath the active electrode, E1, and, hence, there is *no* approaching wave front. This can be demonstrated by moving E1 slightly off the motor point, which will then create a small positivity in front of the major negative phase.

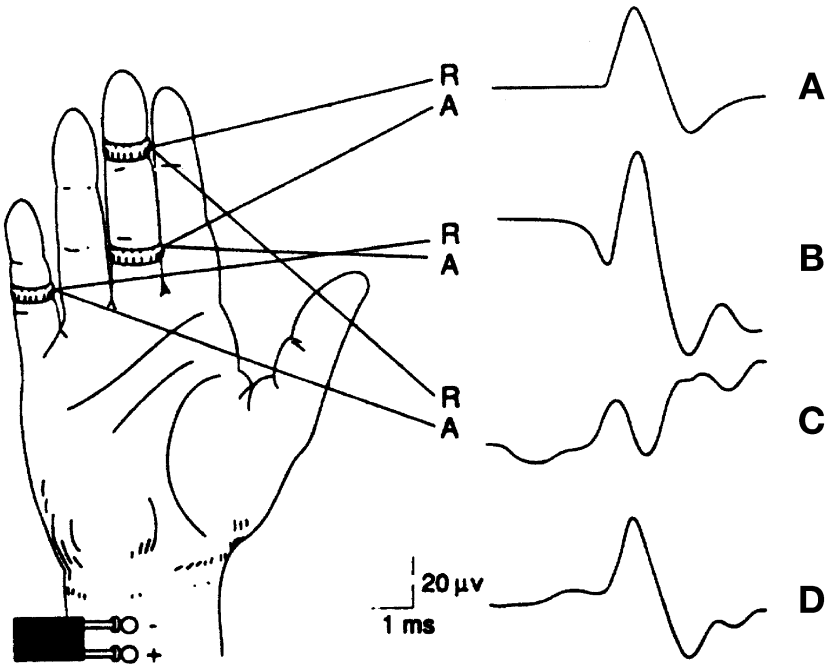

Fig. 3. Median digit 3 sensory studies. Comparisons are made between the standard bipolar arrangement (A) and other arrangements to better understand how the standard potential is generated. In A, the active electrode "A" and the reference electrode "R" are both placed on digit 3 to obtain the standard bipolar recording. In B, the reference electrode is moved to digit 5 to produce a true "referential recording." Note how an initial positivity is observed (because of the approaching wavefront) and the peak-to-peak amplitude is higher than the baseline-to-peak observed in A. In C, the reference electrode is maintained on digit 3, but the active electrode "A" is moved away. This reveals what is being recorded by the reference electrode alone: a small initial negativity and larger second positivity. In D, the responses from B and C are digitally added, giving approximately what is observed in A.

Regardless, the negative peak amplitude that is being measured is still very much a product of what the two electrodes are sensing. It is appealing to think that the active electrode is sensing the depolarization of the muscle and the inactive is seeing a flat line. This is actually pretty much the case for standard median and peroneal motor conduction studies, in which only a small subset of muscles on the hand or foot are depolarizing. However, this is definitely not true in ulnar and tibial motor studies, in which the majority of the muscles in the hand and foot are all depolarizing, essentially "electrifying" the entire structure. This was demonstrated by Kincaid et al., in a study in which the authors evaluated what the reference electrode was actually seeing in different parts of the hand (Figs. 4 and 5). In these studies, the active electrode was placed on different parts of the hand and the reference electrode was moved to the opposite side of the body so that E2 could be viewed as a true reference. As can be seen, nearly the entire hand is "electrified" when the ulnar nerve is stimulated (Fig. 4) and volume-conducted waveforms can be picked up all over the hand (even on the tips of the fingers); hence, there really is no inactive site for this muscle. When stimulating the median nerve, however, virtually no activity is picked up in any location, except in the region of the thenar eminence (Fig. 5). Similar results are also found by evaluating the tibial and peroneal nerves in the feet; the tibial nerve analogous to the ulnar and the peroneal nerve is analogous to the median.

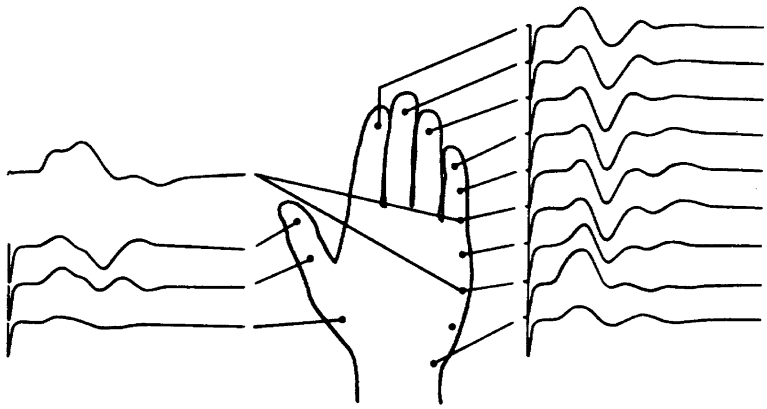

Fig. 4. Volume-conducted potentials recorded from various parts of the hand with stimulation of the *ulnar* nerve. Note how potentials can be recorded from nearly the entire hand, even the tips of the fingers. From Kincaid et al., 1993 with permission.

