The challenge of hard-to-reach spaces in mechanical fossil preparation: development of a novel short-bodied air scribe with a flexible head

**Key Words:** fossil preparation; pneumatic air scribe; palaeontological methods; laboratory techniques; micropreparation
ABSTRACT

Pneumatic air scribes are the primary tools used for mechanical fossil preparation, especially in vertebrate fossils. However, their long and straight, pen-shaped shafts (generally 100–150 mm in length) and fixed heads limit the working angle in narrow and hard-to-reach spaces, such as the intricate surfaces of pneumatic bones and inside deep cavities (e.g., sauropod vertebrae). Moreover, when preparing microvertebrate fossils (e.g., frogs, lizards, and small mammals), the limited working space for long air scribes between the microscope’s objective lens and the fossil specimen restricts effective preparation. To overcome these challenges, we developed a novel short-bodied air scribe (Wada-type air scribe) constructed from hardware readily available at home improvement stores. The new Wada-type air scribe has an extremely short body (35 mm) and the handle with a hinge can be attached to make the working angle adjustable, allowing users to hold it in an ergonomically natural hand position during preparation. Despite its short body, performance of the newly developed Wada-type air scribe is comparable to conventional air scribes with a similar stylus size. In addition, the Wada-type air scribe can upcycle used styli that are too short to continue using in the conventional air scribe. Together with its maneuverability in the limited space, the novel configuration of the Wada-type air scribe
overcomes disadvantages of the conventional air scribes.

PLAIN LANGUAGE SUMMARY

Fossil preparation is the process of removing rock matrix from fossils that are found on the Earth's surface and is essential work for paleontological research. One of the main tools used for fossil preparations is pneumatic air scribes. The conventional air scribes are pen-shaped, with long bodies (over 100 mm) and fixed working angles, making them unsuitable for use in narrow or hard-to-reach spaces. To address this issue, we developed a new air scribe (the Wada-type air scribe). The Wada-type air scribe has a much shorter body (35 mm) and a handle with a hinge, which allows the working angle to be adjusted between 0 to 90 degrees. This configuration allows users to hold it in a natural and ergonomic hand position during preparation in hard-to-reach places. Here we provide detailed design drawings so that fossil preparators around the world can reproduce and use the novel air scribe.
INTRODUCTION

Fossil preparation is essential to palaeontological research as it transforms rocks into scientific specimens (Brown, 2013). Although most of the basic preparation techniques for fossil vertebrates were already established in early 1900s (Riggs, 1903; Bather, 1908; Hermann, 1908, 1909), new preparation techniques and tools have been developed throughout the last century (e.g., Brinkman 2009; Wada et al. 2012; Shinya et al. 2023). Most of the knowledge on fossil preparation, collection care, and fossil conservation methods are shared by palaeontological communities (Association of Materials & Methods in Palaeontology, 2023; Preparator Resources, 2023; The Paleontology Portal Fossil Preparation, 2023). However, local palaeontological laboratories and museums sometimes independently develop specific preparation methods and techniques based on regional challenges posed by the unique geology, depositional conditions, or preservation biases and the complex morphology of the fossils themselves. Such refined techniques are commonly limited to in-house use and are rarely shared with the broader palaeontological community.

One of the most important innovations made in the field of fossil preparation was the development of the pneumatic hammer which was the prototype of today’s pneumatic air scribes (Riggs, 1903; Brinkman, 2009). Pneumatic air scribes are pen-shaped, hand-held
Jackhammers operated using compressed air and were originally developed as industrial engraving tools (Ratkevich, 1998). This innovative preparation tool was first introduced by palaeontologist Elmer S. Riggs of Chicago’s Field Museum of Natural History in 1903 (Riggs, 1903) and the use of this new preparation tool spread rapidly among American palaeontologists (Brinkman, 2009). Subsequently, numerous technicians have improved on its design and performance with keeping the basic pen-shape over the past 120 years.

