Commercial Broadhead Effect and Quantitative Analysis of Broadhead vs. Firearm Wounds in White-tailed Deer

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Abstract: Trace metal analysis of commercially produced broadheads was conducted to determine the background level of copper and lead contained on the surface of the broadhead following manufacturing. The level of copper and lead from these broadheads was then compared to known copper and lead values from white-tailed deer to determine if inserting a broadhead into the wound tract would influence the quantitative analysis of the wound tract. Although inserting a broadhead into a firearm wound orifice post-mortem changes the morphological appearance of the wound orifice, it does not influence the analysis of the wound tract when analyzed by flame atomic absorption spectrophotometry. Firearm wounds can be differentiated from arrow wounds quantitatively, using flame atomic absorption spectrophotometry, without concern of broadhead interference affecting the results.

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The use of spot chemical tests by chemists to identify copper and lead have been in use for many years (Feigl 1958, Thompson 1996, Feigl and Anger 1972). The application of these tests to the forensic identification of firearm wounds in wildlife, especially white-tailed deer (Odocoileus virginianus) and other big game animals, followed (Stone et al. 1978, Glover 1981, Haag 1981, Woolf and Will 1983, Rhinehart 1983, Steinberg et al. 1984, Lekstrom and Koons 1986, Moore and Haley 1987, Villanueva et al. 1987, Randall and Newby 1989, Stockdale 1989, Adrian 1992). The above tests, however, only provide presumptive evidence because they are qualitative and not quantitative tests. The identification of firearm wounds by flame atomic absorption (FAA) spectrophotometry can provide conclusive evidence since it is a quantitative test (Ravreby 1982, Stockdale 1989).

Broadhead-tipped arrows and firearm wound tracts have morphological and physiological differences. In big game archery hunting, an arrow with a single or multiple blade broadhead is used. The resulting wound tract reflects the geometry of the tip (i.e., a single blade will produce a single straight cut; a 3-bladed broadhead, a Y-shaped cut; a 4-bladed broadhead, a +-shaped cut). A broadhead arrow cuts as it

passes through an animal, causing hemorrhaging, respiratory hypoxia, and/or nerve damage resulting in the death of the animal. An arrow does not have sufficient velocity to create the hydrostatic shock wave and cavitation associated with most firearm projectiles. Therefore, the tissue damage resulting from an arrow wound is confined to the immediate area of the wound tract and does not radiate outward from the wound tract as in a firearm wound. If a broadhead arrow strikes a bone it will cut through the bone, fragment it into large fragments or become imbedded in the bone, depending on the bone's size and density. If the bone is cut into 2 parts, the distal and proximal ends can be articulated.

A firearm projectile impacting the hide of a deer, or similar animal, creates a momentary inward movement of the hide prior to penetration by the projectile, due to the blunt nose of the projectile and the elasticity of the hide. As the bullet penetrates the hide hair is pushed into and along the wound tract. High velocity bullets cause cavitation as they pass through the animal's tissue. A subatmospheric pressure is created by the bullet and cavitation effect which may result in some hair fibers being sucked into the wound tract.

A visual examination of the entrance wound orifice in the hide will usually reveal the presence of an abrasion ring or "collar" around the wound (Randall and Newby 1989). The collar is circular in nature around the wound and is mostly composed of copper, zinc, lead, antimony, nickel and burnt power residues (Ravreby 1982, Villanueva et al. 1987). The collar results from the wiping action as the bullet penetrates the hide. Broadhead-tipped arrows will not leave an abrasion ring around the entrance orifice (Rogers et al. 1990).

A firearm projectile which strikes a bone will create bone fragments of various sizes depending on the particular bone struck, location, and angle of impact. However, in firearm wounds if a bone is fractured there will be numerous minute particles of bone present in the wound tract. The minute particles of bone will be much smaller than those fragments produced by a broadhead arrow.

