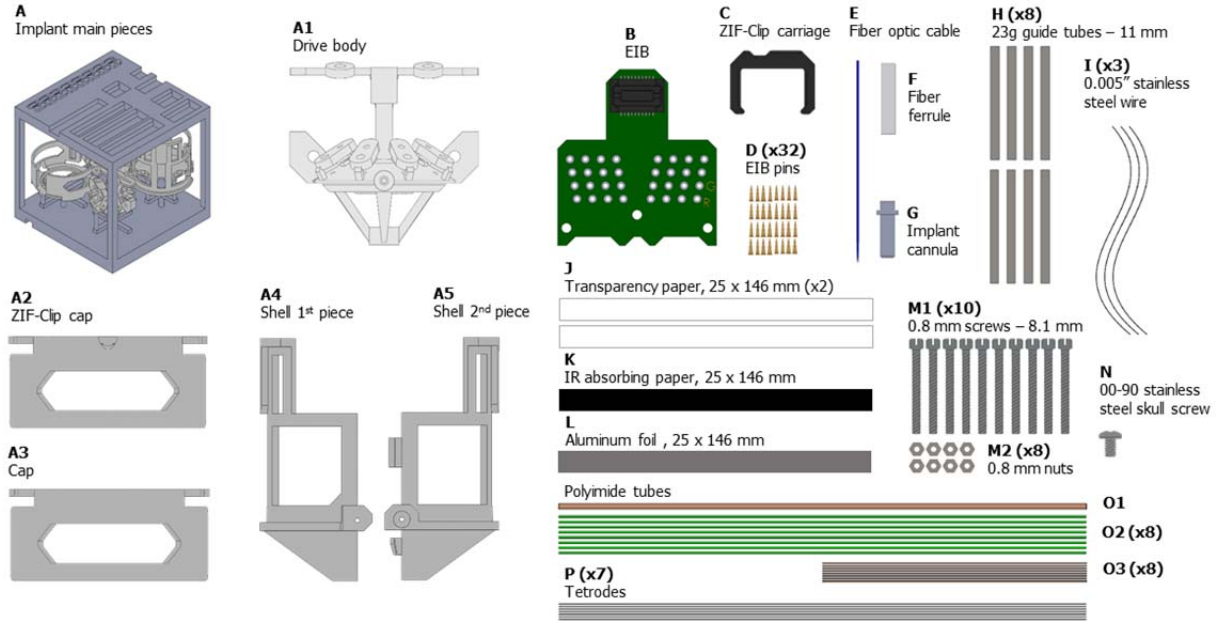


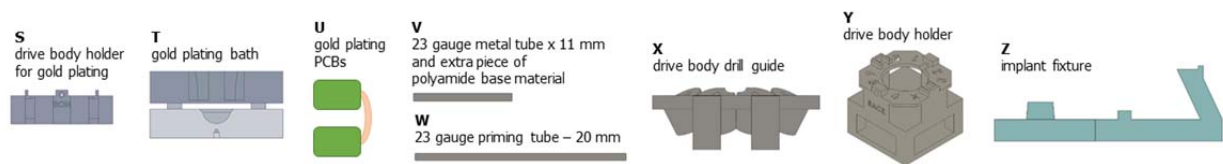
OptoZIF Drive- Supplementary Methods (Materials and Assembly Instruction)



Materials

Name	Description	Material	Units	Vendor	Cost (USD)	Weight (grams)	Notes	
A	Implant main pieces	contains drive body, two caps, and protective shell pieces	3D printed polyamide	1	I-materialize	25	22.77	
A1	Drive body		3D printed polyamide	1	I-materialize	-	0.73	Part of (A)
A2	Cap for use with ZIF-Clip	Protects drive when ZIF-clip or fiber is attached	3D printed polyamide	1	I-materialize	-	0.46	Part of (A)
A3	Cap	Protects drive when drive is not connected with ZIF-clip or fiber	3D printed polyamide	1	I-materialize	-	0.61	Part of (A)
A4	Shell 1 st piece	Protects drive body	3D printed polyamide	1	I-materialize	-	0.39	Part of (A)
A5	Shell 2 nd piece	Protects drive body	3D printed polyamide	1	I-materialize	-	0.40	Part of (A)
B	EIB	Custom PCB	1/32" FR-4	1	PCB Vendor, e.g. Sunstone Circuits	6.50 (in orders of 100)	0.56	
C	ZIF-Clip carriage	Mechanical brace for ZIF-Clip on EIB	Plastic	1	Tucker Davis Technologies (TDT)	3.00	0.05	Needed to prevent damage of ZIF-Clip. PN: ZC32 Shrouds & Caps
D	EIB pins	Large EIB pins	Gold	32	Neuralynx	5.60	0.25	
E	Fiber optic cable	~ 200 micron diameter	Glass	1	ThorLabs	0.01	0.008	
F	Fiber Ferrule	1.25 mm ferrule	stainless steel	1	Precision Fiber Products	6.13	0.05	PN: MM-FER2007-304-265
G	Implant cannula	Provides a consistent implant height and ensures a smooth bevel	3D Printed HD Stainless Steel	1	I-materialize	9.01	0.07	
H	metal guide tubes	23 gauge metal guide tubes, 11 mm in length	Stainless steel	8	SmallParts	0.55	0.12	
I	Stainless steel wire	0.005" Stainless steel wire, 2 inches in length	Stainless steel	3	AM Systems	0.46	0.03	PN: 791400
J	Plastic transparency paper	Forms protective cover, for home cage use.	plastic	2	Various	~0.03	0.46	
K	IR absorbing	Black Flocked Self-	fine fibers on	1	Thor Labs	0.30	0.58	PN: BFP1

	paper	Adhesive Paper	paper					
L	Aluminum foil	For insulating drive caps from EM noise	Aluminum	1	Various	<0.01	0.21	
M1	0.8mm x 0.32" filleted screw	Micro-drive screw	Stainless Steel	10	Antrin Miniature Specialties	10.5	0.28	PN: NAS721CE80-320
M2	0.8mm hex nut	Micro-drive nut	Stainless Steel	8	Antrin Miniature Specialties	8.80	0.15	PN: M0.80
N	00-90 screw	Skull ground connections,	Stainless Steel	1	Antrin Miniature Specialties	0.75	0.025	PN: AMS90/1P-25 00-90x 1/16 SL PAN SST
O1	Plastic fiber optic guide tube	0.0135" ID	Polyimide	1	NeuraLynx	0.65	0.005	
O2	Plastic guide tubes	33g, 0.0071" ID	Polyimide	8	SmallParts	3.36	0.02	PN: TWPT-0071-30
O3	Plastic shuttle tubes	38g, 0.0035" ID	Polyimide	8	NeuraLynx	5.25	0.01	
P	Tetrodes	12.5 µM	Ni-chrome	7	Sandvik	1.03	< .01	PN: U8-DLKL-ONEO
Q	Male connector pin			1	AM Systems	0.72	0.07	PN: 520200
R	Female Connector pin			1	AM Systems	0.72	0.08	PN: 520100



3D Printed Assembly Tools

S – Drive body holder for gold plating – 3D printed polyamide

T – Gold plating bath – 3D printed polyamide

U – Gold plating PCBs – 2x 1/16" FR4 PCB

V – 23g metal guide tube, 11 mm in length – Stainless Steel

W – 23g metal guide tube, 20 mm in length – Stainless Steel

X – Drive body drill guide – 3D High-Definition Stainless Steel

Y – Drive body holder – 3D printed polyamide

Z – Implant fixture – 3D printed polyamide

Recommended Adhesives

Loctite: Cyanoacrylate gel, general purpose adhesive for most assembly gluing operations.

