Somatosensory evoked potentials and sensory nerve conduction velocities in the thoracic limb of mallard ducks (Anas platyrhynchos)

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Objective—To develop a clinically applicable technique for recording cord dorsum potentials (CDPs) following stimulation of the radial and ulnar nerves and establish reference values for radial and ulnar sensory nerve conduction velocities (SNCVs) in the wings of ducks.

Animals—8 clinically normal adult female mallard ducks (Anas platyrhynchos).

Procedures—Radial and ulnar compound nerve action potentials (CNAPs) and CDPs were recorded following distal sensory nerve stimulation. The CDPs were recorded from the interarcuate space between the last cervical vertebra and the first thoracic vertebra. Surgical dissection and transection of the brachial plexus in 1 anesthetized duck were performed to identify nerve root location and confirm functional loss of nerve conduction assessed by loss of the CDP.

Results—Radial and ulnar CNAPs and CDPs were consistently recorded in all birds. Median radial SNCV was 39.3 m/s (range, 36.0 to 49.0 m/s), and ulnar SNCV was 35.3 m/s (range, 28.0 to 40.0 m/s). Surgical transection of the brachial plexus resulted in complete loss of the CDP.

Conclusions and Clinical Relevance—Measurement of radial and ulnar SNCV or CDP is feasible in isoflurane-anesthetized mallard ducks. The CDP accurately reflects sensory nerve conduction through the brachial plexus. Assessment of brachial plexus function in mallard ducks via evaluations of SNCVs and CDPs may have application for diagnosis of traumatic injuries to the brachial plexus, evaluation of neuropathies associated with exposure to toxic chemicals, and assessment of the efficacy of interventions such as brachial plexus nerve blockade. (Am J Vet Res 2008;69:1476–1480)

Electrodiagnostic examination is a fairly noninvasive method of assessing functional neuromuscular disorders in veterinary and human medicine. Routine electrodiagnostic examinations in domestic animals often include electromyography, motor and sensory nerve conduction evaluations, and assessment of SSEPs. Results of these diagnostic tests can help clinicians distinguish between myopathic and neuropathic (axonal or demyelinating) disease processes as well as differentiate between proximal and distal lesions within the peripheral nerves. Motor nerve conduction velocities can be determined by stimulating a minimum of 2 sites along a peripheral nerve and recording the compound muscle action potential (M wave) from a muscle innervated by that nerve. The SNCVs are determined by recording the conducted volley along a peripheral nerve following sensory nerve stimulation. The CNAP is a reflection of peripheral sensory nerve function. Cord dorsum potentials are stationary field potentials that are generated by pools of spinal cord interneurons in the lumbar and cervical intumescences. The presence of a CDP indicates that conducted sensory nerve action potentials from the brachial or lumbar plexus have reached the spinal cord. Despite the development of neuromuscular disorders in avian species, electrodiagnostic evaluations are not routinely performed, and to our knowledge, there is little information describing electrodiagnostic techniques in birds. Electromyography has been used to confirm the presence of brachial plexus avulsions in red-tailed hawks (Buteo jamaicensis) and assess organophosphate-induced delayed neuromuscular blockade.

ABBREVIATIONS
CDP Cord dorsum potential
CNAP Compound nerve action potential
MNCV Motor nerve conduction velocity
SNCV Sensory nerve conduction velocity
SSEP Somatosensory evoked (spinal cord) potential

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pathy in chickens.\(^9\) Reference values for ulnar MNCVs have been determined for rheas (\textit{Rhea americana}) and barred owls (\textit{Strix varia}),\(^1\) and cerebral SSEPs have been evaluated in studies\(^2\) to assess the efficacy of electrical stunning following stimulation of the radial nerve in chickens. Conduction velocities and evoked potentials have also been recorded following radial nerve stimulation and during open surgical laminectomy procedures in pigeons.\(^8,10\) Results of similar invasive experiments investigating evoked potentials and SNCVs following stimulation of the caudal cutaneous femoral nerve in chickens have been reported.\(^11\)

The purpose of the study reported here was to develop a clinically applicable technique for recording CDPs following stimulation of the radial and ulnar nerves and establish reference values for radial and ulnar SNCVs in the wings of ducks. We hypothesized that CNAPs and CDPs could be consistently measured in birds following noninvasive stimulation of the radial and ulnar nerves and that the presence of the CDP would reflect the integrity of the brachial plexus. Mallard ducks (\textit{Anas platyrhynchos}) were chosen as the model species for evaluating these techniques because of their size, tractability, and wing anatomy. It was anticipated that the SNCV and CDP values could potentially be used for assessment of brachial plexus integrity and function in mallard ducks and may be clinically applicable in the diagnosis of traumatic injuries to the brachial plexus; evaluation of toxic neuropathies associated with chemicals such as lead,\(^12,13\) arsenic,\(^14\) and \(n\)-hexane\(^15\), or assessment of the efficacy of therapeutic interventions such as a brachial plexus nerve blockade in this avian species.