This study addresses 2 questions: 1) Can FAA spectrophotometry differentiate between archery and firearm wound tracts? and 2) Does the insertion of a broadhead tipped arrow into the wound tract affect the quantitative results of tissue samples examined by FAA analysis?

Methods

Sample Collection

Commercially manufactured archery broadheads were obtained for testing by contacting known manufactures and requesting samples for each type of broadhead they produced (Table 1). Samples were purchased over-the-counter from Bowhunters Discount Warehouse, Inc., Wellsville, Pa., for those brands of broadheads not supplied by the manufacturers (Table 2). One sample of a discontinued Browning Arms Inc., broadhead came from the author's personal collection.

White-tailed deer samples were obtained from hunters or vehicle/deer collisions.

Table 1. Identification of donated broadheads.

ID No.	Brand Name	Weight (grains)	*N* Blades	Blade Material	Manufacturer
12	Koplin Twister 110	110	3	ss[a]	Koplin Manufacturing, Inc.
13	Koplin Twister 120	120	4	ss	Koplin Manufacturing, Inc.
14	Koplin Twister 140	140	3	ss	Koplin Manufacturing, Inc.
15	Koplin Twister 155	155	4	ss	Koplin Manufacturing, Inc.
16	Black Diamond Eskimo	125	2	cs[b]	Zwickey Archery Co.
17	Darton Broadhead	130	3	ss	Darton Archery
18	Darton Broadhead	135	3	ss	Darton Archery
19	Darton Broadhead	140	4	ss	Darton Archery
20	Punchcutter	75	2	ss	Forestline International Corp.
21	Magnus I	125	4	cs	Magnus Archery
22	Magnus II	140	4	cs	Magnus Archery
23	The Varminter	110	2	ss	Varminter, Inc.
24	Rothhaar Snuffer	200	3	cs	Rothhaar
25	Rothhaar Snuffer (unfinished)	200	3	cs	Rothhaar
26	Slivertip	100	3	ss	Ben Pearson Archer
27	Low Profile	115	4	ss	Ben Pearson Archer
28	Interceptor	190	2	cs	The Simmons System
31	MA-3-S Penetrator	100	3	cs	DEL MA Archery Mfg. Co.
32	MA-3-L Penetrator	125	3	cs	DEL MA Archery Mfg. Co.
33	MA-2-105 Penetrator	105	2	cs	DEL MA Archery Mfg. Co.
34	Zapper	125	3	ss	Bohning Co. Ltd.
35	HC Blazer Max	185	4	cs	Bohning Co. Ltd.
36	Blazer SS	135	4	ss	Bohning Co. Ltd.
37	Ultimate Arrowhead	70	4	polymer	The Compound House
38	Ultimate Arrowhead	100	4	polymer	The Compound House
39	Game Tracker Lightning	90	3	ss	Game Tracker, Inc.
40	Game Tracker Double Cut	130	3	ss	Game Tracker, Inc.
41	Game Tracker 125	125	4	ss	Game Tracker, Inc.
42	Lazer Pro Mag	135	4	ss	Cabela's
43	Savora Super-S Swept-Wing III	117	3	cs	Archers-Ammo, Inc.
44	Savora Super-S Swept-Wing IV	126	4	cs	Archers-Ammo, Inc.
45	Savora Super-Flite	107	3	cs	Archers-Ammo, Inc.
46	Thunder Head 125	125	3	ss	New Archery Products, Inc.
47	Thunder Head 150	150	2	ss	New Archery Products, Ins.
48	Thunder Head 160	160	3	ss	New Archery Products, Inc.
49	Razorbak 4	142	4	ss	New Archery products, Inc.
50	Razorbak 5	142	5	ss	New Archery Products, Inc.
51	Bow Bullet	145	4	ss	Hoyt/Easton Archery Co.
52	Black Hole	130	4	ss	Hoyt/Easton Archery Co.
53	Camo Hunter	145	4	ss	Hoyt/Easton Archery Co.
54	Chuck-It Maxi	95	4	ss	Hoyt/Easton Archery Co.
55	Short Cut	115	4	cs	Hoyt/Easton Archery Co.
56	Sidewinder	125	3	ss	Ultra Products, Ltd.
57	Sidewinder	140	3	ss	Ultra Products, Ltd.
58	(brand name not furnished)	135	2	cs	Delta Industries, Inc.
59	(brand name not furnished)	165	2	cs	Delta Industries, Inc.
61	(brand name not furnished)	100	4	cs	Delta Industries, Inc.
62	(brand name not furnished)	175	4	cs	Delta Industries, Inc.
63	Matador I	130	4	ss	Muzzy Products Corp.
64	(brand name not furnished)	125	3	ss	Precision Shooting Equip., Inc.
65	(brand name not furnished)	130	3	ss	Precision Shooting Equip., Inc.
66	(brand name not furnished)	135	4	ss	Precision Shooting Equip., Inc.
67	(brand name not furnished)	145	4	ss	Precision Shooting Equip., Inc.
68	Mini Spinner	105	3	ss	Golden-Key Futura, Inc.
69	Mini Spinner	115	3	ss	Golden-Key Futura, Inc.
70	Golden Spinner	130	3	ss	Golden-Key Futura, Inc.