Zap-A-Gap: low viscosity cyanoacrylate, used for gluing guide tubes into implant cannula.

Silverprint: Conductive acrylic paint, used for ground wire connections.

Required Tools for Assembly

1. Ceramic tipped Forceps
2. Serrated Scissors (for final cuts to recording electrodes)
3. Dumont #5 Forceps
4. Measuring Calipers
5. Screwdriver for M0.8 screws
6. Razorblades
7. 27 ½ gauge needles (for precision glue application)
8. Fine sandpaper (200-400 grit)
9. Small sharp scissors
10. Wire cutter for ground wire
11. Heat gun for fusing microelectrodes
12. Small hand drill with bits (#52, #55, #65, #70)
13. Current source and gold cyanide solution for gold plating

Assembly Instructions

Prepare electrodes (2 hours)

Use any suitable protocol (Nguyen et al. 2009; Gray et al. 1995, McNaughton et al. 1983)

Prepare enough electrodes for 7 microdrives, plus extras as desired.

Prepare EIB (up to 4 weeks manufacturer lead time)

- Use custom files and commercial PCB manufacturer to make EIB (B).
 - Circuit board thickness must be 1/32" to be compatible with the ZIF-Clip system. Other sizes may damage the ZIF-Clip head-stage.
- Because of the extreme fine pitch (400 microns) used on the for the ZIF-Clip connector, contract a 3rd party PCB assembler to solder the Hirose connectors (DF30FC-20DS-0.4V) to both sides of EIB.
- Can take 2 to 4 weeks to get EIB boards back from manufacturer.

Prepare Metal Tubes (30 minutes)

- Order custom cannula (G) from 3D Printing service.
 - Ordered using I.Materialize's HD Stainless Steel 3D Printing service.
 - Otherwise a 17g syringe needle, cut to 6.5 mm of length and rounded on the distal end can be used.
 - Can take 2 to 4 weeks to get parts.
- Prepare eight 23g metal guide tubes (H.1-H.8)
 - Tubes should be 11 mm in length.
 - When cut using a dremel cutting wheel, approximately 2 mm of material is used.
 - Deburr ends of tubes with appropriate tool.
 - Clean out ends with a 27 ½ gauge syringe needle.
- Prepare various polyimide tubes (O1, O2.1-O2.8, O3.1-O3.8)
 - One fiber optic cable guide tube, cut 50 mm (2 inch) of a 0.0137" polyimide tube (O1)
 - Eight guide tubes, cut 50 mm (2 inch) of 33 gauge polyimide tube (O2.1-O2.8)
 - Eight shuttle tubes, cut 25 mm (1 inch) of 38 gauge polyimide tube (O3.1-O3.8)

Prepare Drive Body (15 minutes)

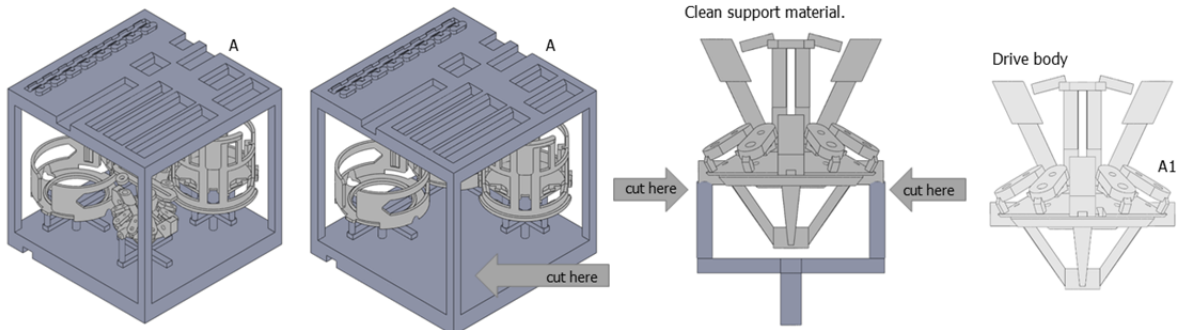
- Check quality of 3D printed main pieces. The designed implant was designed for the highest print qualities using SLS polyamide printing. Most development was completed using I.Materialize's selective laser sintering center in Europe (Belgium). Build qualities from different centers and companies must be carefully inspected for high-quality printing, especially of small features.

Implant main pieces.

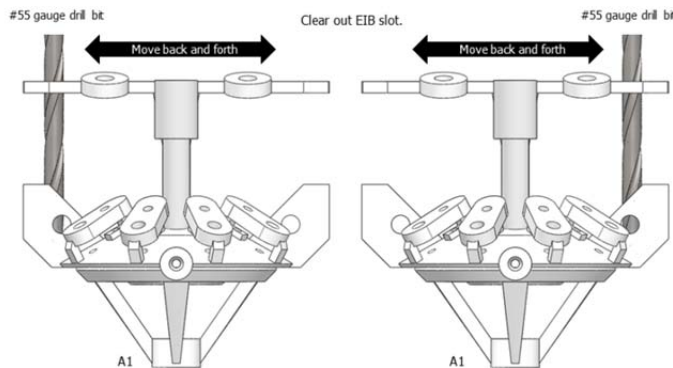
Remove drive body from printed block.

Clean support material.

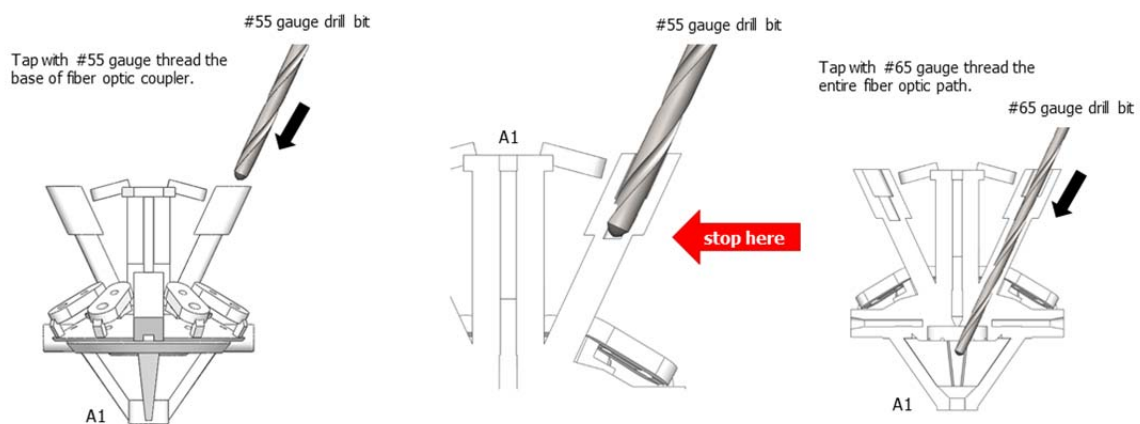
Drive body



- Remove drive body (A1) from printed piece (A) with wire cutters. The remaining material on the body can be cleared with a razor blade.
- Most holes are purposely undersized and must be cleared with the appropriate drill bits. Process is done with manual tool set.