Nowadays, well-established manufactures such as USA-based Chicago Pneumatic® and PaleoTools® provide air scribes of variable sizes (100–150 mm in length) and power depending on the volume and hardness of the rock matrix and fossil specimens (Chicago Pneumatic, 2023; PaleoTools, 2023) to the various palaeontological laboratories and museum worldwide, and the air scribes are even now regarded as the workhorse of mechanical preparation.

Commercially available pneumatic air scribes have also been used for fossil preparations in the Museum of Nature and Human Activities Hyogo (MNHAH), Japan because the vertebrate fossils from Hyogo prefecture, southwestern Japan, are often preserved in well consolidated mudstone and manual preparation technique using a pin vise fitted with a tungsten carbide needle has been ineffective. The mechanical preparation
method using air scribes was often the only choice to prepare both macro-vertebrate fossils including sauropod and hadrosaurid dinosaurs and anthracotheriid mammals (Tsubamoto et al., 2007; Saegusa and Ikeda, 2014; Kobayashi et al., 2021) and micro-vertebrate fossils including frogs, lizards, eggshells, and small mammals (Ikeda and Saegusa, 2013; Kusuhashi et al., 2013; Ikeda et al., 2015; Ikeda et al., 2016; Tanaka et al., 2016; Tanaka et al., 2020; Ikeda et al., 2022). Even a nearly complete three-dimensionally preserved articulated Mesozoic frog skeleton whose snout-vent length is less than 30 mm had to be prepared with air scribes because chemical preparation methods (Rutzky et al., 1994) could not be applied for the risk of damaging vulnerable micro-vertebrate elements. Besides, 3D images obtained from non-destructive method such as computed tomography (CT) were insufficient to examine its morphology in detail (Ikeda et al., 2016).

While using commercially available air scribes, preparators were often required to hold them at awkward angles when removing matrix from hard-to-reach spaces in highly complex and fragile fossils, such as the intricate surfaces of pneumatic bones and inside deep cavities (e.g., sauropod vertebrae) (Figure 1A). Even the smallest available air scribes (e.g., Micro Jack 1 by PaleoTools®) sometimes become stuck between the objective lens of the microscope and the fossil (Figure 1B), making it nearly impossible to use them.
effectively. To overcome these disadvantages experienced using conventional long-bodied air scribes, we developed an extremely short bodied air scribe with a handle that can adjust the angle of impact using hardware readily available at home improvement stores. We named it the Wada-type air scribe, named after the principal developer Kazumi Wada. The first prototype was made in the MNHAH Dinosaur lab in 2014 (Figure S1) and it has since been refined and improved upon, testing several different versions of the tools, and the current model of the Wada-type air scribe described in this manuscript was completed in 2015. The Wada-type air scribe is an innovative fossil preparation tool in terms of highly modifying the basic pen-shaped form and expanding upon the performance of the conventional air scribe. Here we describe how to construct the Wada-type air scribe so that fossil preparators in other laboratories can reproduce and add it to the preparation tools.

MATERIALS AND METHODS

Ten components are required for building the model (Wada-type air scribe and a handle) and are shown and listed in Figure 2. The hardware components used to build the air scribe can be found at affordable prices in home improvement stores. Components were selected based on the processability, compatibility, and strength. General tools including
hand grinding machine, drill taps, and punches were used to process all metal (e.g., cutting, shaping, and drilling).

The components used for the Wada-type air scribe were as follows: (1) one hexagon headed bolt with thread size M8, (2) one high nut with thread size M8, (3) one hex socket head cap bolt, high tensile strength steel with thread size M8, (4) one straight-type union with thread size M4, (5) one O-ring with outer diameter 1.75 mm, and (6) one set of air scribe stylus with a spring and an O-ring (used and shortened stylus from Micro Jack 2 by PaleoTools® was used).

The components used for the handle were as follows: (7) one steel bar [10 mm in diameter and 65 mm in length], (8) two polished steel plates [15 mm in height, 50 mm in length, and 4.5 mm in thickness], (9) one headless screw with thread size M3, and (10) one hex socket head cap bolt with thread size M4.