71	Golden Spinner	140	3	ss	Golden-Key Futura, Inc.
72	Xi Laser Point	110	3	ss	Indian Industries, Inc.
73	Xi The Edge	110	3	ss	Indian Industries, Inc.
74	Serpentine	185	2	cs	Browning Arms, Inc.
76	Dura-Lite	80	2	ss	Lewis & Lewis
79	Arrow Walker Mega	112	3	ss	The Thoughtful Co.
86	Rocky Mountain Ultra Lite	110	3	ss	Barrie Archery
87	Rocky Mountain Grand	150	3	ss	Barrie Archery
88	Rocky Mountain Supreme	160	3	ss	Barrie Archery
89	Mach 110	110	3	cs	Satellite Archery
90	Centershot	120	3	ss	Satellite Archery
91	Titan	124	4	2ss/2cs	Satellite Archery
92	Aero	125	3	cs	Satellite Archery
94	Mag 125	125	4	ss	Satellite Archery
95	Hunter	130	3	cs	Satellite Archery
96	Supra	135	3	ss	Satellite Archery
97	Satellite II	175	4	cs	Satellite Archery
98	Satellite II-XL	145	4	cs	Satellite Archery
99	Bruin	130	3	ss	Bear Archery
100	Bruin	145	4	ss	Bear Archery
101	Bruin Lite	95	3	ss	Bear Archery
102	Grizzly	125	3	ss	Bear Archery
103	Grizzly	130	4	ss	Bear Archery
104	Grizzly II	130	3	ss	Bear Archery
105	Grizzly II	145	4	ss	Bear Archery
106	Kodiak	120	3	ss	Bear Archery
107	Kodiak	135	4	ss	Bear Archery
109	Polar	120	3	ss	Bear Archery
110	Polar	130	4	ss	Bear Archery
111	Razor Head	145	4	ss	Bear Archery

a. ss = stainless steel

b. cs = carbon steel

Preparation of Stock Solutions

A 0.16M solution of nitric acid (HNO_3) was prepared by adding 10 ml of concentrated HNO_3 to Milli-Q purified deionized water to prepare 1 liter. Five percent trichloroacetic acid (TCA) (weight/volume) was prepared by adding 50 gm of TCA to Milli-Q purified deionized water to prepare 1 liter. Two 100-g samples of Amberlite

Table 2. Identification of purchased broadheads.