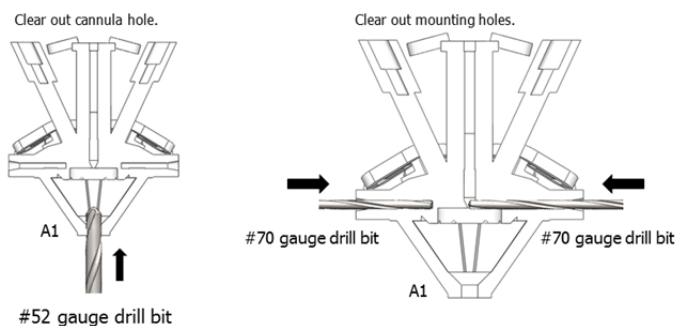


- If necessary, clear out the EIB space with #55 gauge drill bit.
 - Test by placing EIB board in its position and checking if the holes line up on both sides.



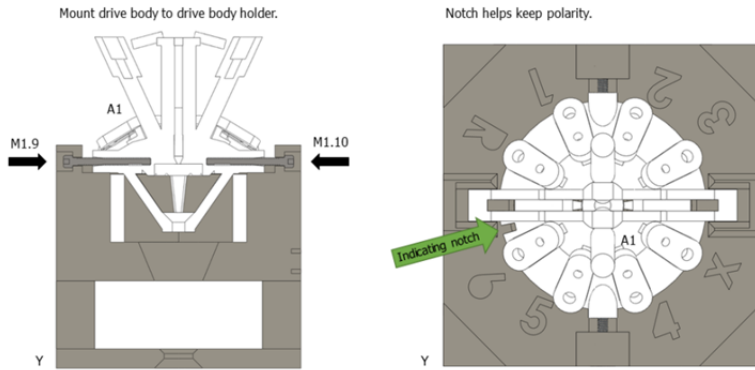
Clean fiber optic receptacle. Use fingers to support the tube while drilling.

- Use #55 gauge drill bit to clear out the top of the fiber receptacle, i.e. where the fiber ferrule is attached later. This is approximately 2.5 mm deep.
- Use smaller #65 gauge drill bit to clear remaining fiber optic path in drive body. This is approximately 14 mm deep from the top of the receptacle.



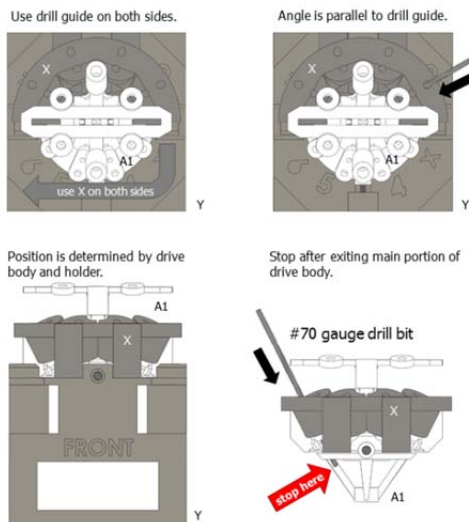
- Clean bottom cannula hole for implant cannula (G) using #52 drill bit.
 - Make sure drill is inserted straight. This step is usually performed with the drive upside down.
- Clean side mounting holes with #70 gauge drill bit. Between 6 mm to 9 mm of material should be cleared out on both sides.

Load Drive Body in Holder (5 minutes)

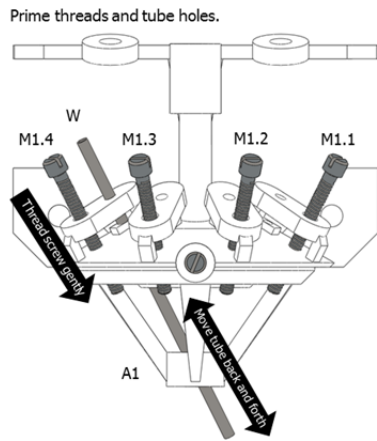


- The drive has two sides, but is completely symmetric, except for a small notch on one side. Thus, it's possible to select front (optical fiber) and back (ground pin) sides to ensure naming consistency. The standard convention employed here is to have the notch on the back side. The EIB front side (with text) and fiber will be on the front side of the drive body.
 - With this convention, R is the reference, 6 tetrodes are listed in clockwise direction (1 through 6), with an unused (labelled X) position interrupting on the back side.
- The drive will be inserted and removed from the holder multiple times during the assembly process.

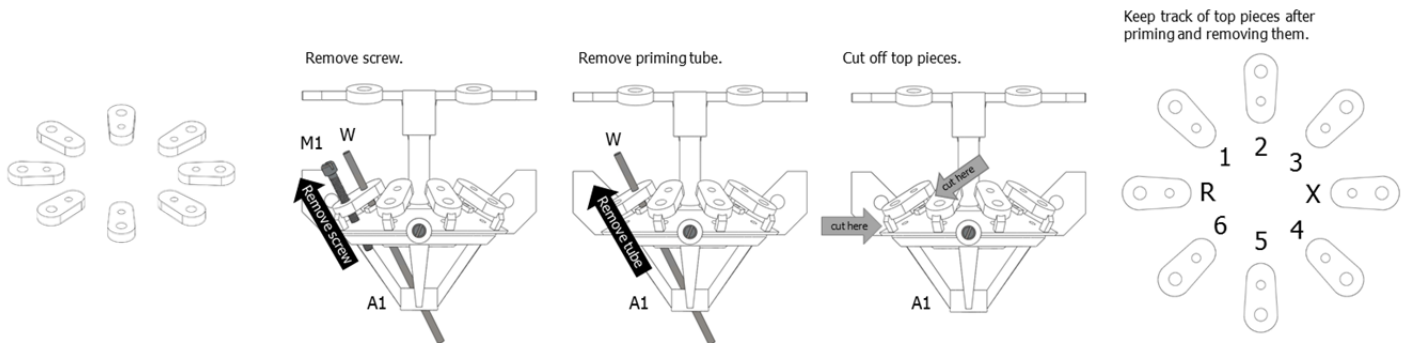
Prime Microdrive Holes in Drive Body (30 minutes)



- Using the drive body drill guide (X), create #70 gauge drill bit holes for all eight Microdrive positions. Use the #70 gauge drill bit for all 16 holes, 8 on each side, 2 for each microdrive.
- Entry direction should be parallel with guide holes.
- Complete manual drilling of each hole until the drill bit appears underneath the main drive body. This is approximately 12 mm deep.
- Flush out all the holes using a long 23 gauge stainless steel tube when complete.