**Design Drawings**

The design drawings and production flow of the Wada-type air scribe and handle parts are described herein by Figures 3–7.

**Wada-type air scribe.** The Wada-type air scribe was composed of three parts: junction (Figure 3B–E), cylinder (Figure 3G–J), and bushing (Figure 3L–O). The measurements of
each processed component are shown in Figures 3D, E, I, J, N, O. Each part of the Wada-type air scribe was constructed by the following production flows. The detailed production flow of the three parts can be found in Appendix (Figure S2–4).

(1) Junction: One-fifth of the screw head of a hexagon-headed bolt (Figure 3A) was cut out. The hexagonal head was ground cylindrically before being diagonally cut at approximately 70 degrees from the horizontal plane (Figure 3B, C) and shallow groove was created for an O-ring at the base of the head (Figure 3C). From the diagonally cut surface of the rounded head, a tapped hole with thread size M4 was made (Figure 3D, E). A hole (dia. 1 mm) was drilled into this tapped hole on the opposite side of the hex head (Figure 3E). To enhance air pressure, an orifice was fashioned through reduction of the diameter at the hole surface to 0.5 mm (Figure 3C, E) with the aid of a small hammer and a nail (See step 5 in Figure S2). Finally, the surface with the orifice was polished using sandpapers (#400–#2000).

(2) Cylinder: The corners of the high nut were rounded off and ground into a cylinder (Figure 3F, G), then chamfer the left and right lateral sides to set an attached handle later. The width between the left and right surfaces was approximately 10 mm (Figure 3I). A small depression (dia. 3 mm) was made in the center of the right side of the
surface (Figure 3 G, H), for a headless screw (component 9 in Figure 2), which
functions as the fulcrum for the body angle adjustment.

(3) **Bushing:** A bushing was made from the middle part of the hexagonal socket head cap
bolt (thread size M8) (Figure 3K–M). A 1.6 mm guide hole for a stylus was drilled in
the center of the bushing (Figure 3O). The end of thread was ground to a 5 mm long
and 4 mm diameter cylinder (Figure 3M, O) to create an ‘insertion part’ that a spring
can fit over it (Figure 4). The left and right sides of the tip of bushing was chamfered
(Figure 3L, M) since it was easier to pick up using fingers or pliers when the bushing
was screwed to the cylinder and a groove for the exhaust was made on both sides
(Figure 3N). The processed bushing was quenched for hardening.

(4) **Assemblage of the three parts:** An assembly of the Wada-type air scribe is shown in
Figure 5. A straight-type union was screwed into the junction, with an optimum-size O-
ring in-between to make the connection air tight. An air-line was then connected to the
straight-type union. Another O-ring was inserted at the base of the thread side of the
junction before connecting it to the cylinder. A stylus with an O-ring and a spring was
placed through the guide hole of the bushing, and the bushing was screwed into the
cylinder.
Handle. The handle is composed of three parts: support rod and two body-holders (Figure 6). The handle was constructed using the following production flow: Two polished steel plates were cut in elliptical shape to create left and right body-holders and the lateral surfaces that face outside were ground to make them easy to grasp (Figure 6A). A 4 mm clearance hole with a round depression with a diameter of 7 mm, which corresponds to the head size of the hex socket head cap bolt, on the right body-holder and a tapped hole (thread size M4) on the left body-holder were drilled (Figure 6A, B). A hex socket head cap bolt (thread size M4) (component 10 in Figure 2) was inserted through the holes (Figure 6D) and use this to fasten the left and right body-holders as a locking screw when the air scribe body is clamped between them. An additional tapped hole (thread size M3) for a headless screw (component 9 in Figure 2) was drilled into the right body-holder (Figure 6A, E). The headless screw functions as a fulcrum for the air scribe body angle when the handle is attached to the Wada-type air scribe. The interval between the left and right body-holders was adjusted to approximately 10 mm which is the same as the width of the air scribe body (Figure 6C).