ID No.	Brand Name	Weight (grains)	*N* Blades	Blade Material	Manufacturer
77	Anderson 243 Mini Magnum	118	4	ss[a]	Anderson Designs, Inc.
78	Anderson 245 Magnum	125	4	ss	Anderson Designs, Inc.
80	Wasp Cam-Lok	150	6	cs[b]	Wasp Archery Products
81	Wasp Series II	140	4	cs	Wasp Archery Products
82	Wasp Series II	140	4	ss	Wasp Archery Products
83	Wasp Series III	180	4	ss	Wasp Archery Products
84	Wasp Series IV High Profile	150	4	ss	Wasp Archery Products
85	Wasp Hi-Tech XLS	105	4	ss	Wasp Archery Products

a. ss = stainless steel

b. cs = carbon steel

IR-120 were each washed with 4 volumes of Milli-Q purified deionized water to remove excess acid, and were added to the 1 liter of 0.16M HNO_3 and 5% TCA. The mixtures were inverted twice daily but otherwise were allowed to stand for 3 days. The 0.16M HNO_3 5% TCA were each decanted and stored at 8C. Amberlite IR-120 was added to remove any lead in the HNO_3 and TCA.

The stock reference solutions of copper and lead were prepared daily from the 1,000 ppm Fisher Scientific reference solutions. Dilutions were made using 0.16M HNO_3.

All glassware was cleaned using 1.6M HNO_3 followed by multiple rinsing with Milli-Q purified deionized water.

Extraction Procedures

In this study trace amounts of copper and lead were removed from the surface of sample broadheads using an instantaneous or "grab" sampling technique. Five drops of 0.16M HNO_3 was transferred by Pasteur pipet to the tip of a cotton swab. The saturated swap was rubbed across the entire surface of the broadhead and then placed in a 2.0-ml polyethylene microvial containing 1.0 ml 0.16M HNO_3 for 60 seconds. The swab was then pressed against the side of the microvial and rotated upward to remove excess HNO_3 from the swab. An Eppendorf pipet was used to remove 0.1 ml of the sample and dispense it into a second microvial containing 0.9 ml 0.16M HNO_3 providing a 10-fold dilution of the initial sample. The samples were loaded into an automated sampling carousel for analysis. Control blanks were interspersed with the test samples to monitor accuracy.

To check background levels, 11 blank cotton swabs were treated with 5 drops of 0.16M HNO_3 placed in a microvial containing 1.0 ml of 0.16M HNO_3 for 60 seconds, and then removed as described above. These 11 sample blanks were analyzed to determine the background level of copper and lead in the 0.16M HNO_3 and cotton swabs.

Experimental firearm and archery wounds were made by shooting the carcasses of white-tailed deer at ranges from 5–25 m. The following bullet types were fired through either a rifle or pistol to create controlled wound samples: (1) .22 caliber, short, solid point, waxed bullet; (2) .22 caliber, long rifle, solid point, waxed bullet; (3) .22 caliber, long rifle, hollow-point, waxed bullet; (4) .22 caliber, long rifle, hollow-point, copper-plated bullet; 95) .38 special caliber, wadcutter bullet; (6) .38 special caliber, +P, semi-jacketed, hollow-point bullet; (7) .357 magnum caliber, semi-jacketed, hollow-point bullet; (8) .25 caliber, full metal jacket bullet; (9) .30 caliber, M1 carbine, full metal jacket bullet; (10) .30 caliber M1 carbine semi-jacketed, hollow-point bullet. A 3-bladed, 125-grain Thunderhead broadhead attached to an Easton Gamegetter 2018 aluminum arrow shaft was used to produce the controlled archery wounds.

Atomic Absorption Analysis of Broadheads

Atomic absorption (AA) analysis with graphite tube atomization (GTA) for quantitative measurement of copper and lead was conducted by automated programmable injection of a 8.0 µl sample into a Varian SpectrAA-10 equipped with a GTA-

95 graphite furnace and pyrolytic coated graphite tube. Standards were prepared by programmable automixing. Initial graphite furnace temperature was 75C with 8 programmed steps for copper and 7 programmed steps for lead. The graphite furnace programs were modifications of original Varian programs (Rothery 1982). The final temperature for copper was 2300C and 2000C for lead (Table 3).

