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3D Printing for Low-cost, Rapid Prototyping of Eyelid Crutches

Michael G. Sun, B.S.¹, Duangmontree Rojdamrongratana, M.D.¹, Mark I. Rosenblatt, M.D., Ph.D., M.B.A.¹, Vinay K. Aakalu, M.D., M.P.H.¹, Charles Q. Yu, M.D.¹

¹University of Illinois at Chicago, Department of Ophthalmology and Visual Sciences

Abstract

Blepharoptosis or ptosis is a common and potentially debilitating clinical problem. Long-term, surgical treatment for ptosis caused by progressive myopathies can be challenging due to potential recurrence and complications associated with facial muscle weakness. When surgical treatment is no longer effective, an eyelid crutch can be used as an alternative intervention. This report demonstrates how 3D printing was used to rapidly design, prototype, and manufacture new custom-fit eyelid crutches at a low cost.

Keywords

blepharoptosis; eyelid crutch; progressive myopathy; lagophthalmos; 3D printing

INTRODUCTION

Blepharoptosis or ptosis is a common problem that can cause decreased quality of life. If the upper eyelid obscures the visual axis, ptosis can affect the visual field and inhibit activities of daily living^(1, 2). While surgery is often the treatment of choice for most visually significant ptosis; ptosis from progressive myopathies such as chronic progressive external ophthalmoplegia (CPEO), myotonic dystrophy, etc. can be challenging due to recurrence after surgery and complications associated with orbicularis weakness and lagophthalmos⁽³⁾. In our case, an eyelid crutch was chosen as an alternative intervention for a patient with CPEO related bilateral ptosis. Traditional crutches, however, have disadvantages as they lack malleability and need to be customized for each patient which requires a specialized optician and can cost approximately \$80-\$100⁽⁴⁾. 3D printing can be used as a low-cost alternative to manufacture devices such as the eyelid crutch as this technology is becoming cheaper, more common, and more available at many medical centers and academic institutions^(5–8). This report describes the use of a commercially available 3D design software and printer to create a removable and easily adjustable eyelid crutch.

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CASE REPORT

A retrospective review of patient records was conducted after obtaining an IRB waiver through the University of Illinois at Chicago (UIC) and adheres to the tenets of the Declaration of Helsinki as amended in 2008. This is an investigational device that is exempt from pre-market notification and falls under Class I of FDA guidelines: (<http://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/CFRSearch.cfm?fr=886.5600>). The patient gave informed, written consent for using personal information and images in this report. An 84 year-old African American female who was previously diagnosed with a CPEO variant, Kearns-Sayre syndrome, presented for recurrent bilateral blepharoptosis. She had a history of multiple eyelid surgeries in order address the ptosis over several years including a physiologic sling, as described by Putterman⁽⁹⁾, and browplasty to elevate her eyebrows. Her ptosis recurred due to progression of her ophthalmoplegia. In addition, the patient had developed significant keratopathy with inferior corneal thinning due to incomplete blinking and orbicularis weakness, although she exhibited minimal lagophthalmos. She was able to achieve close to zero lagophthalmos with a forcible blink. At the time of presentation, the patient was reluctant to pursue further surgical options. She was offered fitting for standard eyelid crutches at a local optical shop, but the cost of these traditional crutches was prohibitive. Thus, we sought to address the need for a low-cost and non-operative treatment for her ptosis. We utilized a Stratasys Objet30 Prime 3D printer (Stratasys, Eden Prairie, MN) with a SolidWorks® (Dassault Systèmes, Vélizy-Villacoublay, France) based design for creating an eyelid crutch.

In designing the eyelid crutch for our patient, measurements of patient's marginal reflex distance-1 (MRD-1), eyelid dimensions, and dimensions of the patient's existing eyeglass frames were taken. An eyelid crutch consisting of two clips connected by an arched support was designed using SolidWorks® (Figure 1). The crutch was printed using biocompatible MED610 material from a Stratasys Objet30 Prime printer. MRD-1 before use of eyelid crutches was -2mm OU and subjective vision was poor (Figure 2). While using the crutches, patient reported significant improvement in vision and MRD-1 improved to 1mm (Figure 3). The patient was also able to achieve adequate eye closure while wearing the crutches (Figure 4). Further iteration of the prototype was undertaken for patient comfort and better attachment. At the five-month follow-up, the patient reported continued use of the crutches during activities of daily living with subjective improvement in vision and quality of life. There was no worsening of the ocular surface. We provided the patient additional copies of the eyelid crutches to account for any breakage.

DISCUSSION

Blepharoptosis is a condition that can range from mild cosmetic concerns to severe visual impairment. While surgery is often necessary, chronically recurring ptosis and patient comorbidities sometimes warrant alternative non-surgical interventions. Although our patient was able to function for many years with surgical interventions for her ptosis, her CPEO, orbicularis and frontalis muscle weakness, incomplete blink, corneal desiccation, and advancing age mandated alternative solutions to improve her daily function.