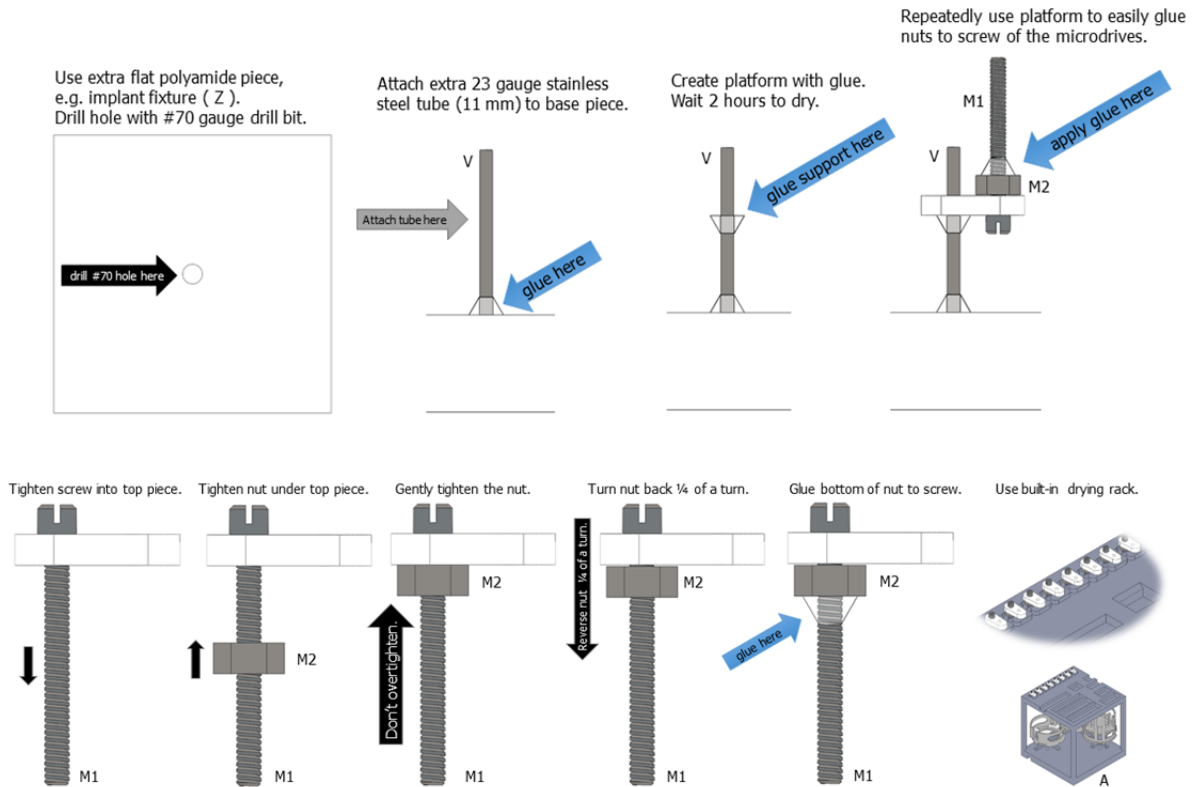


- Do not remove drive body from holder.
- Prime the drive by screwing in all eight 0.8 mm screws (M1.1-M1.8).
- When screwing in each screw, place the long 23 gauge tube (W) as a priming tube to improve drive performance. Note, for clarity of presentation, the screws are shown removed in the illustration below.
- Carefully thread the 0.8 mm screws (M1.1-M1.8), keeping in mind that one should back up a few turns after each advance to ensure smooth threads (Approximately 2 turns back for each ½ -1 full forward turn).
- The screws should remain parallel to the hole while threading with the screw.
- Flush out all the holes using a long 23 gauge steel tube (W), moving the tube back and forth.



- Remove all eight microdrives from main body.
 - Remove the screw (M1) with the priming tube (W) inserted.
 - Remove the priming tube (W).
 - Cut off individual top piece using wire cutters and trim excess material on top piece with a razor blade.
 - Keep track of each top piece's original location.

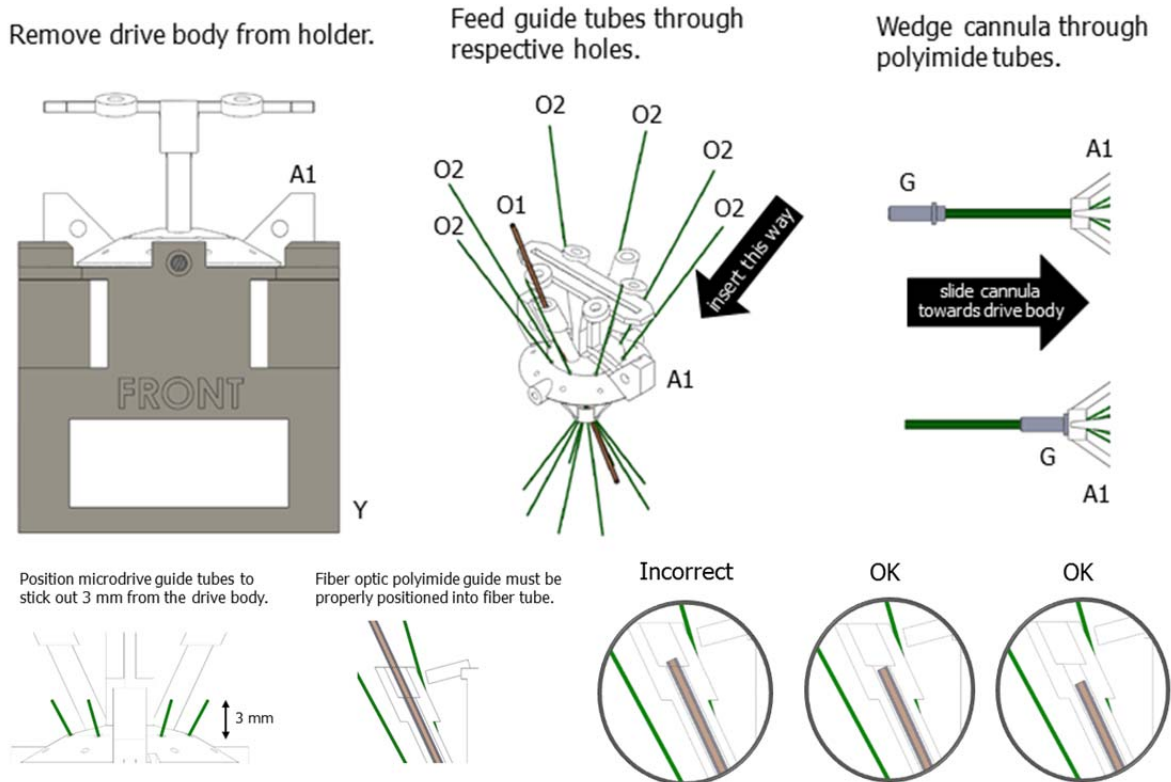
Build Microdrive assemblies (30 minutes + 2 hours)



