Elevated Orbital Pressure: Another Untoward Effect of Massive Resuscitation after Burn Injury

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Background: Fluid resuscitation remains a fundamental component of early burn care management. However, recent studies suggest that excessive volumes of resuscitation are being administered. Overresuscitation results in negative sequelae including abdominal and extremity compartment syndromes. Elevated intraocular pressure (IOP) has been described as another potentially devastating effect of massive fluid resuscitation in trauma patients. The orbit, similar to the abdomen and extremity, is a compartment, limited to expansion from edema anteriorly by the eyelids and orbital septum, and posteriorly by the bony orbital walls. The purpose of this study was to review the incidence of elevated IOP in a series of patients with major burn injury.

Methods: We retrospectively reviewed the charts of 13 consecutive patients admitted to our burn center with burn sizes >25% total body surface area (TBSA). All patients underwent serial IOP measurements for the first 72 hours following admission. Medical records were reviewed for fluid resuscitation volume, IOP measurements, need for canthotomy, and results of canthotomy procedures.

Results: Five of 13 patients had IOP >30 mm Hg and required lateral canthotomy. Canthotomy immediately reduced IOP ($p = 0.009$). Patients who developed elevated IOP received a significantly larger fluid resuscitation (9.0 cc/kg/%TBSA versus 6.0 cc/kg/%TBSA, $p = 0.02$). Elevated IOP was significantly associated with delivery of larger fluid resuscitation volume ($p = 0.027$).

Conclusions: Massive fluid resuscitation following burn injury can result in orbital compartment syndrome requiring lateral canthotomy. Early diagnosis and treatment of orbital compartment syndrome should be incorporated into the management of patients with major burn injury receiving large fluid resuscitation volume.

Key Words: Burn, Orbit, Intraocular pressure, Fluid, Resuscitation.

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Fluid resuscitation remains a fundamental component of the early management of the burned patient. The negative sequelae of underresuscitation—development of burn shock, multiorgan dysfunction and increased burn wound depth—have long been appreciated. Baxter first described using 3.7 to 4.3 cc/kg per percentage total body surface area (%TBSA) burned of lactated Ringers as a guideline for effective fluid resuscitation following burn injury.[1] However, several recent studies suggest there is a trend toward overresuscitation. Friedrich and colleagues[2] compared volume of fluid resuscitation delivered in the first 24 hours after injury of 10 patients in the 1970s with age and %TBSA-matched patients in the year 2000 and found the patients in 2000 received over twice the volume of resuscitation. In a multicenter survey, Engrav and colleagues[3] found that 58% of patients with large burns received greater than 4.3 cc/kg/%TBSA and, more recently, Cancio and colleagues[4] reported that the Baxter formula underestimated fluid requirements in 84% of their patients.

Although the need to provide adequate volumes of fluid resuscitation is clear, this recent trend of increasing volumes—or "fluid creep"[5]—is not without consequence. Abdominal and extremity compartment syndrome, pulmonary edema leading to prolonged ventilatory support, and the development of acute respiratory distress syndrome can result from the administration of large volumes of fluid. These potential complications can impact both morbidity and mortality.[6–10] Given the potential devastating consequences of untreated compartment syndromes, early diagnosis and timely abdominal or extremity decompression have become critical issues in the early management of severe burn injury.[11–13]

Elevated intraocular pressure (IOP) has been described as another untoward, and potentially devastating, effect of large volume fluid resuscitation in trauma patients.[14] The orbit, similar to the abdomen and extremity, is a compartment, limited to expansion from edema anteriorly by the eyelids and orbital septum, and posteriorly by the bony orbital walls. Elevated orbital pressures, transmitted through the globe and measured as elevated IOP, can result in ischemic optic neuropathy (ION) and blindness. Early diagnosis and timely lateral canthotomy/cantholysis (Fig. 1) to decompress the orbit and reduce orbital pressure is required to prevent