Non-surgical options for complicated cases of ptosis are limited. The use of scleral contact lenses has been explored as an option. These lenses are made of rigid gas permeable (RGP) materials and are established for the treatment of corneal diseases and refractive errors. They are able to mechanically elevate the eyelid and provide some improvement for ptosis⁽¹⁰⁾. Alternatively, a device known as the magnetic levator prosthesis (MLP) is currently being investigated as another non-surgical intervention. Eyelid elevation is achieved by adhering a magnetic strip to the upper eyelid and coupling this to another magnet attached to an eyeglass frame⁽¹¹⁾.

An eyelid crutch is an assistive device designed to attach onto a patient's eyewear and help lift the eyelid for patients unable to undergo surgery, or for whom the ptosis is considered temporary. Traditional eyelid crutches are made of a plastic or metal and require a specialized optician for custom fitting and attachment⁽¹²⁾. A challenge of manufacturing these crutches is the variability among individual patients. Precise measurements need to be made to account for both facial structure differences among patients and eyeglass dimension variability.

Traditional eyelid crutches therefore cannot be easily manufactured on a large scale, as they have to be customized for each patient. The crutch itself and the installment can range from \$80-\$100⁽⁴⁾, which may be a barrier for some patients, as it was for ours. Additionally, alterations to existing crutches may be tedious as they have to be brought back to the optician. To address these challenges, we used 3D design and printing to manufacture a more universal, removable and adjustable eyelid crutch for patients with ptosis.

Here we used 3D printing to design and manufacture a new prototype for the eyelid crutch. We designed a crutch that is easily removable and more adjustable than a traditional crutch. Our crutch consists of two clips connected by a supporting arch and is made to attach onto the upper frame of a patient's eyewear (Figure 1). Our goal was to design an eyelid crutch that can be used by many patients with different eyeglass frames. The challenge in designing a crutch that attaches onto different frames is that each pair of glasses has unique dimensions. The relevant dimension for our design is the thickness of the upper frame to which the eyelid crutch attaches to and can vary widely between different glasses.

To address this issue, we introduced an angled clip design into the eyelid crutch (Figure 5). While simple, this modification allows the crutch to accommodate eyewear frames of multiple thicknesses. The clip is stretched when attached to the upper frame, which creates a tension that holds the crutch in place. This modification also allows the user to adjust the length of the crutch arch for improved comfort (Figure 6). Since tension of both clips holds the crutch in place, the distances of the two clips can be adjusted. Varying the distance between the two clips will vary the projection of the arch. This lets the user easily adjust the crutch within seconds to provide ideal ptosis relief while also retaining comfort. This is a significant improvement as it allows one eyelid crutch design to be suitable for multiple users. While we believe our design to be malleable enough to fit a range of eyeglasses and patients, one design may not be completely universal. Other versions with minor changes in clip dimensions and arch length may be necessary to accommodate all eyewear frames.

Regardless of these improvements, a possible long term complication of eyelid crutch overuse is ocular desiccation. Lagophthalmos, or incomplete eyelid closure, can be a complication as it can be difficult to close the eyelid while wearing an eyelid crutch. Incomplete blinking may cause corneal compromise, even in the face of minimal lagophthalmos⁽¹³⁾. It is important with any eyelid crutch to adequately educate the patient on the need for lubrication, proper fitting, and avoiding overuse. Another advantage of our design is that it is removable, unlike many traditional crutches. Patients are therefore able to easily adjust their usage to prevent desiccation related complications. Additionally, our crutches can be 3D printed with flexible materials that potentially allow for better eye closure compared to rigid tradition crutches, although further studies will have to be done to compare to the traditional crutches. Finally, eyelid crutch manufacturing is not limited to 3D printing. With our 3D design, eyelid crutches have the potential for large-scale, cheap manufacturing through alternate methods such as injection molding. The crutches could therefore be used in developing countries and could potentially provide many individuals temporary relief from ptosis who may otherwise not have access to traditional interventions.

CONCLUSION

3D design and printing was used to make a removable, adjustable, inexpensive, and more universal eyelid crutch. The cheap manufacturing of the eyelid crutch also offers the potential of large-scale production and use in developing countries. However, further prospective studies with larger sample sizes will need to be done to assess the long-term effectiveness and possible pitfalls of our eyelid crutch compared to traditional crutches.

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Figure 1.
SolidWorks® 3D design of the eyelid crutch.

Figure 2.
Patient before using eyelid crutches.

Figure 3.
Patient during the use of eyelid crutches.

Figure 4.
Eye closure during the use of eyelid crutches.

Figure 5.
SolidWorks® 3D design emphasizing the angled clip.

Figure 6.
Adjustability of the eyelid crutch.