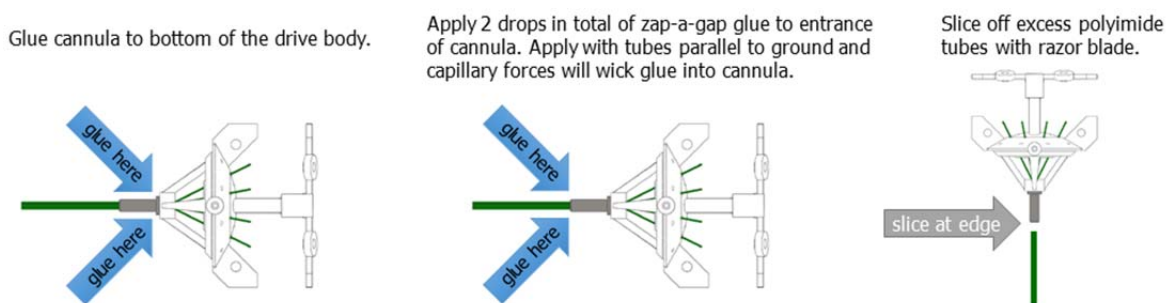
- Prepare all eight microdrives from top pieces.
 - Screw (M1) into top piece.
 - Tighten nut (M2) to the underside of the top piece.
 - Make sure to tighten the nut all the way into top piece, but don't overdo it. It has been found that tightening and then a slight untightening (¼ turn) provides the most appropriate fitting. It can be helpful to hold the nut with a forceps while tightening.
 - Use Loctite on the underside of the nut to lock the top piece into a freely rotating, but tightly controlled mechanical microdrive.
 - A simple apparatus shown above can be used to easily glue drives.
 - It's recommend to apply the Loctite with a 27 ½ gauge syringe needle under a microscope.
 - Wait two hours for glue to dry.
 - Keep track of top pieces and their original location on the drive.
 - Use the built-in drying rack that's part of the main Implant main pieces (A).



Place Guide Tubes and Cannula in Drive Body (30 minutes + 2 hours)

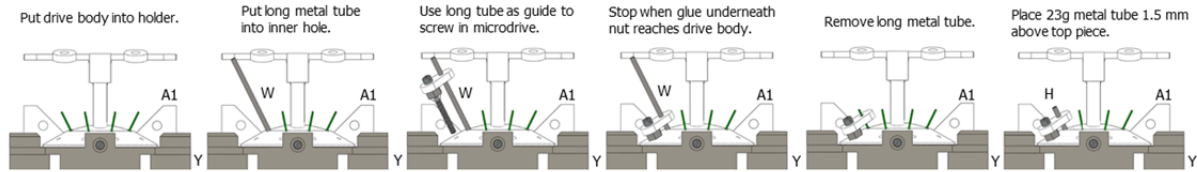


- Remove drive body (A1) from drive body holder (Y).
- Through the top, thread fiber optic guide tube (O1) and eight guide tubes (O2) through their respective holes in the drive body.
- Allow tubes to exit the small bottom hole of the drive body.
 - Most tubes will fit easily, use tweezers to push the other tubes through.
- Wedge implant cannula (G) through tubes into bottom of drive body.
- Before gluing guide tubes into place, position tubes appropriately.
- Microdrive guide tubes (O2) should extend 3 mm from drive body (A1).
- Fiber optic guide tube (O1) must be positioned below the larger hole.

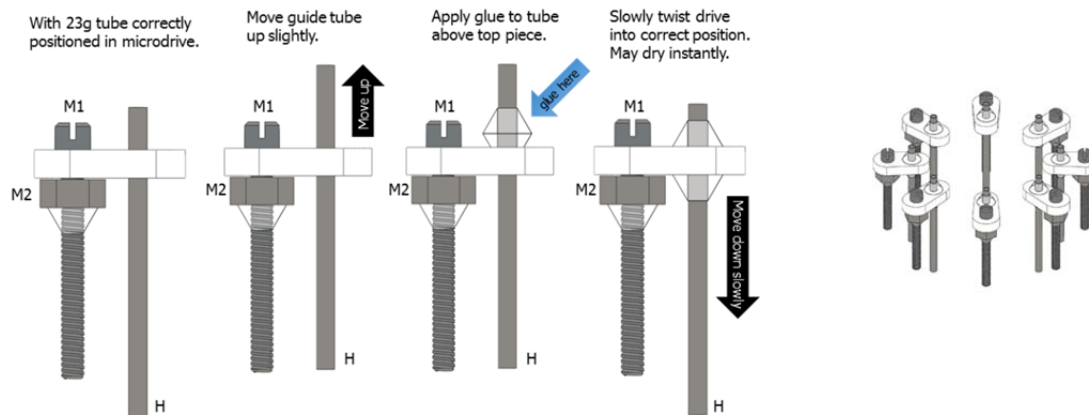


- Using Loctite, glue cannula (G) to drive body.
- Using Zap-a-Gap glue, apply two drops of glue to entrance of cannula. Apply with tubes parallel to ground so that capillary forces wick glue into the cannula.
- Wait 2 hours for glue to dry.
- Slice off excess polyimide tubes with a razor blade at the end of the cannula.

Install Microdrives and Attach Guide Tubes into Drive Body (30 minutes + 2 hours)

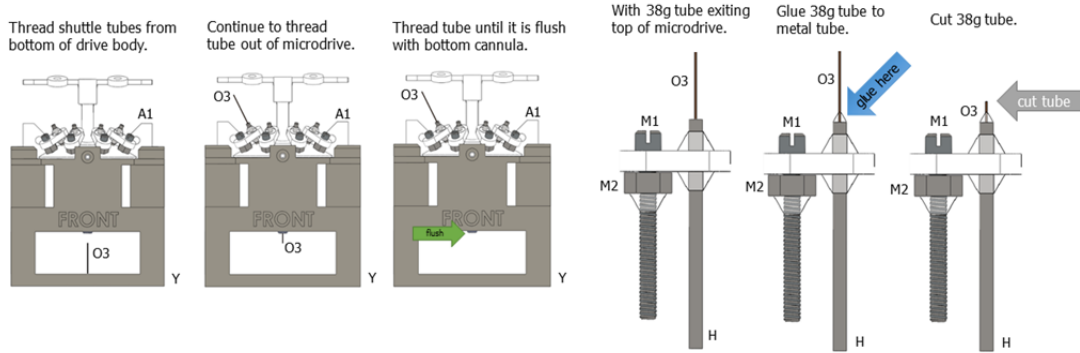


- Put drive body (A1) back in holder (Y).
- For all eight microdrives:
 - Put long metal tube (W) into inner hole.
 - Use long metal tube as guide while screwing in microdrive.
 - Tighten until the glue underneath the nut touches the drive body. Continuing to tighten will strip the guide threads. This distance is about 0.2 mm above the drive body.
 - Take out the long metal tube (W).
 - Insert 23 gauge metal tube (H) into drive body and microdrive.
 - 23 gauge metal tube (H) should be 1.5 mm above the top piece. This is slightly above the top of the screw.

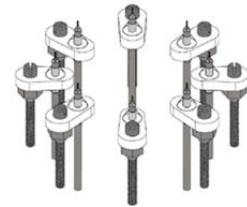


- Glue 23 gauge metal tubes (H) to microdrives:
 - Recommended procedure is to move guide tube up slightly.
 - Apply Loctite glue to bottom of tube using a 27 ½ g needle.
 - Slowly twist metal tube downward to correct position. If done correctly, this will form an instant bond. Be careful not to push too fast.
 - Wait 2 hours for glue to dry.