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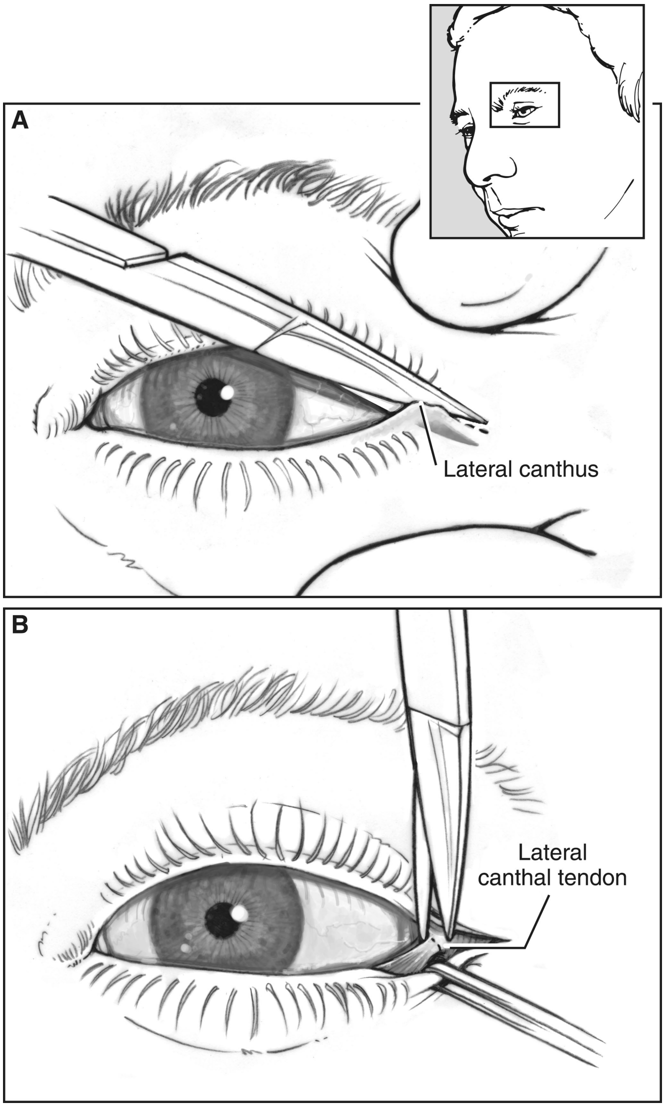

Fig. 1. *(A) Lateral canthotomy is a full thickness incision from skin to conjunctiva through the lateral canthus and canthal tendon. (B) Lateral cantholysis is disinsertion of the lateral canthal tendon.*

ION.[15] There have been several case reports of blindness due to elevated intraocular pressure following burn and other traumatic injuries.[15,16]

The incidence of elevated IOP following severe burn injury is unknown. We suspect that orbital compartment syndrome may occur commonly following massive fluid resuscitation just as abdominal and extremity compartment syndromes do. Although visual disturbances and blindness occur rarely following burn injury, investigation is required to determine the risk factors and the effects of elevated IOP. The purpose of this study is to review the incidence of elevated intraocular in patients with large burn injuries treated in our burn center. We hypothesized that: elevated orbital pressure can occur after thermal injury in the absence of direct ocular injury; patients who receive larger volumes of fluid resuscitation are more likely to develop elevated orbital pressures; and treatment with lateral canthotomy/cantholysis reduces the elevated orbital pressure.

MATERIALS AND METHODS

Following University of Washington Human Subjects Committee Institutional Review Board approval, we retrospectively reviewed records of 13 consecutive adult patients admitted to the University of Washington Burn Center with a burn ≥25% TBSA who underwent IOP monitoring. Based on previous incidental findings of elevated IOP in several patients with extensive burn injuries, it became our standard practice in 2004 to regularly obtain IOP measurements in all patients with burns ≥25% TBSA. IOP measurements were performed by the ophthalmology service using a portable tonometer (Tonopen; Mentor, Santa Barbara, Calif) daily for the first 72 hours following admission.