Coupling. The Wada-type air scribe was clamped between the left and right body-holders of the handle with the headless screw (Figure 7). The air scribe angle could be adjusted and
fixed with the headless set screw from 0 ° (Figure 8A) to approximately 90 ° (Figure 8B) with respect to the handle, and the adjusted angle could be fixed by tightening a hex socket head cap bolt. To reduce the impact from the tool to the hand, the handle was covered with a sponge (Figure 8C).

**DISCUSSION**

The Wada-type air scribe was originally designed to address the disadvantage of the commercially available air scribes (the pen-shaped long-body and the fixed angle) that limited effective fossil preparation in hard-to-reach spaces by Kazumi Wada, former Chief Preparator at the MNHAH Dinosaur Lab. The design of the novel air scribe emerged from the realization that the body length of a conventional air scribe (Figure 9A) was not a critical factor in determining its performance. A prototype was made in 2014 (Figure S1) and we encountered several challenges in balancing the need for a shorter and adjustable angle air scribe with the requirement to maintain optimal performance. One of the biggest challenges was to determine the ideal length of the bushing (Figure 4). Although the bushing provides stability to a stylus, a longer bushing would be contrary to our purpose of making the air scribe as short as possible. In order to minimize overall length of the air
scribe, a part of the bushing was ground to fit inside of a spring thereby extending the
bushing ("insertion part" in Figures 3M, 4B). For the air scribe to operate with the optimal
oscillation, a guide hole length greater than 12 mm is required when the diameter of the
stylus is 1.6 mm and the base of the stylus and the insertion part of the bushing must not
make contact (Figure 4B). Furthermore, we found that the distance between the base of the
stylus and the insertion part must be greater than 1 mm which is the amplitude of the spring
during one stylus stroke. To meet these requirements, the length of the insertion part was
adjusted to 5 mm in length and 4 mm in width and the total length of the bushing became
15 mm (Figure 3O). As a result, we were able to successfully reduce the overall length of
the Wada-type air scribe to 35 mm, which is the shortest air scribe in the paleontological
laboratories to our knowledge. It is also inexpensive to build with only 10 components
readily available in the home-improvement stores. Despite its significantly short body, the
performance of this air scribe is equivalent to that of conventional long-bodied air scribes
with a similar stylus size.

Additional challenges were to make this air scribe easy to hold and the impact angle
adjustable. Since the Wada-type air scribe is only 35 mm in length, it can be too small to
hold for a long period for preparators. An addition of a holder solved this issue but the
holder with a hinge was the additional innovation because the user could fix the air scribe between 0° to 90° in relation to the holder (Figures 7, 8) and allowed the users to hold the Wada-type air scribe in agronomical position, especially during the preparation in the hard-to-reach spaces (Figure 10A).

The novel configuration of the Wada-type air scribe with the attached handle (the adjustable angled tip and short body) also allowed to work in micropreparation more comfortably and effectively (Figure 10A). Micropreparation of small fossils can be completely obliterated with needle slip (Madsen and Larson, 1996): thus, it is important for a preparator to have a full control of the tool under a microscope. The Wada-type air scribe also proves to be remarkably functional without getting stuck between the objective lens of the microscope and the fossil specimen due to its extremely short body and adjustable impact angle (Figure 10B).

Finally, the Wada-type air scribe can upcycle styli from the Micro Jack (PaleoTools®) that are too short to continue using in the existing products. The Wada-type air scribe can fit styli as short as 25 mm in length: thus, it can help to maximize the use of styli and reduce waste in a palaeontological laboratory.
CONCLUSION

We described herein a detailed, step-by-step materials and methods to build the short-bodied Wada-type air scribe, so that fossil preparators across the world can reproduce and use it. While most of the knowledge on fossil preparation techniques and methods has been shared by most palaeontological communities, unique and highly specialized preparation methods and techniques independently developed by local palaeontological laboratories and museums are rarely shared. We believe that the active publication and demonstration of in-house paleontological tools and methods further enhances the development of fossil preparation techniques and strengthens paleontological research.