**Materials and Methods**

**Ducks**—Eight adult female mallard ducks (\textit{Anas platyrhynchos}) that weighed 0.9 to 1.1 kg were obtained from a commercial breeder. Physical examination, CBC, and plasma biochemical analyses were performed on each duck to evaluate its health status prior to study commencement. The study was approved by the Institutional Care and Use Committee of the University of California, Davis (protocol No. 06-12209).

**Anesthesia and instrumentation**—Each duck was manually restrained, and anesthesia was induced with 5% isoflurane\(^6\) administered via a face mask. Once relaxation occurred, each duck was intubated with an uncuffed 3.0- or 3.5-mm-diameter endotracheal tube and maintained via inhalation of 1.5% to 3.5% isoflurane for the duration of the procedure. A capnometer\(^8\) was attached to the endotracheal tube, and end-tidal \(\text{CO}_2\) concentration was measured. Intermittent positive-pressure ventilation was instituted to maintain end-tidal \(\text{CO}_2\) values at 25 to 45 mm Hg. Core body temperature was measured by use of an esophageal thermometer.\(^7\) A circulating warm water blanket and external heat lamp were used to maintain body temperature at 37\(^\circ\)C to 39\(^\circ\)C. Heart rate was monitored by use of a 9.7-Hz adult flat Doppler probe\(^7\) placed over the medial metatarsal artery. A cuff with a width approximately equal to 40% of the pelvic limb circumference was placed proximal to the Doppler probe and attached to a manual sphygmo- manometer\(^7\) for measurement of systolic arterial blood pressure. Depth of anesthesia was monitored on the basis of a combination of clinical signs (eg, muscle tone and withdrawal reflexes) and autonomic responses (heart rate and arterial blood pressures), and alterations in the concentration of inhalant anesthetic were made accordingly.

**Experimental design**—In 5 of the 8 birds, both the left and right wings were evaluated (a washout period of at least 2 weeks was allowed to elapse between evaluations); in 3 birds, only 1 wing was evaluated. The single test wing or order of wing testing was determined by stratified random selection.

Each bird was placed in lateral recumbency with the test wing fully extended and supported from an elevated clamp. This provided access to the entire ventral aspect of the wing. Pairs of polytetrafluoroethylene-coated stainless steel monopolar electrodes\(^6\) were used for both stimulating and recording purposes; tip exposure was 5 mm for all electrodes. An additional platinum subdermal needle electrode\(^6\) was used as a ground electrode and inserted SC between the radius and ulna at a point halfway between the stimulating and recording electrodes. A surface temperature probe\(^7\) was positioned on the wing just cranial to the ground electrode. Wing temperature was maintained at 32\(^\circ\) to 36\(^\circ\)C by use of an infrared heat lamp.

Prior to each procedure, electrodes were sterilized in boiling deionized water for a minimum of 20 minutes. Electrodes were then electrolytically cleaned to reduce electrode impedance\(^6\) to \(5 \text{ k}\Omega\). All stimulating and recording electrodes were 20 mm in length except the cord dorsum recording electrode, which was 25 mm in length.

Two stimulating electrodes for the radial nerve were placed percutaneously at the cranial edge of the wing near the center of the carpometacarpus; 1 electrode was placed dorsally and 1 electrode was placed ventrally beneath the secondary feathers (Figure 1). Two stimulating electrodes for the ulnar nerve were placed percutaneously at the caudal edge of the ventral aspect of the wing near the center of the metacarpus. The cathode and anode of each pair were separated by a distance of 7 mm, and the electrode tips were positioned proximally with the electrodes parallel to one another. Each pair was connected to separate stimulator probes.\(^6\) The stimulator probes were isolated by use of transformer isolation. The recording electrodes for the ulnar nerve were placed percutaneously, adjacent to the cutaneous ulnar vein near the medial aspect of the point of the elbow. The recording electrodes for the radial nerve were placed percutaneously, cranial to the point of the elbow approximately halfway between the caudal aspect of the elbow joint and the cranial edge of the wing. The reference electrodes were placed 7 mm cranial to the recording electrodes. Both sets of recording electrodes were oriented with the tips pointing proximally. Placement of the cord dorsum electrode was performed by palpating the depression between the last cervical vertebra and the first thoracic vertebra and gently inserting the needle into the interarcuate space. A reference electrode was positioned SC approximately 3 cm laterally adjacent to the cord dorsum electrode.
Stimulus intensity of 5 mA was used for both SNCVs and CDPs; a supramaximal stimulus was achieved at 7 Hz for 0.2 milliseconds by use of a rectangular stimulus pulse. At least 1,000 impulses were averaged. Distance between stimulation and recording sites on the surface of the skin was determined with a tape measure along the presumed course of the nerve. Latency was defined as the time between the stimulus onset and the first positive peak of the CNAP. Amplitudes for the radial and ulnar CNAPs and CDPs were determined by calculating the voltage difference between the first positive peak and the highest negative peak. Stimulus intensity, CNAP latency, CNAP amplitude, and CDP amplitude following sensory nerve stimulation were determined by use of a neurodiagnostic system. The SNCV was calculated as the stimulus to recording site distance divided by the CNAP latency. Ducks were monitored for adverse effects for 24 hours after the procedures.