Copper and lead analysis both used single element hollow cathode lamps. A wavelength of 324.8 nm with a current of 4 mA and a slit width of 0.5 nm was used for copper. A wavelength of 283.3 nm with a current of 5 mA and a slit width of 0.5 nm was used for lead. Background correction was off for both copper and lead. The measurement time for each sample was 3.0 sec with 2 replications (Rothery 1982).

Atomic Absorption Analysis of Tissue Samples

Field preparation of experimental wounds for flame atomic absorption (FAA) spectrophotometry consisted of cutting hair from the hide with stainless steel scissors and excising a 7.6 × 7.6-cm section of hide that contained the entrance wound orifice with a single-edge stainless steel razor blade. The excised hide was then placed in a Whirl-Pak and marked. The wound tract in the skeletal tissue under the excised hide was then removed so that at least 3 cm^3 of muscle tissue containing the wound tract was collected, this sample was placed in a separate Whirl-Pak and marked.

A control sample of hide and skeletal tissue was collected by moving approximately 7.6 to 10.2 cm from the wound site and using the same collecting procedures as for the wound sites. The control samples were placed in separate Whirl-Pak bags and marked. All samples were refrigerated if analysis was to be done within 48 hours or frozen until preparation for analysis by AA testing.

Table 3. Furnace parameters for copper and lead analysis.

Step No.	Temperature (C)	Time (sec)	Gas Flow	Gas Type	Read Command
Copper Parameters					
1	75	5	3	Nitrogen	No
2	90	60	3	Nitrogen	No
3	120	10	3	Nitrogen	No
4	400	2	3	Nitrogen	No
5	400	2	0	Nitrogen	No
6	2,300	1	0	Nitrogen	Yes
7	2,300	2	0	Nitrogen	Yes
8	2,300	1	3	Nitrogen	No
Lead Parameters					
1	75	5	3	Nitrogen	No
2	90	60	3	Nitrogen	No
3	120	10	3	Nitrogen	No
4	120	2	0	Nitrogen	No
5	2,000	1	0	Nitrogen	Yes
6	2,000	2	0	Nitrogen	Yes
7	2,000	1	3	Nitrogen	No

Samples were prepared for FAA testing by accurately weighing 5 gm of hide (wet weight [ww]) and 5 gm of tissue (ww) from the collected wound samples and placing them in separate 25 × 150-mm glass tubes. Control samples were prepared by accurately weighing 5 gm of hide (ww) and 5 gm of tissue (ww) from the control samples and placing them in separate 25 × 150 mm glass tubes. Ten milliliters of 5% TCA was added to each sample tube and allowed to stand 18–24 hours. Samples were then decanted and centrifuged for 30 minutes on a clinical centrifuge.

Copper and lead analysis both used single element hollow cathode lamps (Varian Techtron Pty. Ltd.). A wavelength of 324.8 nm with a current of 10 mA and a slit width of 0.5 nm was used for copper. A wavelength of 217.0 nm with a current of 5 mA and a slit of 0.1 nm was used for lead. Background correction was on for both copper and lead. The fuel was air-acetylene with a measurement time for each sample of 2.0 seconds and 3 replications (Table 4).

Spot Tests

A spot test for copper and lead was performed on 11 additional broadheads not subjected to AA GTA analysis and on all experimental hide wounds. An initial test for copper was performed using dithiooxamide (DTO). DTO was prepared prior to testing by mixing 2.0 mg of DTO with 95% ethanol to prepare a 0.2% (weight/volume) solution (0.2% Rubenic acid). The "lift" or solubilizer solution was ammonia and distilled water (1:1) applied to Whatman No. 2 filter paper.

The initial copper test was followed by a rhodizonic acid test to detect the presence of lead. The rhodizonic acid was prepared by mixing approximately 0.7 mg of disodium rhodizonate with 100 ml of distilled water. The rhodizonic acid solution

Table 4. Flame atomic absorption parameters for copper and lead analysis.

