Introduction

Severe ocular trauma is a major cause of profound visual loss among young persons, who may be at higher risk of subsequent injury to their fellow eye. Traditional practice has been to observe or enucleate eyes with no light perception (NLP) after open globe injury (OGI) to reduce the risk of sympathetic ophthalmia or for cosmetic reasons.\[1,2\] Loss of light perception (LP) after open globe injury, however, does not necessarily mean that the patient will have permanent visual loss.\[3-12\] Reported visual recovery rates from NLP to LP or better after globe rupture range from 4%-33%.\[3-12\] In one study of 73 NLP eyes (73 patients) with OGI that underwent primary repair, final visual acuity was LP or better in 17 (23%) eyes.\[12\] In this series, final vision was 20/100 in 1 eye (1%), counting fingers in 2 eyes (3%), hand motions in 9 eyes (12%), LP in 5 eyes (7%), and NLP in 56 eyes (77%).\[12\]

Patient Selection

There is no single finding, except optic nerve transection or avulsion, that allows clinicians to be certain that NLP status is permanent after OGI.\[5-12\] Unfortunately, optic nerve avulsion can be difficult to confirm in the setting of severe globe trauma because the dural sheath often remains attached to the globe even if retrolaminally.
neural tissue is disrupted.\textsuperscript{[13-15]} In contrast to a complete optic nerve transection, an optic nerve avulsion may be partial, and partial return of visual function has been documented in some cases.\textsuperscript{[19]}

Data from our institution indicate that neither patient gender, the type of injury (e.g., rupture vs. laceration), the presence of retinal detachment/vitreous hemorrhage/choroidal hemorrhage, occurrence of intraocular tissue prolapse, nor ocular trauma score is significantly predictive of visual prognosis [Table 1].\textsuperscript{[12]} Although there was a suggestion that eyes with zone 2 injury might be more likely to recover from NLP, this result was of borderline statistical significance and is probably not clinically important.

Unfortunately, the information gained from clinical examination is often of limited value. Assessment of LP with the indirect ophthalmoscope, for example, is not always reliable.\textsuperscript{[16]} Cognitive status (e.g., patient age, unconscious, intoxicated, incompetent) influences the result as can anatomic changes that once reversed allow recovery of LP (e.g., choroidal or subretinal hemorrhage ± dense vitreous hemorrhage, particularly in the presence of retinal detachment). Even a severe hyphema can be associated with a relative afferent pupillary defect.\textsuperscript{[17]}

For this reason, it may be more useful to focus on anatomic findings rather than psychophysical findings when assessing visual prognosis. First, one attempts to identify findings that are amenable to surgical repair the correction of which may reverse NLP status, e.g., retinal detachment with subretinal hemorrhage or choroidal hemorrhage [Figure 1]. These findings are often well demonstrated with B-scan echography. Second, one attempts to identify findings that are consistent with irreversible visual loss, e.g., optic nerve avulsion, optic nerve transection, or profound loss of intraocular contents. These findings can be demonstrated with CT or MRI imaging, but optic nerve avulsion may be difficult to confirm with neuro-imaging in the setting of acute severe globe trauma [Figure 2].\textsuperscript{[13,15,18]} Even in the setting of complete optic nerve transection, neuroimaging may reveal what appears to be a surprisingly intact optic nerve complex [Figure 3]. Nonetheless, in some cases, the only way the status of the globe and optic nerve can be explored reliably is with CT/MRI imaging [Figure 4].

**SURGICAL APPROACH: STAGED SURGERY**

The first procedure typically involves repair of the globe rupture/laceration (if possible), removal of intraocular foreign bodies, excision or removal of damaged tissue (e.g., extruded/contaminated tissue, cataractous lens), and drainage of choroidal hemorrhage (usually not possible). If the globe cannot be closed, it is reasonable to consider primary enucleation [Figure 5]. Ideally, the second procedure is undertaken when the suprachoroidal hemorrhage has liquefied (determined by serial echography), typically within 2 weeks of the injury [Figure 6]. Surgical timing may be very important for increasing the chance of anatomic and functional success. Techniques involved in the second procedure depend on the nature of the injury. If the optical axis of the cornea is damaged, an intraocular keratoprosthesis is used with penetrating keratoplasty completed at the end of the case. If choroidal hemorrhage is present, use of a 6 mm infusion cannula may facilitate infusion into the vitreous cavity (vs. inadvertent infusion into the suprachoroidal space). Alternatively, one may infuse balanced salt solution into the vitreous cavity via a limbal infusion system. In many cases, residual lens and/or foreign material may be present and should be removed. Typically, this scenario occurs in patients with multiple glass intraocular foreign bodies (e.g., after motor vehicle accident), where small slivers of glass may remain hidden in clots of blood.

