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Contrast Radiography With Positive-Pressure Insufflation in Northern Pintails (*Anas acuta*)

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Abstract: Contrast radiography with positive-pressure insufflation (PPI) at 20 cm of water pressure was evaluated for safety and analyzed for potential diagnostic use in 6 male northern pintails (*Anas acuta*). Ducks were anesthetized for either 2 or 3 procedures, 1 week apart, then euthanized and necropsied after the final procedure. Air sac areas on survey and PPI radiographs were measured to calculate average percent increase of visible air sac area after PPI. No clinical complications resulted from PPI procedures. Birds recovered quickly without respiratory distress. No gross or microscopic respiratory lesions associated with PPI were identified at necropsy. Average percent increases in air sac areas resulting from PPI on lateral and ventrodorsal radiographs were 79% and 90%, respectively. As judged subjectively by attending clinical veterinarians, cardiohepatic, air sac, lung, renal, gastrointestinal, vertebral, and testicular margins and boundaries were more distinct as a result of PPI. PPI in an avian patient using air as a negative contrast medium is a safe, effective technique that potentially allows increased radiographic diagnostic capability.

Key words: contrast radiography, negative contrast, air sac insufflation, positive-pressure ventilation, avian, duck, northern pintail, *Anas acuta*

Introduction

Visualization of internal avian structures can be achieved by a variety of diagnostic imaging techniques, including routine survey or contrast radiography, ultrasonography, fluoroscopy, xeroradiography, nuclear scintigraphy, magnetic resonance imaging, or computed tomography.[1–6] Interpretation of images is generally based on clinical experience and knowledge of avian anatomy. Plain radiographs have potentially limited visualization of avian anatomical details because of overlying, compacted soft tissue structures in addition to typically minimal fat stores within the bird's coelomic cavity that contribute to a lack of contrast.[1,3] Additional imaging techniques may be necessary for aiding the diagnosis of disease conditions in avian patients.[1]

Unlike mammalian respiratory anatomy, the avian respiratory system consists of a series of interconnecting air passages, including bronchi, parabronchi, air capillaries of the lungs, and membranous pulmonary air sacs.[7] Gas exchange occurs within air capillaries, which form a 3-dimensional network encompassed by blood vessels.[7,8] Air sacs are thin walled with limited vascularity and represent an adaptation for efficient respiration, insulation, and buoyancy mechanisms in birds.[7,8] Birds in the order Anseriformes have 4 pairs of air sacs (cervical, cranial thoracic, caudal thoracic, and abdominal) and an unpaired clavicular air sac at the thoracic inlet.[7]

Contrast can be used to improve visualization of details on radiographs. Negative contrast radiography in mammals is generally achieved by placing air or carbon dioxide in body cavities or hollow organs to improve visualization of internal organs and their borders on radiographs. In birds, air sacs provide inherent regions of negative contrast on radiographs through which surrounding structures can often be visualized.[3] In an anesthetized, intubated bird, air sacs can be insufflated manually to increase total air sac area, thus using air as a negative contrast medium. This principle is similar to when a human patient inhales and holds their breath during a chest radiograph. The lung fields are expanded, increasing the air volume, which leads to improved contrast resolution of thoracic structures.

The objectives of this prospective study were to

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investigate the potential diagnostic use of a positive-pressure insufflation (PPI) radiographic technique in northern pintails (*Anas acuta*). No previous reports investigating PPI in avian patients have been published to date.

Materials and Methods

The 6 adult male northern pintails studied were managed in a manner approved by the facility's Animal Care and Use Committee. The pintails were destined for euthanasia because of chronic, progressive disease conditions, including mature cataracts or osteoarthritis, but were in adequate health for the study based on weight, appetite, and attitude. No obvious additional physical problems were observed.

The pintails were divided randomly into 2 groups (n = 3). Two (group A) or 3 (group B) separate procedures were performed 1 week apart to compare different series of procedures intended to duplicate possible clinical time courses of diagnosis and follow-up.