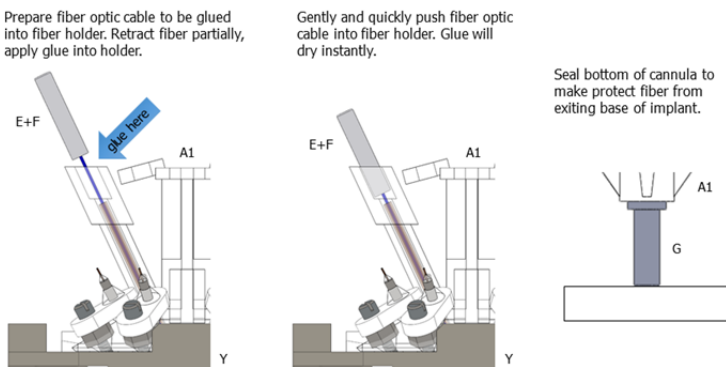
Install Shuttle Tubes into Microdrives (45 minutes + 2 hours)



- For all eight microdrives:
 - Via bottom of drive, thread 38 gauge polyimide shuttle tubes (O3) through guide tubes (O2).
 - This is an appropriate time to map position where each Microdrive exists the implant cannula for later reference.
 - If desired, the drive can be removed from the holder and placed upside down under a microscope for this step.
 - Thread tubes until they are flush with the bottom cannula (G).
 - Glue 38 gauge polyimide shuttle tubes (O3) to 23 gauge metal tube (H). Excessive glue may cause damage to the polyimide on run down and fuse the shuttle tube to the guide tube.
 - Wait 2 hours for glue to dry.
 - Cut top of tube, leaving about 1 mm above 23 gauge metal guide tube (H).

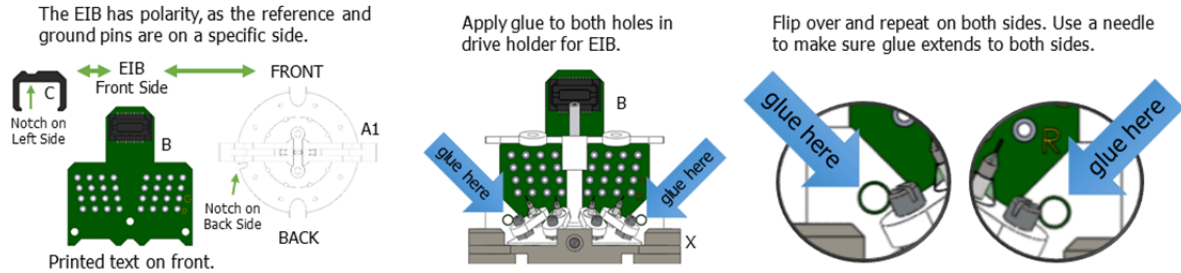


Install Fiber Optic Cable (15 minutes + 2 hours)



- Make sure that the bottom of the cannula (G) is pressed against a rigid surface to prevent the fiber from protruding from the cannula.
 - Thread fiber optic cable (E) through the fiber guide polyimide tube (O1).
 - With the fiber cable and ferrule (E+F) slightly retracted, apply Loctite glue to fiber holder.
 - Quickly insert fiber cable and fiber cannula (E+F) into fiber holder.
- Glue will dry almost instantly, but be careful not to push too fast or the fiber cable may break.

Integrate EIB into Drive Body (15 minutes + 2 hours)

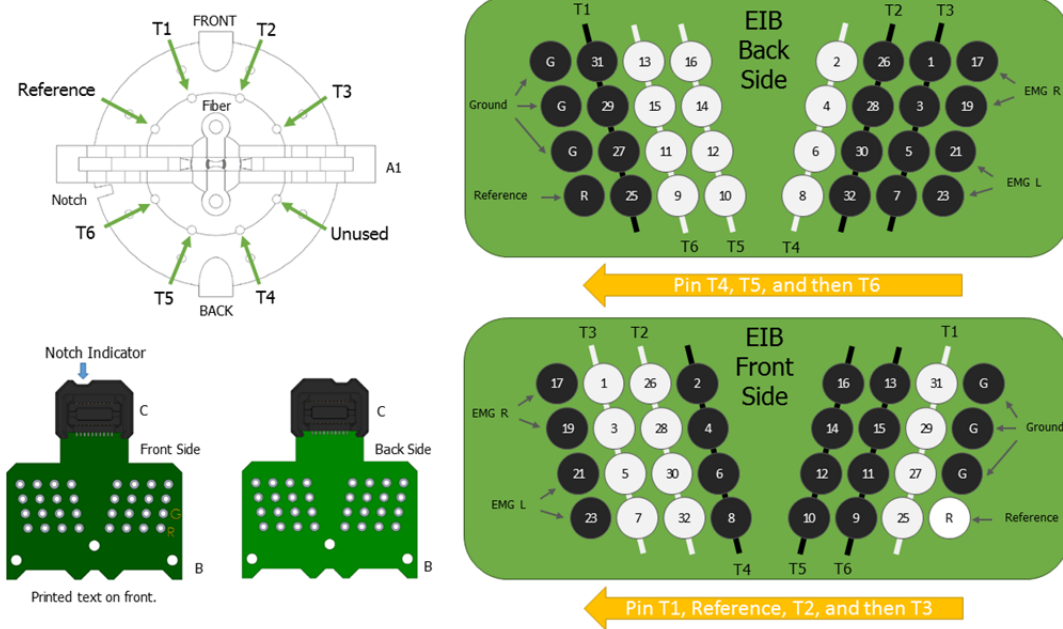


- Insert EIB (B) into drive body (A1).
 - The front size of the EIB contains text. The front side of the drive body doesn't contain a notch.
- Apply Loctite to both holes when EIB is lined up with drive body.
- Repeat on other side of the drive.
- Use a needle to ensure that glue spans the length of the EIB and drive body on both the top and bottom of the EIB.
- Attach ZIF-Clip carriage (C) to EIB. The plastic carriage (C) indicates and determines connector polarity. The notch on the left side indicates the front side. The front side of the EIB contains printed text.

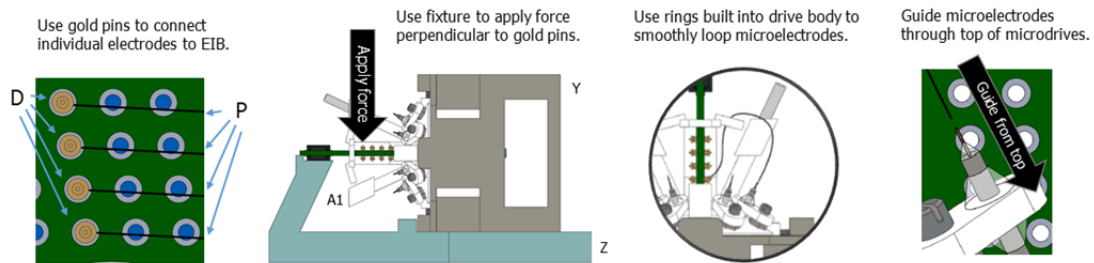
Integrate Gold Pin Ground Connection and Pin to EIB (15 min)

- Solder a 2 inch length of 0.005" stainless steel wire (I) to a female gold pin connector (R). Make sure that the solder on the outside of the connector doesn't substantially change the outer diameter or it won't fit in the ground pin receptacle.
- Test fit the gold pin connector in the ground pin receptacle.
- Once a good fit has been established, remove the pin, place a drop of Loctite in the hold, and then quickly reinsert the pin.
- Use a small needle to add additional glue at the junction between the gold pin and the receptacle.
- Pin the wire from the ground pin to the one of the ground slots on the EIB.
 - This can be done either before or after installing recording electrodes, depending on preference.
 - The wire can be passed underneath the microdrives in positions 5 and 6 in order to avoid interfering with the fragile microwires.