We reviewed patient demographic and clinical data including age, sex, %TBSA burned, presence of inhalation injury, intubation, periorbital burn, predicted volume of fluid resuscitation (based on the Baxter formula of 4.0 cc/kg/%TBSA), volume of fluid resuscitation delivered (lactated Ringers solution was used in all patients), and ratio of delivered to predicted volume of resuscitation. The outcomes of interest were IOP, need for lateral canthotomy/cantholysis, and change in IOP after lateral canthotomy/cantholysis. The criterion for lateral canthotomy/cantholysis was an IOP ≥30 mm Hg.[17] The ophthalmology service performed all lateral canthotomies/cantholyses.

The Mann-Whitney *U* test was used to test for potential differences between continuous variables and the χ^2 or Fisher's (two-tailed) exact test was used to test for potential differences in proportions between categorical variables of the two groups. Linear regression was used evaluate for an association between IOP and total volume of fluid resuscitation delivered in the first 24-hour period after admission. Due to the small number of patients and variability in distribution of IOP variance, this outcome variable was logarithmically transformed, which reduced variability based on scatterplots. Results are reported as means ± SD. Statistical analyses were performed using Stata 8.0 software (StataCorp, College Station, Tex, 2004). A p value <0.05 was considered statistically significant.

RESULTS

The demographics and clinical characteristics of the 13 consecutive patients reviewed in this study are shown in Table 1. The 13 patients (nine male and four female) had an average burn size of 39.6 ± 7.9% TBSA. Average patient age was 39.7 ± 13.9 years. Seven patients (53%) had evidence of inhalation injury (determined clinically) and 12 patients were intubated and pharmacologically sedated before admission. Nine of the 13 patients had periorbital burns. No patients had other head trauma, facial fractures, or direct orbital injuries and all patients remained in the supine position throughout the first 72 hours following admission. For all patients, the predicted average volume of fluid resuscitation calculated by

Table 1 Demographic and Clinical Characteristics of Patients

	All Patients
Age (years)	39.7 ± 13.9
Range	19–69
Men	9 (69.2)
Intraocular pressure (mm Hg)	
24 hours	30.0 ± 24.6
48 hours	30.4 ± 17.1
72 hours	14.4 ± 5.2
Weight (kg)	88.5 ± 26.0
Range	59.4–144
%TBSA burned (second and third degree)	39.6 ± 7.9
Range	28–50
Type of burn	
Flame	12 (92.3)
Electrical	1 (7.7)
Smoke inhalation injury	7 (53.8)
Intubated	12 (92.3)
Periorbital burn	9 (69.2)
Total volume of resuscitation	
Predicted, first 24 hours (mL)	13,709 ± 3,727*
Received, first 24 hours (mL)	23,964 ± 7,887
Received, first 24 hours (mL/kg/%TBSA)	7.1 ± 2.1
Urine output, first 24 hours (mL/kg/h)	0.8 ± 0.6
Lateral canthotomy/cantholysis	5 (38.5)
Extremity escharotomy	7 (53.8)
Decompressive laparotomy	0 (0)
Mortality	2 (15.4)

Data are expressed as n (%) or means ± SD (continuous variables) unless otherwise noted.

*Predicted by Baxter formula (4 mL/kg/%TBSA).

the Baxter formula (4 cc/kg/%TBSA) was 13,709.2 ± 3,726.5 cc (Table 2). However, the average volume of fluid delivered to patients in the first 24 hours after injury was 23,963.8 ± 7,887.4 cc (7.1 ± 2.1 cc/kg/%TBSA), 1.8 times greater than predicted by the Baxter formula ($p = 0.001$).