A pilot study at our facility compared PPI radiographs of northern pintails taken at 0, 10, 20, 30, and 40 cm of water (M. B., J. S., unpublished data, October 1998). An insufflation pressure of 20 cm of water proved optimal because higher pressures did not appear to increase the size of the air sacs significantly or to improve the quality of visualization of internal structures, as determined subjectively by attending clinicians (J. S., M. B.). We chose to radiograph at 0 and 20 cm of water pressure to compare visualization and thus potential diagnostic capability.

Anesthesia was induced via facemask with isoflurane (Enflurane, Abbott Laboratories, North Chicago, IL, USA) in oxygen at dosages adjusted to individual patient requirements. Once anesthetized, ducks were intubated with a semiflexible silicone endotracheal tube (2.5-mm internal diameter, uncuffed or cuff not inflated; Aire-Cuf, Bivona Inc, Gary, IN, USA) and maintained at a surgical plane of anesthesia. A rebreathing circuit fitted with a ventilation bag (1 L) and a manometer (units in cm of water) was used.

Tabletop radiographic procedures were used. Anesthetized birds were positioned on 35 × 42.5-cm (14 × 17-in) radiographic cassettes. Whole-body radiographs were taken without and then with PPI. PPI at 20 cm of water pressure was applied manually to the ventilation bag of a closed rebreathing circuit attached to each anesthetized, intubated bird while radiographs were taken. Total procedure time averaged 20 minutes.

After the first procedure, ducks were monitored until recovered and returned to their enclosures for 1 week. To evaluate effects of PPI, ducks were fully recovered after their last procedure, then euthanized with ketamine hydrochloride (100 mg/kg [46 mg/lb] IM; Ketaset, Fort Dodge Animal Health, Fort Dodge, IA, USA), followed 15 minutes later by sodium pentobarbital (390 mg/kg IV; Beuthasol, Delmarva Labs Inc, Midlothian, VA, USA). Complete postmortem examinations were performed either after the second procedure (group A; n = 3), or after a third procedure (group B; n = 3) 1 week later.

Pairs of survey and PPI radiographs (with water pressure levels marked on each radiograph) were critically evaluated by attending veterinarians (M. B., J. S.) for enhanced visualization of internal organs. Visual appearances of radiographic detail and densities, as well as margins of the heart, liver, spleen, lungs, air sacs, kidneys, testes, and intestines, were compared subjectively on each pair of radiographs for observable advantages of PPI. General clinical impressions were noted, but no formal scoring system was employed.

Each radiograph was digitized (Nikon Coolpix 950, Nikon Inc, Melville, NY, USA) and subsequently analyzed by 1 investigator (J. S.) in the following manner. Radiolucent portions of intracoelomic air sacs, which included partial overlap with lung regions, were traced manually via a touch-pad/mouse system with software capable of measuring multiple polygonal areas (Scion Image, Scion Corporation, Frederick, MD, USA). Criteria for boundaries guiding tracings were based upon identification of distinctly visible air densities corresponding to known avian anatomical lung and air sac regions. Figures 1 and 2 depict examples of how the lung and air sac regions were digitally traced to compare total area increases due to PPI.

Radiographs were traced individually as separate images; tracings of pairs of survey and PPI radiographs were not compared during the process of measuring areas. Each radiograph had unique anatomical shapes and varying amounts of overlap of air sacs and lungs. Air densities known to correspond to thoracic and abdominal air sacs and lungs were traced either separately or as 1 polygon depending on the radiograph itself and positioning (lateral or ventrodorsal).

A marker of known length was used on each radiograph to standardize measurements in square millimeters. Only 1 investigator (J. S.) performed all tracings and operated area measurement software; thus, any variations in areas calculated were considered a result of truly observed changes due to PPI. Total air sac and lung areas traced from sur-