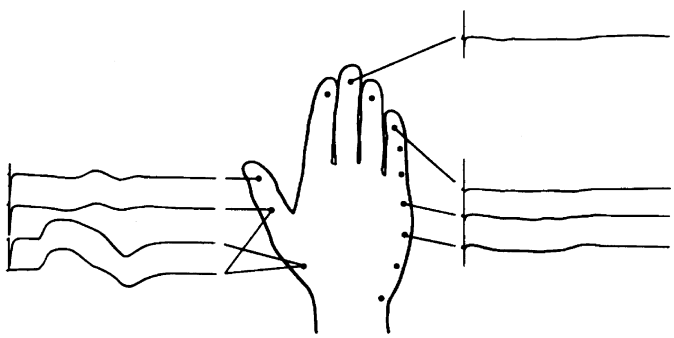

Fig. 5. Volume conducted potentials recorded from the hand with stimulation of the *median* nerve. Note how potentials can only be recorded in the vicinity of the thenar eminence, where the median-innervated muscles reside. From Kincaid et al., 1993 with permission.

Hence, when performing a standard ulnar motor study, the ultimate configuration of the motor response is a composite of what E1 and E2 are sensing. The large positivity that is sensed over the fifth metacarpal–phalangeal joint is subtracted from the response detected directly over the hypothenar muscles. Subtracting this positivity will cause it to become a negativity, leading to the characteristic "double-humped" ulnar motor potential (Fig. 6). The same exercise for the median nerve, on the other hand, produces essentially no change in the amplitude/configuration of the motor response because the E2 activity is negligible.

4.3. EMG

4.3.1. Fibrillation Potentials and Positive Sharp Waves

Fibrillation potentials and positive sharp waves are both produced by the electrical depolarization of single muscle fibers. However, they have dramatically different morphologies, as illustrated in Figs. 3 and 4, Chapter 14. They appear so dissimilar because of volume conduction effects. Fibrillation potentials are thought to represent the depolarization of a single muscle fiber observed from a short distance by the needle electrode. Hence, the reason for its triphasic nature is very similar to a sensory nerve conduction study, with an approaching

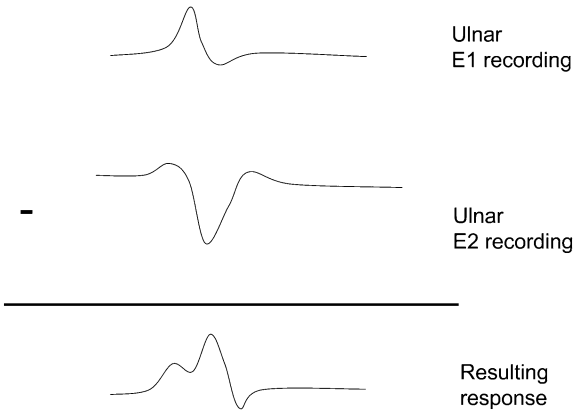

Fig. 6. Approximate digital addition of the ulnar motor response recorded from the hypothenar eminence and that recorded from the fifth MCP joint, leading to the typical "double-humped" ulnar motor response.

wave front causing the initial positivity, the major negative spike being induced by the depolarization traveling underneath the electrode, and the trailing positivity caused by the departing wavefront. This is in contrast with a positive sharp wave, in which it is proposed that needle is in actual contact with the fiber being recorded. The mechanical deformation of the myocyte membrane by the needle is thought to partially depolarize the cell. Hence, the approaching wave front produces an initial positivity and then the negativity begins to develop, but essentially aborts as it comes into contact with the depolarized area of muscle membrane. Although these are only models and the real phenomenon is likely more complex, they are helpful in understanding how two different waveforms can be produced by a single generator.

4.3.2. End-Plate Spikes

These potentials are similar to fibrillation potentials in that they represent the depolarization of a single muscle fiber. However, they are different in that needle movement at the end plate induces the firing of the muscle fiber and, hence, the action potential is generated immediately beneath the needle. Accordingly, unlike fibrillation potentials, they are usually biphasic—with an initial negativity followed by a positivity. The fact that these potentials are generated immediately beneath the needle is similar to a motor conduction study, in which the depolarization of the muscle fibers begins under the surface electrode.

