Surgery and Recovery in Space

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Experiment Team

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RATIONALE

Nerves can have a profound effect on the skeletal muscles that they serve. To understand the development of antigravity muscles in weightlessness, it is important to study not only the muscles, but also their innervation. These nerves originate from motor neurons in the spinal cord. To study specific spinal neurons, they must be labeled to distinguish them from other nerve cells in the spinal cord. This is commonly done using retrograde labeling, which involves depositing a small amount of a label in the muscle of interest. The label is taken up by the motor nerve terminals and transported back up the nerve axons to the nerve cell body in the spinal cord. When tissue sections of the spinal cord are examined under a light microscope, labeled nerve cells serving the injected muscle are readily resolved.

Performing retrograde labeling, however, presents technical challenges. First, for this experiment, the muscles to be labeled are very small—a millimeter or two in diameter—so the label must be injected in microliter quantities using a fine needle. Second, microsurgery is required to expose the muscle for accurate injection. Third, proper anesthesia and recovery techniques are essential to ensure that the rats can tolerate the procedure easily and recover without difficulty. Fourth, in space this must be done within a workstation that keeps the work area about an arm's length away from the eyes.

For Neurolab, the procedures and techniques to perform recovery surgery were developed and used for the first time in space. Five, 21-day-old rats were anesthetized, and their soleus and extensor digitorum longus leg muscles were injected with label. The surgical incisions were closed with wound adhesive. All rats tolerated the procedure well, and they all recovered uneventfully. The wound sites were healing cleanly when examined two days after the surgery. The procedures worked well and demonstrate that, if needed in the future, challenging and delicate surgical procedures can be performed in space.

PROCEDURE DESCRIPTION

Anesthesia

Administering proper anesthesia for small rats can be difficult. Too much anesthesia can kill the rat, and inadequate anesthesia is unacceptable. The difference between a fatal and an acceptable dose may be just a few tenths of a milliliter. To develop the anesthesia protocol for Neurolab, extensive testing was performed preflight. A combination of acepromazine, xylazine, and ketamine (a Ketaset cocktail) was used for anesthesia. Different doses were tested to determine which dose provided the best anesthesia, while allowing for a full recovery. A nomogram chart was developed, based on preflight testing, that listed the dose to give based on the length of the rat's tail. Tail length was shown to correlate strongly with the rat's weight. Neurolab was not equipped to measure the rat's body mass in microgravity. The nomogram defined individualized doses appropriate for the rat's size. The anesthesia was administered into a forelimb muscle using an insulin-type syringe with a 25-gauge needle. Typical doses were 0.3–0.5 cc. Figure 1 shows the contents of an anesthesia kit. The syringes were prefilled, and there was Velcro attached to the syringe body and the syringe caps. The syringes were placed in bags with removable seals. In use, the card holding the syringes was removed from the plastic bag and attached on the inside of the general-purpose workstation (GPWS) with Velcro. As needed, the syringes were removed individually from the card and replaced after injecting.

During the mission, the anesthesia protocol had to be modified slightly. The rats on the mission had not grown as large as rats of the same age had grown on the ground. In addition, inflight, several rats had unexpected foreshortening of their tails. This meant that tail length could no longer be used as an accurate predictor of the body weight. Preflight training, however, had provided experience with the use of the anesthetic and its effectiveness. The typical dose that had been used in preflight training was reduced by approximately 25%. This provided excellent anesthesia. One rat received an extra 0.1 cc dose because of a delay in the anesthetic effect.

Procedure

Figure 2 shows the GPWS during a preflight training session with the front door open. Before the procedure, the crewmember would unstow the necessary equipment from stowage areas in the Spacelab and place it into the GPWS. The equipment included the cork-topped worktable (Figure 3) and all of the necessary kits and surgical tools (small scissors, retractor, forceps). In addition, a clear plastic box with a screen lid was used as the area in which the rats could awaken safely from