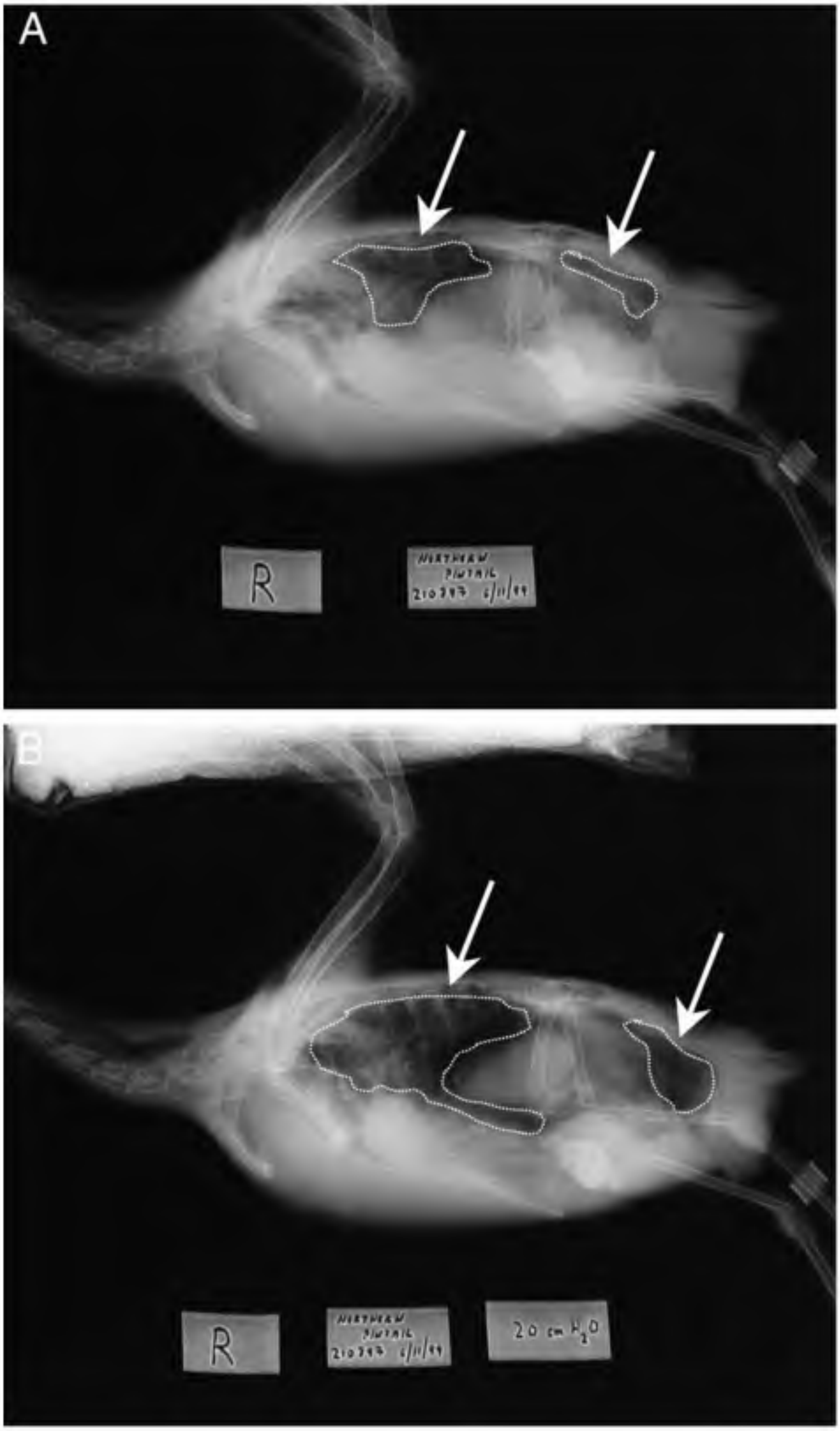

Figure 1. Lateral whole-body radiographs (digitized) of a northern pintail depicting how air sacs and lungs were traced (dashed lines) for area measurement comparisons (arrows) between (A) survey radiographs and (B) radiographs with positive-pressure insufflation techniques.

Figure 2. Ventrodorsal whole-body radiographs (digitized) of a northern pintail depicting how air sacs and lungs were traced (dashed lines) for area measurement comparisons (arrowheads) between (A) survey radiographs and (B) radiographs with positive-pressure insufflation techniques.

vey lateral and ventrodorsal radiographs for each procedure were compared to PPI radiographs of the same views, respectively. For each pintail, the difference between total traced or visible areas of air sacs and lungs was calculated. Differences for each view were combined and averaged as a percent change.