Experimental studies demonstrated detection rates of 57% and 11% for helical CT and MRI, respectively, depending on the size of the glass foreign body.\textsuperscript{[19]} In addition to excision of vitreous hemorrhage, subretinal hemorrhage should be removed if there is an open retinal break or if there is substantial subfoveal blood. Subretinal fibrosis can develop surprisingly rapidly in the setting of post-traumatic rhegmatogenous retinal detachment and may prevent retinal reattachment. Typically, a large retinotomy is made to access the subretinal space if there is posterior peripapillary (“napkin ring”) subretinal fibrosis, and bimanual dissection with chandelier illumination is used to remove the tissue. Often, perfluorodecalin is used to reattach the retina and express subretinal hemorrhage, particularly if a 360-degree retinotomy has been created.\textsuperscript{[20]}

In such cases, the residual peripheral retina is excised completely to forestall the development of anterior proliferative vitreoretinopathy with cyclitic membrane formation and hypotony. If retina is incarcerated in the wound or if there is an extensive retinal break, silicone oil tamponade is used typically. Cyclitic membrane formation can begin to develop relatively soon after OGI. Routinely, one should examine the episcleral space using scleral indentation and the co-axial illumination of the operating microscope to identify and excise such tissue.

**BENEFIT OF PARS PLANA VITRECTOMY**

In our series, 15 (21%) of 73 eyes that presented with NLP after OGI, were LP at postoperative day-1 after open globe repair, and underwent pars plana vitrectomy to manage retinal detachment, vitreous hemorrhage, proliferative vitreoretinopathy, and/or choroidal
Table 1. Prognostic factors in no light perception eyes after open globe injury[12]

| Visual outcome | Not improved (NLP) | Improved (>LP) | Total | P* |
|----------------|-------------------|----------------|-------|----|
| Number of eyes | 56                | 17             | 73    | -  |
| Age (years)    | 46                | 45.8           | 46.2  | 0.97|
| Sex (%)        |                   |                |       |    |
| Male           | 42 (75)           | 13 (76)        | 55 (75)| 0.84|
| Female         | 14 (25)           | 4 (24)         | 18 (25)|    |
| Eye (%)        |                   |                |       |    |
| OD             | 19 (34)           | 8 (47)         | 27 (37)| 0.49|
| OS             | 37 (66)           | 9 (53)         | 46 (63)|    |
| Type of injury |                   |                |       |    |
| Rupture (%)    | 42 (75)           | 11 (65)        | 53 (73)| 0.6 |
| Laceration (%) | 14 (25)           | 6 (35)         | 20 (27)| -  |
| Perforation    | 2                 | 0              | 2     | -  |
| IOFB (%)       | 0 (0)             | 1 (6)          | 1 (1) | -  |
| Hyphema (%)†   | 47 (87)           | 16 (94)        | 63 (89)| 0.71|
| Extent of injury (%)† |       |                |       |    |
| Zone 1         | 10 (18)           | 3 (18)         | 13 (18)| 0.76|
| Zone 2         | 10 (18)           | 8 (47)         | 18 (25)| 0.04|
| Zone 3         | 35 (64)           | 6 (35)         | 41 (57)| 0.08|
| Location (%)   |                   |                |       |    |
| Corneal        | 11 (16)           | 3 (18)         | 14 (19)| -  |
| Scleral        | 22 (39)           | 7 (41)         | 29 (40)| 0.89|
| Corneoscleral  | 24 (43)           | 7 (41)         | 31 (42)| 0.88|
| Lens status†   |                   |                |       |    |
| Phakic (%)     | 14 (35)           | 8 (53)         | 22 (40)| 0.35|
| Aphakic (%)    | 22 (55)           | 6 (40)         | 23 (42)| 0.85|
| Pseudophakic (%)| 4 (10)            | 1 (7)          | 5 (9)  | 0.89|
| Unknown        | 16                | 2              | 18    | -  |
| RD (%)†        | 30 (57)           | 12 (71)        | 42 (60)| 0.46|
| VH (%)†        | 29 (54)           | 11 (65)        | 40 (56)| 0.56|
| Choroidal hemorrhage (%)† | 23 (45) | 7 (41) | 30 (44) | 1.0 |
| Intraocular tissue prolapse (%) | 47 (87) | 14 (82) | 70 (85) | 0.93 |
| OTS category (%)|                 |                |       |    |
| 1              | 21 (88)           | 8 (89)         | 29 (85)| 0.62|
| 2              | 3 (13)            | 1 (11)         | 5 (15) |    |
| OTS (raw score)| 30.7             | 27             | 29.7  | 0.55|
| Number of reoperations | 0.05     | 1.24          | 0.33  | 0.0002|
| Number of PPV (%) | 1 (2)            | 14 (82)        | 15 (21)| <0.0001|
| Number of hospital days | 5       | 5             | 5     | 0.72|