Copper Parameters	
Fuel:	Air-acetylene
Slit width:	0.5 mm
Wavelength:	324.8 nm
Source current:	10 mA
Burner height:	Light path at 3 mm above burner tip
Background correction:	On
Replicate:	3
Integration:	3 sec
Delay time:	2 sec
Lead parameters	
Fuel:	Air-acetylene
Slit width:	0.1 mm
Wavelength:	217.0 nm
Source current:	5 mA
Burner height:	Light path at 3 mm above burner tip
Background correction:	On
Replicate:	3
Integration:	2 sec
Delay time:	2 sec

was not prepared until immediately prior to testing since rhodizonic acid has a shelf-life of 2–3 hours after mixing. The "lift" or solubilizer solution was a buffer solution of 1.5 g of sodium hydrogen tartrate and 1.5 g of tartaric acid mixed with 100 ml of distilled water applied by spray to Whatman No. 2 filter paper. A 0.6M hydrochloric acid (HCI) spray solution was used to acidify the pH and cause a color shift from pink to deep purple indicating the presence of lead. The rhodizonic acid, buffer solution, and 0.6M HCI were placed in individual spray bottles (Stockdale 1989).

Chemical reactivity was assured by conducting a control test for copper and lead prior to broadhead and tissue examination. The control test for copper was performed by placing 2 drops of ammonia solution on the filter paper and then pressing a piece of copper against the damp area for 5–10 seconds. One to 2 drops of DTO was then added to the test spot. The immediate appearance of a dark greenish to black color indicated a positive reaction (Feigl and Anger 1972) and served as a reference for positive tests.

A control test for lead was performed by spraying a piece of Whatman No. 2 filter paper with the sodium hydrogen tartrate/tartaric acid buffer solution until it was damp. A piece of lead was pressed against the filter paper for 60 seconds followed by spraying rhodizonic acid on the test site. The immediate appearance of a pink color indicates a positive test for lead or antimony. A 0.6M HCI spray solution was used on the test site to acidify pH and cause a color shift to deep purple indicating the presence of lead (Stockdale 1989).

Results and Discussion

Neither copper nor lead was detected on any of the broadheads ($N = 11$) using the spot chemical tests. Similar results were obtained when control samples of white-tailed deer hide ($N = 12$) were tested using spot chemical tests and found negative for copper and lead. Control samples of deer hide were then punctured by broadhead-tipped arrows ($N = 4$) and retested for copper and lead. Again neither copper nor lead was detected on the broadhead or hide using spot tests.

Spot chemical tests for copper ($N = 42$) and lead ($N = 67$) were conducted on experimental wound orifices ($N = 67$). DTO detected copper in 35.7% ($N = 15$) and rhodizonic acid detected lead in 52.2% ($N = 35$) of the firearm induced hide wounds. The insertion of a broadhead arrow into the wound orifice had no affect on either the DTO ($N = 11$) or rhodizonic acid test ($N = 11$).

The 11 cotton swabs utilized as control blanks indicated a background level of 4.5 ppb (SD = 0.6) and 0.4 ppb (SD = 0.09) copper and lead, respectively, from the swabs and HNO_3. Known control samples were analyzed as an internal monitoring of instrument accuracy.

Quantitative analysis of 93 commercially produced broadheads for copper by AA GTA indicated a minimum of 0.33 ppb and a maximum of 1,460 ppb with a mean of 94.9 ppb (SD = 231). Analysis of the same broadheads for lead by AA GTA indicated a minimum of 1.56 ppb and a maximum of 423 ppb with a mean of 35.4 ppb (SD = 71.1). Five broadheads exceed the copper mean by more than 2 SD while 6

exceed the level mean by more than 2 SD. The 5 broadheads which exceed the copper mean plus 2 SD do not exceed the lead mean plus 1 SD. Similarly, the 6 broadheads which exceed the lead mean plus 2 SD are < 50% of the copper mean (Table 5).

