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Low profile halo head fixation in non-human primates

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HIGHLIGHTS

- We present a simple halo head fixation system for non-human primates.
- The low profile of the halo maximizes area of skull available for cranial implants.
- The device can be used shortly after implantation and is easy to maintain.
- Large animals can be head fixed.
- There is minimal MRI distortion from the permanent titanium foot plates.

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ABSTRACT

Background: We present a new halo technique for head fixation of non-human primates during electrophysiological recording experiments. Our aim was to build on previous halo designs in order to create a simple low profile system that provided long-term stability.
New method: Our design incorporates sharp skull pins that are directly threaded through a low set halo frame and are seated into implanted titanium foot plates on the skull. The inwardly directed skull pins provide an easily calibrated force against the skull.
Results: This device allowed for head fixation within 1 week after implantation surgery. The low-profile design maximized the area of the skull available and potential implant orientations for electrophysiological experiments. It was easily maintained and was stable in 2 animals for the 6–8 months of testing. The quality of single unit neural recordings collected while using this device to head fix was indistinguishable from traditional head-post fixation. The foot plates used in this system did not result in significant MRI distortion in the location of deep brain targets (~0.5 mm) of a 3D printed phantom skull.
Comparison with existing method(s): The low profile design of this halo design allows greater access to the majority of the frontal, parietal, and occipital skull. It has fewer parts and can hold larger animals than previous halo designs.
Conclusions: Given the stability, simplicity, immediate usability, and low profile of our head fixation device, we propose that it is a practical and useful means for performing electrophysiological recording experiments on non-human primates.

1. Introduction

Ridged skull fixation is routinely performed in non-human primates (NHPs) in order to optimally perform neuronal recordings during arm or saccadic eye movements. A traditional method of head fixation employs a vertically oriented head post that is anchored to the skull with dental acrylic and surgical bone screws and typically incorporates a recording chamber for access to the brain (Mountcastle et al., 1975). The drawbacks and complications

Abbreviation: NHPs, non-human primates.

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of acrylic caps include the surgical invasiveness of implantation, the high incidence of chronic infections in the potential space between the acrylic and the skull, and loosening of the cap due to tissue undergrowth, infection, and bone necrosis (Lanz et al., 2013). These factors may lead to catastrophic implant failure involving both the recording chamber and head fixation and may result in large sections of skull breaking off with the implant.

While acrylic-free titanium head posts can circumvent some of these issues (Adams et al., 2007; Lanz et al., 2013) several labs have focused on developing halo ring head fixation systems that are fixed to the skull at multiple anchor points (Fig. 1) (Friendlich, 1973; Davis et al., 2009; Isoda et al., 2005; Pigarev et al., 2009). A clear advantage of the halo fixation method is that it preserves much of the frontal, parietal, and occipital skull surfaces for large or multiple recording chambers (Pigarev et al., 2009). Furthermore, animals can be head fixed immediately after implantation in comparison to acrylic-free head post techniques that often require a prolonged healing period for osseous integration (Betelak et al., 2001; Hacking et al., 2012; Lanz et al., 2013). In addition, the halo technique is reversible, well tolerated, and likely reduces the risk of implant failure due to the distribution of the shear and tensile forces in multiple sites around the skull rather than in one area. Recently, completely non-invasive head fixation has been achieved using constricting templates that are molded to a NHP's head (Amemori et al., 2015; Drucker et al., 2015). However, this technique does not circumvent the major infection risks associated with acute intracranial electrophysiology, may result in pressure sores and pain as a result of rigid head constraint against soft tissue, and obscures visualization of stimulation evoked facial movements.

Other minimally invasive halo fixation techniques have been proposed previously. Friendlich (1973) and Isoda et al. (2005) used sharp skull pin fixation translated from human stereotactic neurosurgical procedures (see Fig. 1A and B). Although these devices could be used immediately after a brief implantation procedure, there was a potential for pin loosening. In human patients, pin loosening with halo fixation is a common complication (36% of patients) with complete dislodgement occurring in up to 10% of these patients (Garfin et al., 1986) that may result in severe scalp or muscle lacerations. The potential for pin dislodgement in NHPs is exacerbated by the relatively shallow angle of their skulls relative to humans. Pigarev et al. (2009) described their evolving halo technique that employed 5 posts that abutted the skull to constrain movement. A recognized drawback was a chronic drift of the halo on the skull which was overcome by screwing multiple posts into the skull and reinforcing them with acrylic and sleeves with base plates (Fig. 1C). Davis et al. (2009) similarly dealt with the problem of pin loosening and halo movement by inserting blunt titanium pins into predrilled holes in the skull through fixed reinforcing titanium plates (Fig. 1D).