When comparing each bird to itself, minor variations occurred in manual tracings of lungs and air sacs, resulting in slightly different values of total square millimeters from procedure to procedure. These differences resulted from slight changes in radiographic positioning and amount of ingesta present, and from inherent limitations of manual tracing or digitization processes. We did not attempt to statistically analyze these minor variations, given that our primary focus was on visually observable advantages of PPI and not specific area values.

Comprehensive necropsies were performed on each pintail duck within 2 hours of euthanasia. All organs were examined grossly and histopathologically. Tissue sections were fixed in 10% neutral buffered formalin, embedded in paraffin, sectioned at 6 μm, stained with hematoxylin and eosin, and examined microscopically.

Results

Based on clinical assessments by attending veterinarians, visualization of intracoelomic structures on PPI radiographs was improved versus survey radiographs. Boundaries of lungs and air sacs became more distinct because of better contrast resolution with PPI. Cardiohepatic, lung, renal, gastrointestinal, and vertebral margins, as well as testicular shape and size, were more easily distinguished and assessed for potential abnormalities on PPI radiographs versus plain radiographs. Figures 1 through 4 illustrate examples of enhanced visualization of avian internal structures and increased air sac areas achieved with PPI.

Birds recovered quickly without respiratory dis-

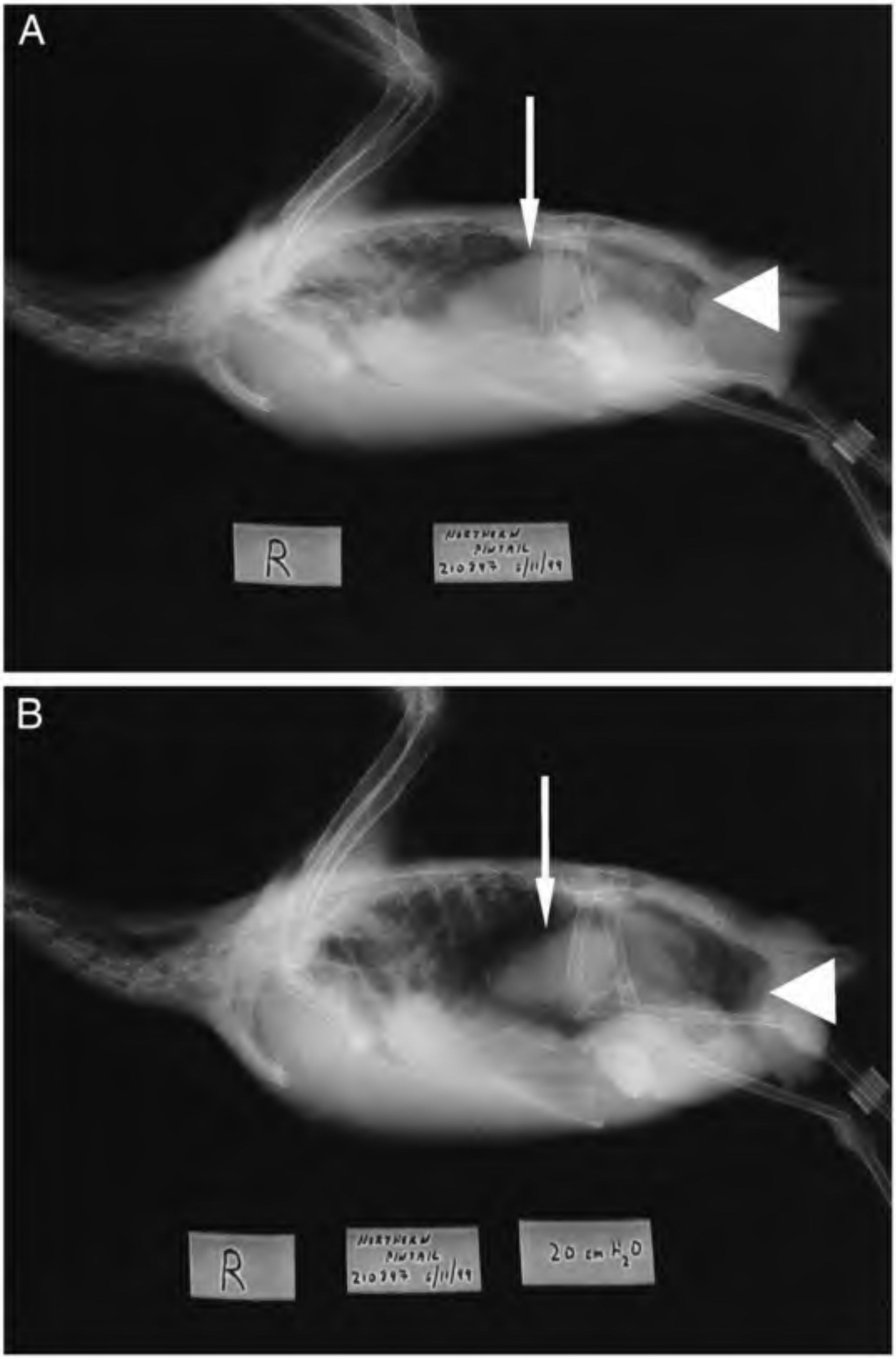

Figure 3. (A) Lateral survey radiograph and (B) lateral positive-pressure insufflation (PPI) radiograph (digitized) of an anesthetized, intubated northern pintail. Note enhanced visualization of internal structures, including testes (arrows) and abdominal air sacs (arrowheads), as a result of PPI.