IOP from each eye was measured daily on each patient in each eye for the first 72 hours after admission. The IOP from right and left eye from all times points for each patient were first compared and no significant differences were found (26 ± 19 versus 24 ± 19 mm Hg, respectively; $p = 0.5$). Because no differences were found between the right and left eye of each patient, measurements at each time point were combined and averaged for all subsequent analyses.

We next performed a subgroup analysis comparing the demographic and injury characteristics of the cohort of patients who had an elevated IOP and required canthotomy/cantholysis (Table 3). Five of the 13 patients had an IOP >30 mm Hg and therefore underwent bilateral lateral canthotomy/cantholysis. Two patients had canthotomy/cantholysis performed within 24 hours of admission, whereas three patients had canthotomy/cantholysis within 48 hours of admission. Canthotomy/cantholysis immediately and significantly decreased the IOP in all patients to <30 mm Hg with an average decrease from 65.3 ± 14.4 to 24.9 ± 6.7 mm Hg ($p = 0.009$; Fig. 2).

The average volume of fluid resuscitation in the first 24 hours after admission was significantly greater for patients who had an elevated IOP and had canthotomy/cantholysis performed (31,440.0 ± 3,639.1 cc [9.0 ± 1.9 cc/kg/%TBSA burned or 0.35 ± 0.14 L/kg] versus 19,291.1 ± 5,848.3 cc [6.0 ± 1.2 cc/kg/%TBSA burned or 0.24 ± 0.64 L/kg]; $p = 0.02$). All patients who received >27,000 cc of fluid resuscitation in the first 24 hours after admission had an average IOP >30 mm Hg and had canthotomy/cantholysis performed.

There were no differences in %TBSA, weight, or sex between groups of patients who had elevated IOP and required canthotomy/cantholysis and those who did not have elevated IOP or require canthotomy/cantholysis ($p > 0.05$). However, patients who had elevated IOP and required canthotomy/cantholysis were older than those who did not have canthotomy/cantholysis (49.4 ± 12.3 versus 33.6 ± 11.5, respectively; $p = 0.05$). Additionally, all five patients who required canthotomy/cantholysis and four of the eight patients who did not require canthotomy/cantholysis suffered periorbital burns.

Table 2 Clinical Characteristics of Individual Patients

Patient	Weight (kg)	24-Hour Resuscitation				Intraocular Pressure (mm Hg)		
		Predicted (mL)*	Received (mL)	Received (mL/kg/%TBSA)	Received (L/kg)	24 hours	48 hours	72 hours
1	134.4	18,816	33,500	7.1	0.25	90†	32	11.5
2	144	20,160	35,000	6.9	0.24	23	58†	15.5
3	68	12,240	31,000	10.1	0.46	65†	29	14.5
4	59.4	11,405	32,200	11.3	0.54	20.5	59.5†	27.5
5	91.5	10,980	25,500	9.3	0.28	18.5	54†	20.5
6	69.4	11,382	14,300	5.0	0.21	12.5	22.5	14
7	91.3	18,260	26,000	5.7	0.28	30.5	9	13
8	78.9	8,837	15,500	7.0	0.20	21	23.5	6.5
9	94	16,920	18,600	4.4	0.20	12	13	13.5
10	84	9,408	12,700	5.4	0.15	17	16.5	9
11	101	14,948	26,500	7.1	0.26	19	19.5	13
12	72	12,960	25,700	7.9	0.36	12	14	16
13	62	11,904	15,029	5.1	0.24	14	23.5	13

*Predicted by Baxter formula (4 mL/kg/%TBSA).

†Bilateral lateral canthotomy/cantholysis performed after intraocular pressure measurement.