In this study, we describe a simplified halo head fixation method for NHPs that is derived from previous halo techniques. Our design incorporates sharp skull pins that are directly threaded through a low set halo and are seated into implanted titanium foot plates on the skull. The inwardly directed skull pins provide an easily calibrated force against the skull that can be chronically maintained to avoid pin loosening. The low-profile design maximizes the surface area of the skull available and potential implant orientations for electrophysiological experiments.

2. Methods

2.1. Subjects

The present experiments were conducted on two Chinese origin male rhesus macaques (*Macaca mulatta*). At the time of their halo implantation, monkey M was 6 years old and weighed 13.0 kg, and monkey E was 5 years old and weighed 9.2 kg. All procedures were approved by the Queen's University Animal Care Committee and were in full compliance with the Canadian Council on Animal Care guidelines on the care and use of laboratory animals.

2.2. Design of halo frame

The halo was designed according to the larger animal's skull and soft tissues (monkey M) because it could be transferable to the smaller animal by simply using longer skull pins. A pre-operative MRI scan was obtained (3T, 0.6 mm voxel, T1 sequence) and the external skull and soft tissue anatomy were segmented (Mimics, Materialise Belgium). The segmented anatomy was used to design a halo with 3D printing software (Magics, Materialise Belgium). The halo was designed to fit as low as possible on the monkey's skull in order to maximize the space available for cranial implants (Fig. 2).

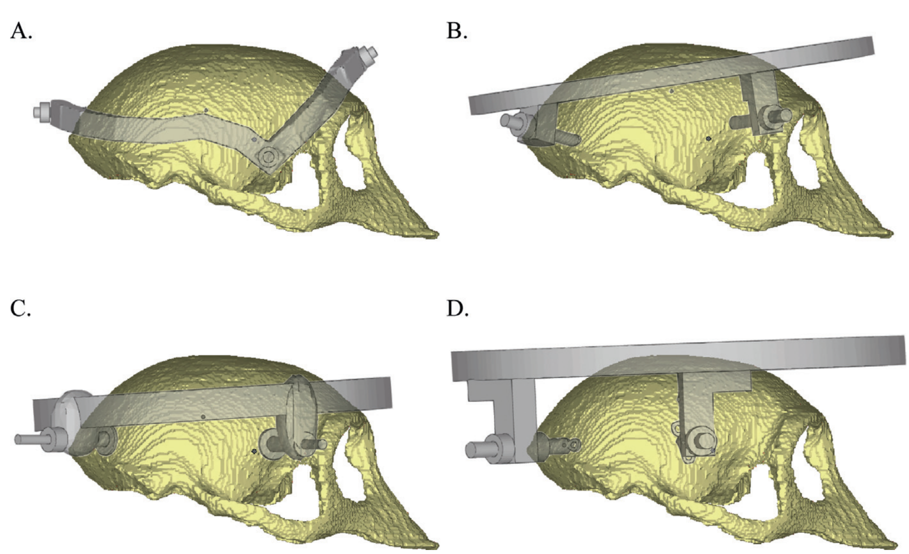

Fig. 1. A graphical comparison of different NHP halo techniques. The halo sizes were modified to fit the skull of an animal used in the present study (monkey M). (A) Friendlich (1973) used a fitted low profile halo with skull pins. (B) Isoda et al. (2005) used a flat head ring with offset posts to hold the skull pins. (C) Pigarev et al. (2009) used a low set flat acrylic ring that was fastened to multiple surgically implanted posts (the description of version 2 was used to estimate the halo's position and fit). (D) Davis et al. (2009) used a flat halo frame with offset posts to hold the blunt skull pins that fit into surgically implanted titanium reinforcement plates.