4.3.3. Motor Unit Potentials

When in close proximity to the muscle fibers of a single motor unit, the motor unit potential will have higher amplitude and, when more distant, the amplitude will decrease and the general sharpness of this waveform will decrease. The duration tends to be more immune to these volume conduction and tissue filtering effects, with it being relatively consistent regardless of the distance the needle electrode is placed from the motor unit potential being recorded. Hence, the single most useful parameter when evaluating a motor unit is its duration.

4.4. Somatosensory Evoked Potentials

Somatosensory potentials are usually recorded in a bipolar fashion with both recording electrodes placed near the generator source (e.g., spinal cord or scalp). This approach measures near-field potentials. However, by widely spacing the recording electrodes, early waveforms in the form of far-field potentials can also be observed. Although initially

thought to be due to a specific neuronal generator of some form, such as ganglia or individual neurons, it was recognized by Jun Kimura and others that these waveforms were actually being caused by a waveform traveling from one body segment into another, the so-called standing waves or virtual dipoles noted above in Section 3. These waveforms have also been called "junctional" or "boundary" potentials. The most prominent and most carefully studied of these is the P9 potential obtained with stimulation of the median nerve. It is thought that this is caused by the intersection of the arm with the trunk. Similar "virtual dipoles" can be demonstrated in standard digital sensory nerve conduction studies, if performed in a referential fashion; however, these are usually irrelevant when performed in a standard bipolar manner.

SUGGESTED READING

Dumitru D, Delisa JA. AAEM Minimonograph #10: Volume Conduction. Muscle Nerve 1991;14:605–624.

Frith RW, Benstead TJ, Daube JR. Stationary waves recorded at the shoulder after median nerve stimulation. Neurology 1986;36:1458–1464.

Kimura J, Kimura A, Ishida T, et al. What determines the latency and amplitude of stationary peaks in far-field recordings? Ann Neurol 1986;19(5):479–486.

Kincaid JC, Brashear A, Markand ON. The influence of the reference electrode on CMAP configuration. Muscle Nerve 1993;16(4):392–396.

Lagerlund TD. Volume conduction. In: Daube J, ed. Clinical Neurophysiology. Oxford University Press, New York, NY, 2002, pp. 28–36.

REVIEW QUESTIONS

1. What causes the initial positivity of a normal median compound motor action potential when the active electrode is *not* placed over the motor point of the abductor pollicis brevis muscle?
   A. Depolarization of distant muscles.
   B. A retreating wavefront.
   C. An approaching wavefront.
   D. A stationary wavefront.
   E. None of the above.
2. End-plate spikes lack an initial positivity because:
   A. The depolarization initiates immediately beneath the needle.
   B. They are not generated by muscle fibers.
   C. The axon initiates the depolarization.
   D. The wavefront is forced to abruptly stop by the presence of the needle.
   E. The depolarization involves only the proximal portion of the muscle fiber.
3. In the volume conduction model described, which of the following is true?
   A. The depolarizing wavefront produces current lines that fan out away from the current sink.
   B. There is symmetry between the depolarizing and repolarizing regions of the nerve.
   C. Inward current produces a negative deflection on the oscilloscope regardless of the location of the electrodes.
   D. The rise time of the observed potential is independent of distance from the axon.
   E. Electrons are moving in the direction opposite current flow.
4. Which of the following statements regarding positive sharp waves and fibrillation potentials is true?
   A. Positive waves represent an action potential traveling down a large muscle fiber; fibrillation potentials represent an action potential traveling down a small muscle fiber.
   B. Fibrillation potentials are recorded when the needle is in contact with a muscle fiber.
   C. Fibrillation potentials are induced by movement of the needle against the muscle fiber.
   D. Positive sharp waves result from an aborted muscle fiber depolarization.
   E. Fibrillation potentials initiate immediately beneath the recording needle electrode.