To assess the effect of brachial plexus transection on SSEPs, surgical exploration and open unilateral transection of all brachial plexus nerve roots were performed on 1 anesthetized duck. The duck was positioned in lateral recumbency with the test wing fully extended and suspended from an elevated clamp; after placement of electrodes as described, initial electrophysiology measurements were obtained. Without altering the position of the wing or electrodes, a 1.5-cm skin incision was made in the ventral axillary region. Via careful blunt dissection of the subcutaneous tissues, the brachial plexus and all 4 branches of the brachial plexus (ventral branches of the 2 most caudal cervical spinal nerves and 2 most cranial thoracic spinal nerves) were exposed and transected. Electrodiagnostic procedures were then repeated. The anesthetized duck was euthanatized via IV injection of pentobarbital sodium and phenytoin sodium following this procedure.

**Statistical analysis**—For ducks in which both wings were evaluated, electrophysiologic values derived from the 2 wings were averaged and the mean value was used for overall analysis; single values were used for analysis in birds in which only 1 wing was evaluated. Because of the small sample size, data sets were analyzed via nonparametric methods. Association between each electrophysiologic measurement and wing temperature was evaluated by use of Spearman rank correlation coefficients. Ulnar SNCV was compared with radial SNCV by use of a Mann-Whitney U test. Results were considered significant at a value of P ≤ 0.05. Results are presented as median and range.

**Results**

Each duck was considered clinically normal on the basis of physical examination findings; results for a CBC and plasma biochemical analyses were within reference ranges for mallard ducks. Radial and ulnar CNAPs and CDPs were consistently recorded for all ducks (Table 1). There was no significant difference between the median radial SNCV (38.3 m/s; range, 36.0 to 49.0 m/s) and median ulnar SNCV (35.3 m/s; range, 28.0 to 40.0 m/s). No significant correlation was determined between SNCV and wing temperature in the temperature range tested (32.0° to 36.0°C).

Dissection of the brachial plexus in 1 anesthetized duck clearly revealed the branches of the brachial plexus. Prior to surgery, initial electrophysiologic measurements including SNCV and CNAP values were obtained (radial SNCV, 49.0 m/s; ulnar SNCV, 40.0 m/s; radial CNAP amplitude, 1.5 µV; and ulnar CNAP amplitude, 12.9 µV). The initial CDP amplitudes were obtained from the radial nerve (3.9 µV) and from the ulnar nerve (18.0 µV) following stimulation. Following surgical transection of the branches of the brachial plexus, the CDP was no longer present following either radial nerve or ulnar nerve stimulation (0.0 µV);

**Table 1**—Sensory nerve stimulation data (median [range]) for the radial and ulnar nerves in 8 mallard ducks (Anas platyrhynchos) and wing temperature conditions (median [range]) during assessments.

<table>
<thead>
<tr>
<th>Nerve</th>
<th>SNCV (m/s)</th>
<th>CNAP (µV)</th>
<th>CDP amplitude (µV)</th>
<th>Wing temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radial</td>
<td>38.3 (36.0–49.0)</td>
<td>1.7 (0.9–6.3)</td>
<td>6.9 (3.9–18.8)</td>
<td>35.6 (34.0–36.6)</td>
</tr>
<tr>
<td>Ulnar</td>
<td>35.3 (28.0–40.0)</td>
<td>4.1 (2.3–12.9)</td>
<td>10.6 (1.9–18.0)</td>
<td>35.5 (34.6–36.7)</td>
</tr>
</tbody>
</table>
however, there was no substantial change in SNCV or CNAP amplitude (radial SNCV, 43.0 m/s; ulnar SNCV, 36.0 m/s; radial CNAP amplitude, 2.3 \( \mu \)V; and ulnar CNAP amplitude, 10.7 \( \mu \)V; Figure 2).