Commercial broadheads are manufactured from 1 or a combination of the following materials: carbon steel, 440 stainless steel, and/or aluminum. One manufacture produces a polymer blade. Large single blade broadheads are nearly always carbon steel, while smaller or lightweight broadheads are a combination of stainless or carbon steel and aluminum. An examination of unfinished broadhead blanks and information from manufacturing representatives indicate that most large single blade and some multi-bladed broadheads are brazed to the center ferrule. As a result of

Table 5. Results for copper and lead in samples from commercial broadheads.

Sample ID	Copper conc(ppb)	Lead conc(ppb)	Sample ID	Copper conc(ppb)	Lead conc(ppb)	Sample ID	Copper conc(ppb)	Lead conc(ppb)
12	221.0	19.6	46	7.93	4.86	79	17.6	3.26
13	144.0	279.0	47	29.5	12.8	80	112.0	12.9
14	52.3	21.7	48	7.53	1.96	81	10.1	3.76
15	67.7	22.6	49	6.83	1.66	82	16.8	4.66
16	36.0	12.5	50	7.93	1.76	83	27.6	15.4
17	29.6	32.5	51	4.23	4.16	84	24.4	2.16
18	66.2	71.5	52	29.4	33.3	85	38.9	5.96
19	70.2	78.1	53	88.8	53.5	86	15.2	5.46
20	24.4	6.86	54	4.53	3.56	87	33.7	1.56
21	242	7.66	55	19.0	2.06	88	5.43	2.86
22	820.0	6.66	56	86.2	253.0	89	20.1	2.46
23	25.1	7.46	57	37.0	20.3	90	36.9	19.6
24	821	14.3	58	21.2	3.06	91	29.3	29.6
25	1,160.0	15.6	59	9.63	2.36	92	19.1	8.76
26	50.1	37.7	61	27.5	36.3	94	36.1	16.1
27	27.3	56.4	62	151	15.3	95	13.8	5.06
28	10.1	8.46	63	5.33	18.3	96	15.5	2.56
31	619.0	10.1	64	110	15.9	97	6.03	5.76
32	1,230.0	11.3	65	87.3	12.2	98	14.9	9.46
33	1,460.0	75.7	66	53.8	15.2	99	5.43	2.36
34	48.8	189.0	67	95.8	142.0	100	7.13	3.16
35	73.8	293.0	68	8.03	4.06	101	7.33	1.96
36	72.9	21.6	69	14.1	77.0	102	7.23	1.76
37	7.93	12.3	70	15.2	24.7	103	18.6	2.36
38	21.9	15.9	71	14.0	6.86	104	5.63	2.26
39	40.0	19.8	72	52.1	146.0	105	0.33	2.06
40	131.0	26.9	73	98.5	423.0	106	25.0	14.3
41	69.5	19.8	74	113.0	159.0	107	2.43	2.16
42	9.73	20.7	76	308.0	20.3	109	5.03	4.86
43	39.2	121	77	114.0	6.86	110	3.93	2.36
44	62.7	204.0	78	5.23	3.26	111	13.4	2.26
45	8.03	13.5						
			Mean	94.9	35.4			
			SE	231	71.1			
			Min	0.33	1.56			
			Max	1,460.0	423.0			
			Mean + 2 SE	557	178			

brazing an increased level of copper would not be unexpected on these broadheads. Samples 24 and 25 are large broadheads which exhibit brazing and have levels of copper exceeding 2 SD. Sample 25 is an unfinished blank of Sample 24 and a copper color is present over a large area of the surface.

A second significant reason for elevated levels of copper in commercially manufactured broadheads is the material used to coat the projectile. Samples 31, 32, and 33 were finished in a material which had a yellow brass color and gave copper levels exceeding 2 SD. These samples are an anomaly as the brass color finish affects the copper level, although it does not affect the lead level. These 3 samples are from the same manufacturer, and when they are omitted, the mean level for copper is 59.4 ppb (SD = 126); only 2 broadhead samples exceed the mean by more than 2 SD. This study made no attempt to identify the composition of any coating material.