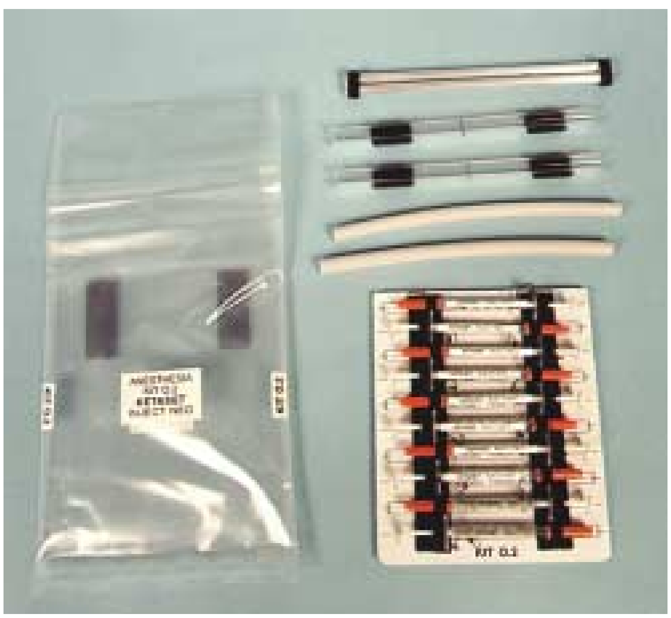

Figure 1. Anesthesia kit for the injection procedure. The individual anesthesia syringes were preloaded with anesthetic, and Velcro was placed both around the syringe and around the cap so they could be used easily in space without floating away. The syringes were mounted on a card that could be placed on the wall of the GPWS within easy reach of the operator. All kits that contained fluids were placed in sealed bags (shown empty and open here) so the fluids would be contained if a syringe broke and would not leak into the spacecraft cabin.

Figure 2. Interior of the GPWS. The workstation provided a containment environment that was isolated from the spacecraft cabin and allowed for procedures (e.g., surgery, use of fixatives, tissue collection) that would involve working with fluids and rodents. A table with a cork top could be placed within the GPWS and secured to the floor with Velcro. All of the other necessary materials could be attached to Velcro on the walls. In the bottom right of the workstation is the clear plastic box used to hold the rats.

Figure 3. This worktable allowed for a variety of procedures to be performed in the GPWS. The table was covered with an absorbent pad, and equipment could be attached to the table either with pins into the cork or by Velcro straps that attached to the Velcro on the sides and bottom of the table. Height was adjustable.

Figure 4. Payload Specialist Jay Buckey is shown wearing magnifying surgical loupes that the crewmembers used while doing delicate work within the workstation.

surgery. Once the workstation was appropriately configured, the crewmember would don gloves, close the GPWS door, and insert his or her arms through the Tyvex gauntlets into the workstation.

Another crewmember would pass an animal cage through the side door of the GPWS, and the rats were transferred to a clear holding box in the workstation. To perform the procedure, anesthesia was administered to a rat and the crewmember would wait 5-10 minutes for it to take effect. Once the rat was sufficiently anesthetized and nonresponsive to foot pinch, the rat was secured to the worktable with a Velcro strap placed loosely around the abdomen. The leg was fixed in position with tape. Prior to beginning surgery, the crewmember cleansed the rat's leg with alcohol.

Since the worktable was approximately an arm's length from the crewmember's eyes and the area of interest was a couple of millimeters in size, magnifying surgical loupes were used (Figure 4). A small incision was made in the rat's leg, the muscles were exposed, and the label was injected. The incision was closed using a skin adhesive (Nexaband). After surgery, the rat was placed in a plastic box to recover. When all of the rats were awake, they were transferred into a cage and rehoused in the Research Animal Holding Facility.

This procedure was performed on FD13 of the Neurolab mission, and it was uneventful. The anesthesia was adequate for all rats, and they all recovered. Examination of the leg wounds two days after surgery showed that the wounds were healing well. Postflight assessment verified that the label had been placed in the correct muscles but, due to technical problems with the label, it was not carried retrogradely to the spinal cord as intended. This procedure was the first time that survival surgery with all of its components (anesthesia, surgery, recovery) had been performed in space.

APPLICATION

This effort showed that the technical problems with performing delicate surgical procedures in space (securing tools, adequate anesthesia, clear field of view) could be solved. This information will be useful for future, longer missions, where surgery may need to be done in space.