Table 3 Comparison of Demographic Characteristics of the Patients Who Had Elevated Intraocular Pressure and Lateral Canthotomy/Cantholysis to Those Who Did Not

Characteristic	Lateral Canthotomy/Cantholysis	No Lateral Canthotomy/Cantholysis	*p* Value
n	5	8	
Age (years)	49.4 ± 12.3	33.6 ± 11.5	0.05
Men	3 (60.0)	6 (46.2)	1
Weight (kg)	99.5 ± 38.3	81.6 ± 13.4	0.67
%TBSA burned (second and third degree)	38.6 ± 7.6	40.3 ± 8.5	0.71
Periorbital burn	5 (100.0)	4 (50.0)	NA
Smoke inhalation injury	5 (100)	2 (25.0)	NA
Intubated	5 (100)	7 (87.5)	NA
Intraocular pressure			
24 hours	43.4 ± 32.4	17.2 ± 6.3	0.04
48 hours	46.5 ± 14.8	17.7 ± 5.4	0.003
72 hours	17.9 ± 6.3	12.3 ± 3.0	0.08
Total volume of resuscitation			
Predicted, first 24 hours (mL)*	14,720 ± 4,402	13,077 ± 3,398	0.46
Received, first 24 hours (mL)	31,440 ± 3,639	19,291 ± 5,848	0.02
Received, first 24 hours (mL/kg/%TBSA)	9.0 ± 2.0	6.0 ± 1.2	0.02
Received, first 24 hours (L/kg)	0.35 ± 0.14	0.24 ± 0.64	0.02
Urine output, first 24 hours (mL/kg/h)	0.6 ± 0.2	1.0 ± 0.7	0.04
Extremity fasciotomy	3 (60.0)	4 (50.0)	1
Decompressive laparotomy	0 (0)	0 (0)	NA
Mortality	2 (40.0)	0 (0)	NA

Data are expressed as n (%) or means ± SD (continuous variables) unless otherwise noted. *P* values were calculated with the use of the Mann-Whitney *U* test for continuous and Pearson's χ^2 or Fisher exact test for categorical variables.

*Predicted by Baxter formula (4 mL/kg/%TBSA).

When examining the relationship of fluid received to IOP, there was a significant positive association between IOP and volume of fluid resuscitation at 24 hours after admission. Linear regression demonstrated that, when comparing two patients, the delivery of one additional liter of crystalloid was associated with a 4.8% elevation of median IOP (95% CI: 0.7 to 9.0%; $p = 0.027$).

Clinical evidence of extremity hypoperfusion was found on seven patients and escharotomy was performed. Three of these seven patients also had elevated IOP and required canthotomy/cantholysis. No patients had decompressive laparotomy performed. However, abdominal compartment pressures were not routinely monitored in these patients. Two of the 13 patients in this series died following failed fluid resuscitation. Both of these patients had canthotomy/cantholysis for elevated IOP and extremity escharotomy for hypoperfusion.

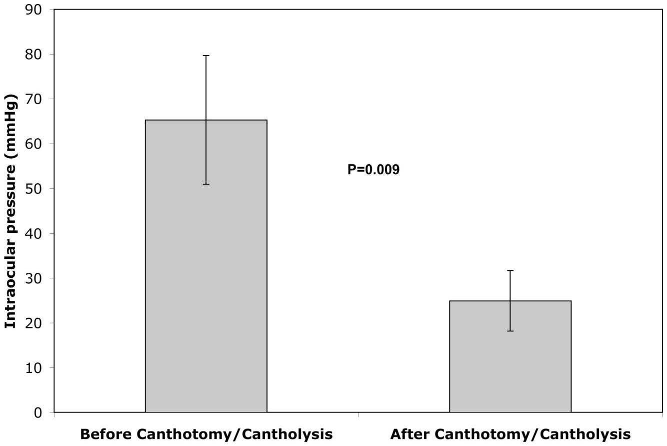

Fig. 2. *Lateral canthotomy/cantholysis significantly and immediately reduced intraocular pressure (IOP) in patients who had an average IOP >30 mm Hg. Bar graph demonstrates IOP before and immediately after lateral canthotomy/cantholysis performed.*