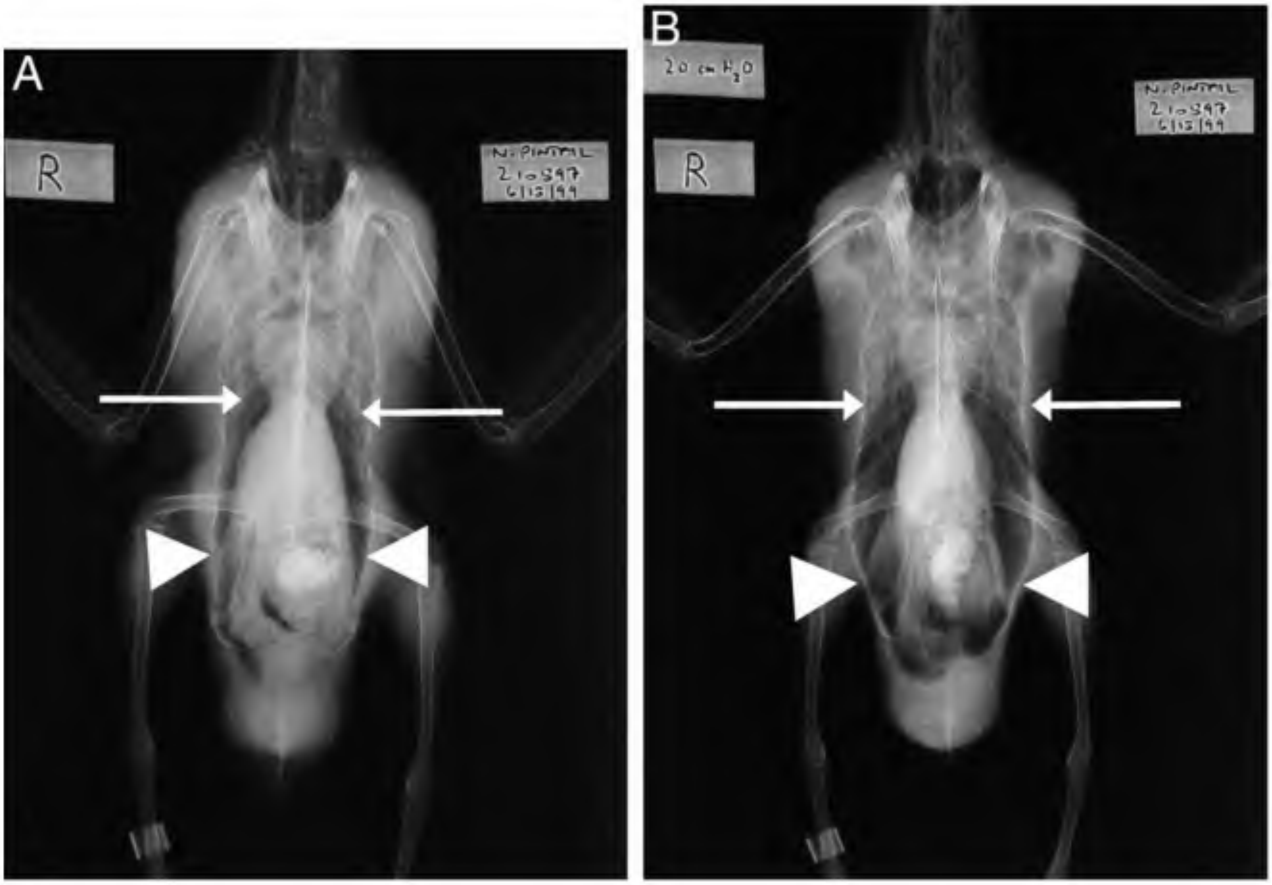

Figure 4. (A) Ventrodorsal survey radiograph and (B) ventrodorsal positive-pressure insufflation (PPI) radiograph (digitized) of an anesthetized, intubated northern pintail. Note enhanced visualization of internal structures, including cardiohepatic silhouettes (arrows) and abdominal air sacs (arrowheads), as a result of PPI.

tress. Because of breath-holding, short periods of assisted respiration were required intermittently during most procedures (14 of 15) to maintain surgical anesthesia and oxygenation of tissues. Pink-tinged mucoid secretions were observed around the tip of the endotracheal tube after extubation in approximately one half of the pintails (7 of 15). Some leakage of anesthetic gases around the endotracheal tube was expected and occurred during PPI, but this did not hinder the ability to maintain 20 cm of water pressure for brief periods (an average of 5 seconds).

On postmortem examination, no gross or histologic lesions attributable to barotrauma were observed. Incidental respiratory tract findings included mild to moderate anthrasilicosis of lung and air sacs, with associated mild to moderate lymphocytic infiltration.

Air sac and lung area measurements (in mm^2) calculated from digitized radiographs, with associated overall percent changes, are presented in Table 1. Average percent area increases resulting from PPI on lateral and ventrodorsal radiographs were 79% and 90%, respectively.

Discussion

Radiography is an important diagnostic tool in avian medicine.[2,3,9] Patient evaluation often includes whole-body survey radiographs to aid in the diagnosis of respiratory system diseases.[1,2,4,8,10] Contrast radiography can be performed with either positive or negative contrast media to further characterize disease conditions. For example, contrast radiography of the psittacine gastrointestinal tract with positive contrast agents (barium sulfate or iohexol) helped identify lesions otherwise not visible on plain films.[11]