Our novel short-bodied air scribe, the Wada-type air scribe, was first designed and developed to overcome the challenges in hard-to-reach spaces in mechanical fossil preparation using commercially available air scribes with a long body and fixed angle of impact in 2014. Over time, we had refined the prototype and as described in detail in this article, the Wada-type air scribe can be made of nuts and bolts that are easy to find in a home-improvement store. By modifying the bushing to fit within a spring, we were able to shorten the overall length of the air scribe while maintaining the sufficient support for a stylus and optimizing the performance. The resulting Wada-type air scribe is 35 mm in
length, which is the smallest air scribe used in the paleontological labs to our knowledge.

The working angle can be adjusted and fixed by attaching a handle with a hinge, allowing
the users to hold it in an ergonomically natural hand position during preparation. This
extremely small air scribe thereby works well under a microscope without getting stuck
between the objective lens and the fossil specimen. The Wada-style air scribe can reuse a
used stylus that is shortened and unable to use it in a commercially available air scribe and
despite of its small size, the performance of this air scribe is equal to that of conventional
air scribe with a similar size stylus. Together with its maneuverability in the limited space,
the novel configuration of the Wada-type air scribe overcomes disadvantages of the
conventional air scribes.
REFERENCES


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FIGURE 1. Usage example of a conventional pen-shaped pneumatic air scribe. A. Fossil preparation inside of the deep cavity. Note that preparators are required to hold the air scribe at an awkward angle when they try to prepare the hard-to-reach area. B. Micropreparation using the pen-shaped air scribe. The handle of the air scribe could be caught on the rim of the objective lens.

FIGURE 2. List of the components for one Wada-type air scribe and a handle. The "M" designation for metric screws indicates the outer diameter of the screw thread in mm.

FIGURE 3. The junction (A-E), cylinder (F-J), and bushing (K-O) in right lateral (A, B, C, F, G, H, K, L, and M), back (D), and front (I and N) views. The component numbers correspond to those of Figure 2. A. One-fifth from the screw head of a hexagon-head bolt; B. the junction part; C. diagram of the junction part; D. the junction; E. the cross section of the junction; F. a high nut; G. the cylinder; H. diagram of the cylinder; I. the cylinder; J. the cross section of the cylinder; K, middle part of a hex socket head cap bolt; L. the bushing; M. diagram of the bushing highlighting the insertion part and an exhaust hole; N. the
bushing; and O. the cross section of the bushing.

FIGURE 4. The assembly drawing of the stylus, spring, and bushing. Note that the distance between the bushing and the base of the stylus must be more than 1 mm.

FIGURE 5. The Wada-type air scribe. A. The anatomy of the Wada-type air scribe. The component numbers correspond to those in the Figure 2; B. the diagram of the Wada-type air scribe in lateral view; and C. the cross section of the Wada-type air scribe in lateral view.

FIGURE 6. The handle. A. The production process of the handle. The component numbers correspond to those in the Figure 2; B. the handle in right lateral view; C. the handle in top view; D. the handle with the hex socket head cap bolt (M4) in bottom view; and E. the handle in left lateral view.

FIGURE 7. The assembly drawing of the Wada-type air scribe and a handle. A. Insert the air scribe between the left and right body-holder; B. angle adjustment of the Wada-type air
scribe; and C. the Wada-type air scribe in right lateral view.

**FIGURE 8.** The Wada-type air scribe. A. Straight angle (0 degree); B. right angle (90 degree); and C. the handle is wrapped in a sponge cover.

**FIGURE 9.** Comparison between the existing and the Wada-type air scribes. A. A pen-shaped air scribe (Micro Jack 3 from PaleoTools®); and B. the Wada-type air scribe.