Integrate Microwires (Tetrodes) into Microdrives (2 hours + 2 hours)

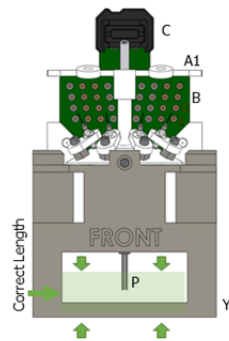


- **Wiring Patterns:**
 - When connecting the microelectrode wiring, the recommended positions are shown.
 - Wiring is easiest going from center out.
 - Start with the back side, connect T4, T5, and then T6.
 - Flip, and finish with the front side, connect the reference, T1, T2, and then T3.
 - Only connect one electrode when connecting the reference electrode. Additional parallel wires being simultaneously pinned will create an impedance mismatch with other channels. The remaining wires can be placed in the holes without pinning.

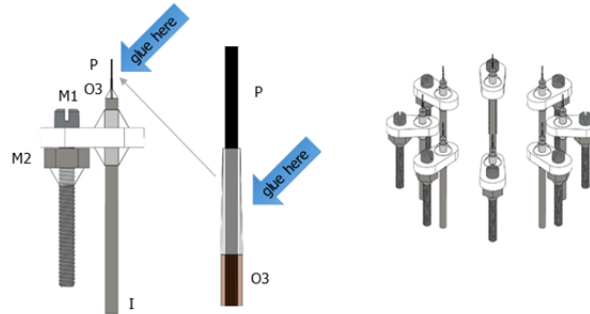


- For all eight microdrives:
 - Working under a microscope, place the wires into the appropriate holes on the EIB.
 - Use gold pins (D) to connect electrodes to EIB (B).
 - Use fixture (Z) and holder (Y) to apply force perpendicular to gold pins. This can be done by pressing the pin with a small screw driver. Excessive force may break the wire.
 - Use built-in rings to loop the microelectrodes (P). The loop should be as small as possible without putting tension on the wire.
 - Guide tetodes (P) through top of microdrives.

With microdrives down, microelectrodes should be more than 3.5 mm but should not exit the holder.



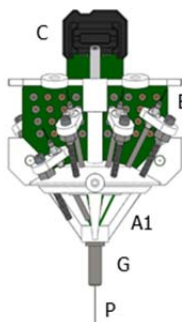
Glue microelectrode to shuttle polyimide tube.



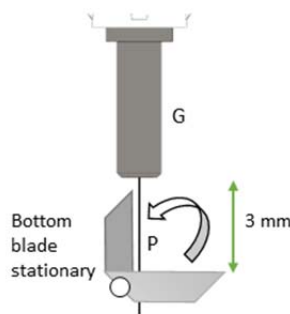
- For all eight microdrives:
 - With the microdrives at their lowest level, cut the microelectrodes (P) so that they are longer than 3.5 mm, but do not exit the holder.
 - Glue microelectrodes (P) to 38 gauge polyimide shuttle tubes (O3). Best done under microscope.
 - Wait two hours for glue to dry.

Final Microelectrode Cuts (2 hours)

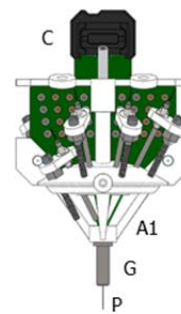
Retract all microdrives except for one to be cut to length.



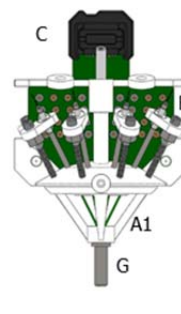
With scissors in fixture after careful measurement, cut microelectrode moving top blade.



Inspect final length microdrive.

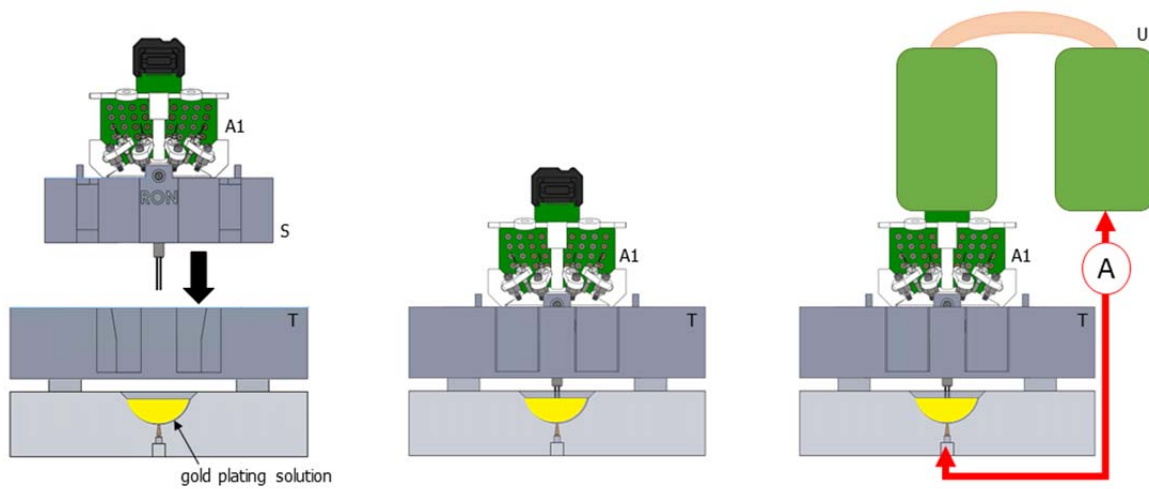


Retract microdrive and repeat.