5. Which of the following SSEP peaks is caused by a virtual dipole?
   A. P9.
   B. P22.
   C. N13.
   D. N5.
   E. N20.
6. An initial positivity can be observed on median antidromic digit 2 sensory recordings by doing which of the following?
   A. Moving the active electrode to digit 5.
   B. Moving the reference electrode to digit 5.
   C. Moving both electrodes to digit 5.
   D. Moving the recording electrodes more closely together.
   E. B and D are both correct.
7. Which of the following statements concerning the reference electrode in a motor recording is most accurate?
   A. It is electrically inactive.
   B. It detects electrical activity from nondepolarizing muscles.
   C. Although electrical active, it usually does not contribute substantially to the recorded waveform with median nerve studies.
   D. Although electrical active, it usually does not contribute substantially to the recorded waveform with tibial nerve studies.
   E. Placing it over a bone ensures that no distant muscle activity is detected.
8. In the absence of a volume conductor, a triphasic wave (e.g., a fibrillation potential) would appear as which of the following?
   A. A biphasic wave with a prominent initial positive peak.
   B. A triphasic wave.
   C. A negative monophasic wave.
   D. A biphasic wave with a prominent trailing positive peak.
   E. An inverted triphasic wave.
9. Which of the following is most likely to have an initial positivity under normal recording conditions?
   A. An antidromic digit 3 median sensory response.
   B. An antidromic digit 5 ulnar sensory response.
   C. An antidromic sural response recorded at the ankle.
   D. A tibial motor response.
   E. A peroneal motor response.
10. An example of a far-field potential is:
   A. A median motor response with the recording electrode over abductor pollicis brevis.
   B. A sural sensory response recorded at the ankle.
   C. Ulnar motor activity detected at the tip of digit 5.
   D. The N14 peak, generated by the medial lemniscus, on upper extremity SSEPs detected on scalp recordings.
   E. C and D are both correct.

REVIEW ANSWERS

1. The correct answer is C. The approaching wavefront causes the initial positivity. Although the depolarization of distant muscles can also cause this phenomenon, this is unlikely to be the case here. A retreating wavefront contributes to the final positivity. Stationary wave fronts are generally not observed in median motor responses.
2. The correct answer is A. In most circumstances, end-plate spikes are generated by the needle tip directly causing a depolarization of the end plate, with the depolarization then traveling away

from the point of contact with the muscle. Hence, an initial negativity is followed by a final positivity. The axon does not initiate the depolarization. The abrupt ending of a muscle fiber depolarization caused by the presence of a needle causes a positive sharp wave, not end-plate spikes.

3. The correct answer is A. The fanning out of the current lines through the medium is essentially what causes volume conduction-related effects. There is *asymmetry* between the depolarizing and repolarizing regions of the nerve because repolarization is a slower process than depolarization. The inward current may produce a negative or positive deflection depending on where the recording electrode is relative to the depolarization. The rise time of the potential increases the further the electrode moves from the nerve. Electrons do not move freely through solution~~ion~~s do.
4. The correct answer is D. Positive sharp waves result when a muscle fiber depolarization abruptly aborts as it travels down the muscle fiber, likely because the needle is in contact with the muscle fiber. Although the amplitude of fibrillation potentials and positive sharp waves is related to muscle fiber size, at least to some extent, size does not result in different morphologies of the recorded waveform. Fibrillation potentials are generally thought to be identified when the needle is not in contact with the muscle fiber. Fibrillation potentials can initiate anywhere relative to the needle electrode.
5. The correct answer is P9. This one is thought to be cause by the change in conduction as the potential crosses from the arm into the trunk.
6. The correct answer is B. By moving the reference electrode to digit 5, the approaching wavefront on the median nerve, which causes the initial positivity, will only be seen by the active electrode and, hence, will appear. Normally, it would be detected by both electrodes and, therefore, cancelled out. Moving the electrodes closer together would decrease the amplitude of the recorded response but would do little else.
7. The correct answer is C. In median and peroneal motor recordings, the reference electrode generally detects very little electrical activity. The reference electrode is "active" in that it is helping to produce the differential recording and, if a muscle is not depolarizing, there is no electrical activity to record. In tibial recordings, the reference electrode detects considerable volume-conducted electrical activity. Although we would like to think that placing the electrode over the bone ensures that no distant muscle activity will be detected, this is not true.
8. The correct answer is C. Without volume conduction, the arriving and departing waveforms would not be detected and the triphasic wave would become a monophasic, somewhat asymmetric negative peak, as shown in Fig. 2. The asymmetry is because the rate of repolarization is slower than the rate of depolarization. None of the other answers is valid.
9. The correct answer is C. Sural and radial sensory responses can be thought of more as "referential" than as "bipolar" because both electrodes are not oriented identically in relation to the nerve, allowing the initial positivity to appear. In standard digit 3 and digit 5 recordings, there is no positivity because they are bipolar recordings and the approaching waveform is seen simultaneously by both electrodes and cancelled out. Motor responses usually do not have initial positivities because the active electrode is placed immediately above the motor point, where the depolarization of the muscle fibers begins. Hence, there is no approaching waveform to cause the positivity.
10. The correct answer is E. In both cases, the electrical activity is being recorded at a distance rather than in the immediate proximity of the generator. In the other two examples, the recording electrodes are placed as close to the generator as possible.