Air as a negative contrast medium has few adverse effects and is useful in veterinary patients for enhancing radiographic diagnoses (eg, pneumocystogram and pneumoperitoneogram). Carbon dioxide can also be placed within organs or body cavities to provide negative contrast. Unlike air, carbon dioxide will dissolve in the bloodstream and is preferable in cases where embolization might occur. Air (or oxygen) should be used in avian patients when inflating lungs and air sacs under pressure to main-

Table 1. Differences (delta) and overall percent change between air sac and lung areas measured on digitized ventrodorsal (VD) and lateral (LAT) survey radiographs versus positive-pressure insufflation (PPI) radiographs obtained weekly from 6 pintails for 2 (group A) or 3 (group B) consecutive weeks, respectively.

Pintail group	Wk of study	VD survey lung/air sac area (mm^2)	VD PPI lung/air sac area (mm^2)	VD delta[a]	VD % change[b]	LAT survey lung/air sac area (mm^2)	LAT PPI lung/air sac area (mm^2)	LAT delta[a]	LAT % change[b]
Group A									
Pintail A	1	1755	4270	2515	143	1905	3124	1219	64
	2	1308	3093	1785	136	870	2068	1198	138
Pintail B	1	1980	3847	1867	94	1210	2269	1059	88
	2	1829	3356	1527	83	1113	1910	798	72
Pintail C	1	1412	3260	1848	131	823	1996	1173	143
	2	1497	3283	1786	119	933	1605	671	72
Group B									
Pintail D	1	1252	2359	1107	88	908	1117	209	23
	2	1412	2564	1152	82	691	1663	972	141
	3	1642	2801	1159	71	948	1714	766	81
Pintail E	1	1980	2764	785	40	1562	2454	892	57
	2	2357	3316	959	41	2540	3754	1215	48
	3	1519	1885	366	24	2245	2600	354	16
Pintail F	1	1188	2363	1175	99	825	1430	605	73
	2	1430	2379	949	66	868	1607	739	85
	3	1395	2080	685	49	1145	1503	358	31
Average % change					90				79
Range (%)					24–143				16–143