One duck died during recovery from anesthesia, likely as a result of endotracheal tube obstruction with thick tracheal secretions. Gross necropsy of this bird and histologic examination of tissues did not reveal any additional abnormalities. No adverse effects were observed in any other ducks during the 24-hour period following these procedures.

Discussion

Radial and ulnar SNCVs were consistently measured in mallard ducks in the present study. Values for SNCV in the mallard ducks were much lower than those previously reported for dogs (mean \( \pm \) SD radial SNCV, 61.7 \( \pm \) 0.76 m/s; ulnar SNCV, 68.4 \( \pm \) 2.71 m/s)\(^3\) and cats (radial SNCV, 83.6 \( \pm \) 8.3 m/s; ulnar SNCV, 89.2 \( \pm \) 10.3 m/s).\(^9\) Sensory nerve conduction velocities in other avian species are also reported to be slower than those recorded for mammals; cutaneous radial SNCV in pigeons was 50 m/s,\(^9\) and cut femoral SNCV in chickens was 43 m/s.\(^11\) Conduction velocity is affected by nerve-fiber diameter and the thickness of the myelin sheath. In pigeons, the cutaneous antebrachii lateralis nerve (cutaneous branch of the radial nerve) has a smaller nerve diameter and a thinner myelin sheath (as determined via electron microscopy) than the corresponding nerves in mammalian species of similar or larger body sizes; similar nerve characteristics in mallard ducks and other avian species may explain the comparatively slower SNCVs recorded in the present and previous studies.\(^9,11\) Further research is warranted to evaluate the relationship between these electrophysiologic findings and the anatomic or morphometric characteristics of sensory nerves in mallard ducks, compared with other avian species and mammals.

In the ducks of the present study, the CDP was consistently recorded. When the brachial plexus was surgically transected in 1 bird, there was complete loss of the CDP, yet the radial and ulnar SNCV and CNAP values changed minimally. These results indicate that the CDP accurately reflects sensory nerve conduction through the brachial plexus in mallard ducks.

Efforts were made to maintain core body and wing temperatures at constant values throughout the electrodiagnostic evaluations. Wing temperatures in the ducks of the present study were consistent with wing temperatures among healthy pigeons.\(^9,20\) No significant correlation between wing temperature and radial or ulnar SNCV in mallard ducks was evident in our study. In other investigations, linear relationships between MNCV and limb temperature in juvenile chickens\(^21\) and between tibial MNCV and cloacal temperature in healthy adult chickens\(^22\) were identified. Linear associations between ulnar MNCV and tissue temperature in dogs\(^23\) and between lateral palmar SNCV and limb temperature in horses\(^24\) have also been determined. However, the 4 aforementioned studies investigated variation in conduction velocity over a wider range of temperatures. In the present study, wing temperature was maintained within a narrow temperature range (32° to 36°C) to maximize the consistency in electrophysiologic measurements among birds and over time. It is likely that any correlation between temperature and SNCV would

![Figure 2](image-url)
be difficult to detect because of the narrow temperature range and the relatively low number of ducks. Additional studies involving electrophysiologic measurements over a wider range of wing temperatures would be necessary to determine whether similar temperature-dependent variation in SNCV is present in avian sensory nerves.

Female ducks were obtained for use in our study in an attempt to minimize aggression in a group housing setting. Differences between males and females of this species are expected to be minimal. To the authors’ knowledge, data from males and females were pooled in previous avian electrophysiologic studies 6–10,20–22 and there are no reports of significant differences in electrophysiologic measurements obtained from male and female birds. Although variability in conduction velocities and action potential amplitudes was evident among individual birds, radial and ulnar SNCV, CNAP, and CDP values were consistently obtained in our study and may serve as baseline values for adult mallard ducks. The procedures were tolerated well with no apparent adverse effects. The technique used in our study has potential for use in the assessment of brachial plexus function and evaluation of peripheral neuropathies associated with toxic chemicals in birds, and it may have clinical applicability in assessments of the efficacy of brachial plexus nerve blockade in avian species.


b. Tidal wave 713, Respiromics, Carlsbad, Calif.
c. Yellow Springs 700 Thermistor, Measurement Specialties, Dayton, Ohio.
d. Parks Medical Electronics, Aloha, Ore.
e. Speidel & Keller, Jungingen, Germany.
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k. Graphpad Instat, version 3.06, 32 bit for Windows, GraphPad Software Inc, San Diego, Calif.

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