Percentages were calculated by dividing each number by the number of eyes at the top of that column. The significance of the P value was set to 0.05. *Univariate analysis was conducted using the Chi-square test. Differences between means were tested using the t-test; †Intraocular foreign body status was unclear in 1 case, hyphema status was unclear in 2 cases because of disorganized globes, zone of injury was not documented in 1 case, and the status of the lens was unknown in 16 cases, 13 of which had hyphema obstructing view past the anterior chamber and 3 cases in which the globe was disorganized. In two cases, the status of the retina was unclear because of disorganized globes and the diagnoses of RD and VH were assumed in these eyes. Retinal status and the presence of VH were not documented in three and two eyes, respectively. Choroidal hemorrhage could not be diagnosed in three eyes because of disorganized globes and was not documented in two eyes. Percentages for all prognostic factors were calculated including only those eyes with complete data. Reproduced with permission from Retina (Soni et al., 2013;33:380-386). IOFB, intraocular foreign body; LP, light perception; NLP, no light perception; OD, oculus dextrus; OS, oculus sinister; OTS, ocular trauma score; PPV, pars plana vitrectomy; RD, retinal detachment; VH, vitreous hemorrhage.
Figure 1. Anatomic findings consistent with reversible NLP status. A 46 year-old man with history of congenital glaucoma, high myopia, S/P enucleation OD, S/P hemorrhagic choroidal detachment during PK for corneal ulcer in the left eye 5 days ago now with NLP vision. NLP, no light perception; PK, penetrating keratoplasty; RD, retinal detachment; S/P, status post; VH, vitreous hemorrhage

Figure 2. Peribulbar and intra-nerve sheath hemorrhage. (a) Peribulbar and perineural hemorrhage (arrow) misidentified as intraneural hemorrhage on noncontrast axial CT scan. (b) Intra-nerve sheath hemorrhage identified on coronal CT (arrow) in a patient with blunt trauma, right orbital floor fracture, and retrobulbar intraconal hemorrhage. Courtesy of Roger Turbin, MD. CT, computed tomography

Figure 3. Traumatic intracranial optic nerve and globe avulsion. (a and b) A 5-year-old boy was struck in the forehead by a falling emergency escape ladder that broke free. He completely avulsed the globe and a 3.5 cm segment of optic nerve, the posterior edge of which extended to the intracranial portion of the nerve. Axial CT: Absent right globe, orbital emphysema, bone fragment, and appearance of “normal nerve sheath complex” (arrows). However, the entire orbital optic nerve (3.5 cm) was avulsed from the intracranial segment of the nerve, and the “intact” segment actually represents an artifact of blood and edema. Courtesy of Roger Turbin, MD. CT, computed tomography

Figure 4. Anatomic findings consistent with irreversible NLP status. (a) Appearance at presentation of a 61-year-old man who sustained multiple craniofacial injuries after a propane tank explosion. (b) Closeup view of ruptured globe. (c) CT findings are illustrated. (d) Appearance after surgical repair. Courtesy of Roger Turbin, MD. CT, computed tomography; NLP, no light perception

14 (82%) underwent pars plana vitrectomy. Eyes that underwent pars plana vitrectomy were significantly more likely to achieve LP or better final vision than those that did not (odds ratio: 257, 95% confidence interval: 25-2659).
Among the 21 eyes that presented with NLP but that recovered LP or better after ruptured globe repair on postoperative day-1, 13 (62%) recovered LP or better vision at last follow-up [Figure 7]. Among the 52 NLP eyes (71%) that did not recover LP on postoperative day-1 after ruptured globe repair, only 4 (8%) recovered LP or better vision at last follow-up.

**FUTURE CONSIDERATIONS**

We consider enucleation for eyes with OGI and NLP and major loss of retinal tissue or confirmed optic nerve avulsion/transection. Eyes with NLP after OGI that undergo successful primary closure with intact optic nerves may be considered for additional surgery, particularly if there is: (1) Recovery of LP on postoperative day-1 after primary repair; (2) treatable pathology underlying the NLP status (e.g. extensive choroidal hemorrhage, extremely dense vitreous hemorrhage; and/or subretinal hemorrhage; (3) NLP in the fellow eye. Patients should be counseled that the chance of recovering ambulatory vision is very low (~5%) under these circumstances.

**Declaration of Patient Consent**

The authors certify that they have obtained all appropriate patient consent forms. In the form the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

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**Conflicts of Interest**

There are no conflicts of interest.

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