**FIGURE 10.** Usage example of the Wada-type air scribe. A. Fossil preparation inside of the deep cavity; and B. Preparation under a microscope using the Wada-type air scribe.
<table>
<thead>
<tr>
<th>Components</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Hexagon headed bolt</td>
<td>M8</td>
</tr>
<tr>
<td>2 High nut</td>
<td>M8</td>
</tr>
<tr>
<td>3 Hex socket head cap bolt</td>
<td>M8</td>
</tr>
<tr>
<td>4 Straight type union</td>
<td>M4</td>
</tr>
<tr>
<td>5 O-ring</td>
<td>outer dia. 1.75 mm</td>
</tr>
<tr>
<td>6 Air scribe stylus</td>
<td>PaleoTools” Micro Jack 2</td>
</tr>
<tr>
<td>7 Steel bar</td>
<td>diameter 10 mm, length 65 mm</td>
</tr>
<tr>
<td>8 Polished steel plate</td>
<td>height 15 mm, length 50 mm, thickness 4.5 mm</td>
</tr>
<tr>
<td>9 Headless screw</td>
<td>M3</td>
</tr>
<tr>
<td>10 Hex socket head cap bolt</td>
<td>M4</td>
</tr>
</tbody>
</table>

Wada-type air scribe

Handle
A

bushing

B

base of the stylus

insertion part

more than 1.0mm
A polished steel plate

8 Shaping
left body-holder

7 steel bar (support rod)
welding
tapped hole (M4)

right body-holder
depression (dia. 7mm)
clearance hole (dia. 4mm)
tapped hole (M3)

10 hex socket head cap bolt (M4)

9 headless screw (M3)

B
clearance hole (dia. 4mm)
tapped hole (M3)

C

D

hex socket head cap bolt (M4)

E
tapped hole (M4)

20 mm
FIGURE S1. The first prototype of the Wada-type air scribe. The body of the short air scribe and the grip were welded together, producing an L-shaped configuration. The impact angle remains fixed at 90 degree and could not be adjustable.
FIGURE S2. The production flow for a junction part. Schematic diagrams in lateral view (upper row) and cross-sections (lower row) are shown.

1. One-fifth of a screw head of a hexagon-headed bolt with thread size M8 (component no. 1 in Figure 2) was utilized as a base material of the junction part. The outline of the junction is depicted as a dotted line.

2. The hexagonal head of the bolt was then shaped into the junction form.

3. A tapped hole with the thread size M4 was drilled.

4. A clearance hole with a diameter of 1 mm was drilled.

5. The diameter of the clearance hole was reduced at the surface using a small hammer and a nail, creating an orifice with a diameter of 0.5 mm (the same diameter of an orifice to air scribes of Micro Jack by PaleoTools®).
FIGURE S3. The production flow for a cylinder part. Schematic diagrams in lateral (upper row) and front (lower row) views are shown.

1. A high nut, measuring 25 mm in length with thread size M8 (component no. 2 in Figure 2), was utilized as the base material for the cylinder part.

2. The corners of the high nut were rounded off and the nut was shaped into a cylinder through grinding.

3. The width of the cylinder was adjusted to 10 mm by chamfering the left and right lateral sides. A small depression with a diameter of 3 mm was created on the right side of the lateral surface.
FIGURE S4. The production flow for a bushing part. Schematic diagrams in lateral (upper row) and front (middle row) views and cross-sections (lower row) are shown.

1. A middle part of a hexagonal socket head cap bolt with thread size M8 (component no. 3 in Figure 2) was utilized as a base material for the bushing part. The outline of the bushing is depicted as a dotted line.

2. The non-threaded portion was grounded into a conical shape with a flat tip, and a guide hole (1.6 mm in diameter) for a stylus was drilled in the center of the bushing. The outline of the insertion part is indicated by a dotted line.

3. The threaded portion was fashioned into the insertion part, which is 5 mm in length and 4 mm in width. The left and right sides of the bushing were chamfered.

4. A narrow notch (exhaust hole) was made on the threaded portion of the bushing on both the left and right sides.