Although not every commercial broadhead was included in this study, manufacturers indicated that other models not submitted for testing are composed of the same materials and only vary by weight (e.g., 125 grains compared to 135 grains). No significant difference would be expected in the level of copper ($P < 0.05$) or lead ($P < 0.05$) if additional broadheads were tested.

Quantitative testing by FAA for background levels of copper and lead in white-tailed deer hide ($N = 36$) detected copper levels ranging from 0.03 to 0.70 ppm (mean = 0.22, SD = 0.15) and lead levels ranging from 0.06 to 0.77 ppm (mean = 0.31, SD = 0.27). FAA analysis of white-tailed deer skeletal muscle tissue ($N = 60$) indicated background levels of copper ranging from 0.08 to 0.72 ppm (mean = 0.34, SD = 0.12) and lead ranging from 0.06 to 0.98 ppm (mean = 0.34, SD = 0.21).

Broadheads grouped by blade number and material can provide a further comparison of copper and lead residue values. Broadhead groupings include 2 blade, carbon steel; 2 blade, stainless steel; 3 blade, carbon steel; 3 blade, stainless steel; ≥4 blade, carbon steel and ≥ blade stainless steel. No significant difference was observed in the lead level between stainless steel and carbon steel blades ($P = 0.01$). However, a significant difference ($P > 0.5$) was observed in the copper level between stainless steel and carbon steel broadheads. Samples of carbon steel broadheads contained approximately 4 times the level of copper as samples of stainless steel broadheads.

Experimental sample testing of both hide and muscle tissue by FAA detected copper and lead levels in excess of the control sample in 100% of known firearm wounds ($N = 44$). Testing of suspected illegal archery kills ($N = 85$) by FAA indicated 65.9% ($N = 56$) were firearm-induced wounds as opposed to arrow wounds. Copper levels exceeding the corresponding control sample ranged from 0.26 to 3.94 ppm in the hide and 0.23 to 5.30 ppm in the meat. Lead levels, which also exceeded the corresponding control sample, ranged from 0.66 to 782.0 ppm in the hide to 1.03 to 947 ppm in the skeletal muscle tissue.

A review of the literature reveals a large amount of data concerning background levels of lead and to a lesser degree, copper, in various animals. However, specific data on lead and copper levels in skeletal muscle tissue or hide tissue is non-existent. Allcroft (1951), reporting on lead poisoning in cattle and sheep, found the highest

levels of lead in the bones with smaller amount in the liver and kidneys. He found the lowest concentrations in the muscles and brain. Sileo and Beyer (1985) examined heavy metals in white-tailed deer in Pennsylvania, albeit they did not sample skeletal muscle. Inferences drawn from these 2 studies agree with my assessment of the levels of copper and lead detected in control samples tested in this study.

Conclusions

This study has examined the majority of commercially-manufactured broadheads produced in the United States at the time of their collection. The study has only quantified the trace amounts of copper and lead contained on the surface of the broadhead received from the manufacture. No attempt has been made to ascertain the origin of the copper and lead residue although in some instances the source was apparent.

The individual and mean levels of copper and lead detected on these broadheads validates the hypothesis that broadhead arrow tips have no effect on suspected firearm wounds in big game animals. Broadheads are not in contact with suspect tissue long enough for any meaningful transfer of material to occur. Mean background levels of copper and lead in the hide and muscle tissue of white-tailed deer are higher than mean levels of these metals rubbed from the surface of broadheads, and if transfer of material were to occur, it would most likely be at a level too low to detect.

Atomic absorption spectrophotometry is a quantitative test which provides conclusive evidence in a court of law. FAA analysis can be used to determine if a wound tract is the result of a firearm or broadhead tipped arrow. FAA analysis will detect elevated levels of copper and lead even if a broadhead tipped arrow has been inserted into a firearm wound orifice post-mortem despite the altering of the morphological appearance of the wound.

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