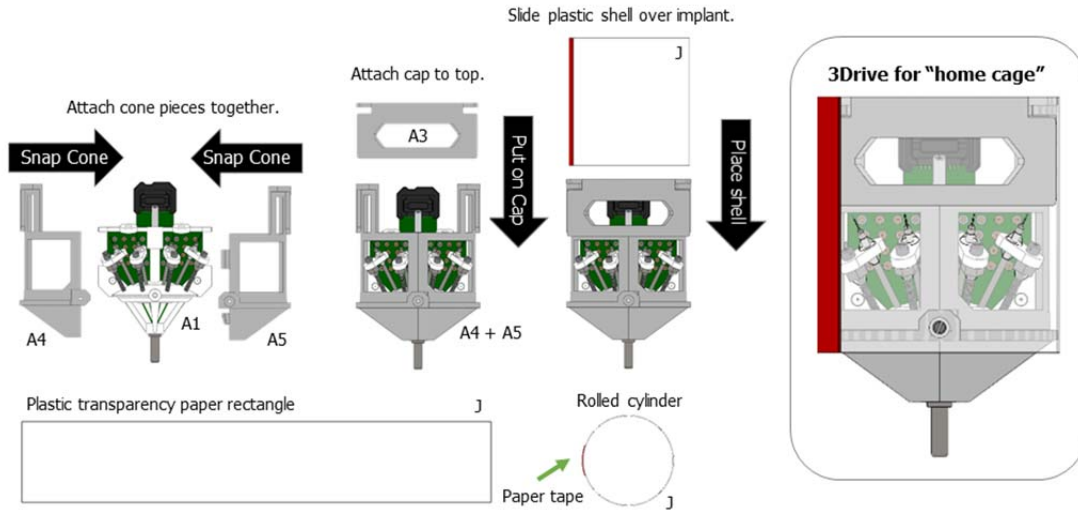
- Remove drive body (A1) from drive holder (Y).
- Retract all microelectrodes (P) into cannula (G).
- Place drive body (A1) in a vice next to serrated microelectrode cutting scissors in second vice.
- Position bottom blade of scissors 3 mm from base of cannula.
- When cutting, move top blade down across the bottom blade.
- Retract finished microelectrode (P) and repeat for all microelectrodes.

Gold Plating of Microelectrodes (1 hour)

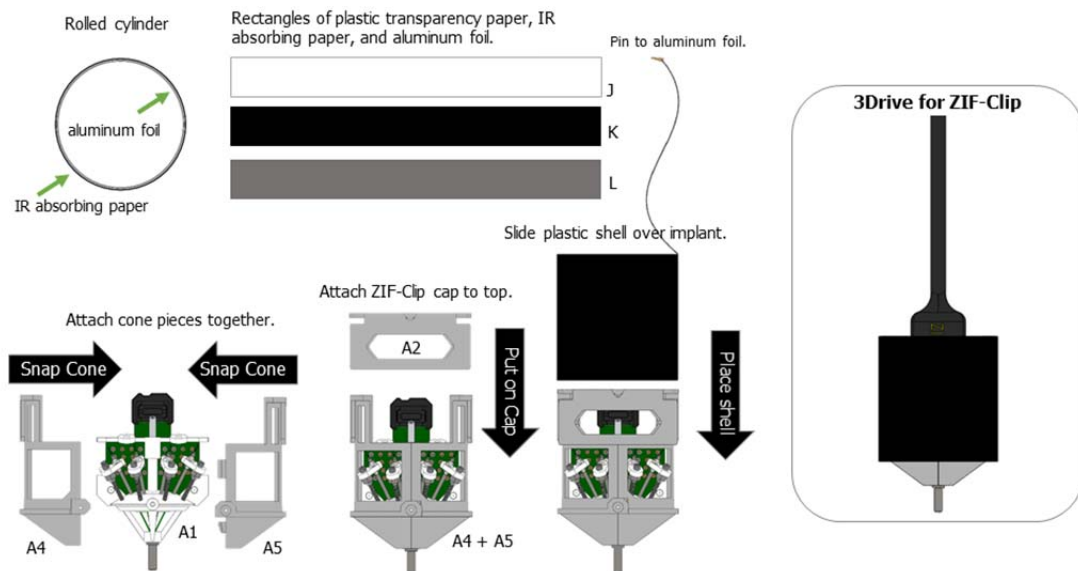


- Place drive in custom gold plating holder (S) with all drives retracted.
- Press the holder into the gold plating base piece (T).
- Turn screws on all microdrives to advance electrode tips into gold solution well.
- Connect ground to the pin in the gold plating fixture.
- Plate each wire to desired impedance by applying direct current ($1.0 \mu\text{A}$) through the microwire to the ground pin according to desired protocol. Use gold plating PCBs (U) for easy access to each microelectrode.
- Record impedance of each wire before and after plating.
- Carefully remove the drive holder from the base piece with the electrodes still extended.
- Clean tip of drive by immersing in ethanol.
- Allow time for the electrodes to dry, then retract each drive until the electrode tip is still 2 full screw turns into the cannula (G) (best done under microscope). This will ensure that there is a consistent and known number of turns before the wires exit the cannula after implantation.

Prepare protective shell and cap (30 minutes)



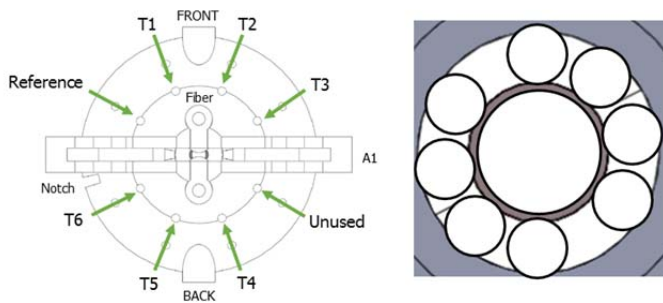
- Cut remaining pieces from the main implant block, i.e. ZIF-Clip cap (A2), cap (A3), and two protective shell pieces (A4+A5) from implant main pieces block (A).
 - Deburr main edges.
- Snap shell pieces (A4+A5) together around drive body (A1).
- Don't screw in. This is only used to make outer shields, the final shell assembly will occur during the implant surgery.
- Snap cap (A3) over top of shell pieces (A4 + A5).
- Make plastic outer shield for "home cage".
 - Cut a rectangle out of transparency paper (J), 25 mm (1 inch) x 146 mm (5 ¾ inches).
 - Roll rectangle into cylinder that fits tightly around cap and shell pieces.
 - Use paper tape to keep cylinder shape.



- Make ground shield for electrophysiological recordings.
 - Cut rectangles out of transparency paper (J), IR absorbing paper (K), and aluminium foil (L).
 - Approximately 25 mm (1 inch) x 146 mm (5 ¾ inches)
 - The aluminum foil cylinder goes inside the plastic transparency cylinder. The IR absorbing paper goes on the outside of the plastic transparency cylinder.
 - Scotch tape can be used in addition to paper tape.
 - A male gold pin (Q) is attached to the aluminum foil by using silver print and a length of 0.005” stainless steel wire (I) about 50 mm (2 inches) long.
 - The ground shield can be reused for multiple mice, although having a backup on hand is recommended.

Record Drive Parameters (15 minutes)

- Record drive weight.
- Record fiber optic transmittance.
- Record cannula output map



Prepare screw for skull ground (15 minutes)

- Prepare a length of ~3” of stainless steel wire (I) and strip about 1 cm from one end.
- Wrap the stripped end of the wire several times around a 00-90 screw (N) just under the screw head.
- Position the tip of the wire on top of the screw head and secure using silver print.
 - It is usually necessary to apply multiple coats to ensure a solid bond.
 - Make sure that the slot on the screw head is not obstructed.

Implant Surgery Notes

- Retract all microelectrodes before placing the implant.
- Attach the grounded skull screw to a ground slot on the EIB.
- Attach the wires from EMG (or other auxiliary recordings to the open space on the EIB)
- After snapping together the protective shell, secure to drive body with two screws