[a] Delta = PPI area − survey area.
[b] Percent change = delta/survey area × 100.

tain normal exchange of oxygen and carbon dioxide across respiratory tissues. In this study, we demonstrated a radiographic technique for birds that used air within an anesthetic circuit to insufflate lungs and air sacs. This method increases negative contrast on whole-body radiographs to better visualize soft tissue structures. Use of the technique resulted in no observable barotrauma, a finding that suggests the safety of this technique in avian patients.

Ducks in this study were intubated to control positive pressure applied to the respiratory system during PPI radiographs, and to measure positive pressure with an in-circuit manometer. Endotracheal tube cuffs were not inflated because birds have complete tracheal cartilage rings. Inflated cuffs could produce cuff-pressure–induced trauma. For this study, the seal between tube and trachea was sufficient to reach and maintain pressures of 20 cm of water during PPI radiography, with minimal air leakage. This was achieved by using a snugly fitted endotracheal tube.

Avian lungs are partially attached to the dorsal body wall and expand minimally compared to the highly distensible lung lobes of mammals. In 1 study, investigators determined that lung volume in Pekin ducks (*Anas platyrhynchos*) is not altered regularly during the respiratory cycle, and lung volume increases by only 1.4% between midinspiration and midexpiration.[12] Intermittent positive-pressure ventilation of an intubated mammal is generally performed with 20 cm of water, a level considered safe in healthy patients.[13,14] The primary theoretical complication of repeated PPI in an avian patient is barotrauma, likely manifested as air sac rupture or respiratory tissue hemorrhage (petechiae and ecchymoses). In this study, no clinical or histologic evidence of barotrauma was found in either group of intubated pintails after PPI with 20 cm of water pressure.

In 7 of 15 procedures, we observed mucoid secretions at the tip of the endotracheal tube upon extubation; however, this anomaly was not correlated with postprocedural clinical signs or necropsy lesions. Incidental histologic findings, including mild anthrasilicosis with associated lymphocytic infiltration, were attributed to chronic carbon exposure in the birds' atmosphere. These findings were consistent with postmortem lesions previously identified in cohort ducks that had been housed in the same area (R. J. M., unpublished data, January 1996–June 2000).

Analysis of our results demonstrates that PPI subjectively improves visualization of many structures observed radiographically; specifically, borders of the heart, liver, lungs, air sacs, kidneys, vertebral column, and testes became more distinct (Figs 3 and 4). Visualization with comparative PPI radiographs over time allowed us to easily observe such features as seasonal testicular enlargement and regression. These observations were based on clinical impressions of the investigators in this study (M. B., J. S.) as they viewed radiographs. Clinical impressions of the investigators in this study may or may not be equivalent to those of other avian clinicians.

More studies using PPI in other avian species and individual birds with lesions are indicated for documenting anatomical radiographic appearances and pathologic conditions and progressive changes over time. In addition, PPI radiography may be helpful in identifying abnormalities that can be further investigated with other noninvasive imaging modalities, such as ultrasound for liver disease,[15,16] laparoscopy for renal disease,[17] and computed tomography for respiratory tract disease[1] or abdominal swelling.[18]

In this study, PPI with 20 cm of water was a safe and effective technique for physically distending the air sacs of anesthetized northern pintails without respiratory system barotrauma. Radiographs during air sac insufflation improved visualization of internal avian structures on both lateral and ventrodorsal radiographs by increasing air sac areas more than 75%.

Conclusions

Avian PPI radiography is a simple and safe clinical technique that increases the volume of air in the air sacs, providing more negative contrast, resolution, or organ separation, thereby enhancing visualization of structures and thus potential diagnostic capability. We postulate that this technique can provide a minimally invasive method of detecting abnormalities in avian internal organs caused by a variety of conditions, for example, granulomatous infections of lungs and air sacs, hepatic neoplasia, renomegaly, and reproductive system changes.

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