DISCUSSION

The Baxter formula is a commonly used method of estimating fluid requirements following burn injury.[1] Although Baxter acknowledged that larger fluid volumes may be required in certain specific circumstances—excessively deep burns, burns accompanied by inhalation injury, and delay in start of resuscitation—a recent trend of increased volume of fluid administered during resuscitation has been reported.[2–5]

Orbital compartment syndrome appears to be an untoward effect of massive fluid resuscitation in patients after major thermal injury. In our retrospective review of 13 patients with major burns, 40% developed significantly elevated IOP requiring orbital decompression with lateral canthotomy/cantholysis. Elevated IOP was significantly and linearly associated with increasing total volume of fluid received in the first 24 hours following injury. However, elevated IOP did not appear to be associated with %TBSA or presence of inhalation injury. The average volume of fluid resuscitation received in the patients in this series requiring canthotomy/cantholysis was 31.4 L in the first 24 hours after admission, or 1.8 times the volume predicted by the Baxter formula. Although none of our patients had a clinical diagnosis of abdominal compartment syndrome, seven patients required extremity escharotomy due to hypoperfusion.

Elevated orbital pressure with associated compartment syndrome can be caused by edema, retrobulbar hemorrhage, air, or foreign material.[18] In patients with major thermal injury, increased IOP may result from orbital and palpebral edema as a result of systemic capillary leak. Edema of the orbital contents enclosed in the bony compartment increases orbital pressure causing compression of orbital soft tissues, which include the optic nerve and intraorbital vasculature. Hypoperfusion of optic nerve vasculature may lead to ischemic optic neuropathy (ION). The high pressure is also transmitted to the globe where the increased orbital pressure can be measured as an elevated IOP. Thus, elevated IOP is an indirect measurement of orbital pressure. When the periorbital skin is also burned, as seen in all five patients who required canthotomy/cantholysis, tightening of the anterior barriers (eyelids/septum) of the orbital compartment can also contribute to elevated IOP. Although topical medications may decrease IOP and its untoward sequelae (i.e., central retinal artery occlusion and glaucoma), they do not decrease elevated orbital pressure. As such, a lateral canthotomy/cantholysis is the appropriate treatment modality.[19]

Visual impairment is not a well-described complication of burn injury. Visual disturbances—including decreased vision and blindness—following burn injury are reported most commonly following electrical injury or direct ocular chemical injury. However, there have been several recent reports of blindness in trauma and burn patients secondary to ION. Vallejo and colleagues[16] reported bilateral blindness due to ION in a patient with 85% TBSA burns who required massive fluid resuscitation and vasopressors to maintain blood pressure. Evans[15] reported extreme orbital congestion with elevated IOP relieved by lateral canthotomy in three patients with severe burns. In addition, Lee and colleagues[20] reported blindness due to ION in nine critically ill patients following massive fluid resuscitation and vasopressor use.

Despite the paucity of historical evidence of visual impairment following burn injury, the findings of this study suggest that IOP should be routinely monitored in patients requiring large volumes of fluid resuscitation. In one study on abdominal compartment syndrome, Ivy and colleagues[7] recommended measuring intra-abdominal compartment pressures after infusion of >0.25 L/kg during the acute resuscitation phase after burn injury. In our series, four of the five patients who developed orbital compartment syndrome and required lateral canthotomy/cantholysis received >0.25 L/kg crystalloid for resuscitation in the first 24 hours after admission. Our data also suggest that that infusion of >0.25 L/kg warrants the need for measuring orbital compartment pressures. Furthermore, visual acuity examinations on burn patients with major burns may be indicated.

This series of 13 patients is small, but clearly identifies the potential for orbital compartment syndrome in patients with major burn injury who receive large volumes of fluid resuscitation. IOP can be easily monitored and effectively treated at the bedside with lateral canthotomy/cantholysis. Based on the findings in this study, we recommend daily measurement of IOP for the first 72 hours after admission for patients with major burn injury requiring fluid volumes in excess of those predicted by the Baxter formula.

REFERENCES

1. Baxter CR, Shires T. Physiological response to crystalloid resuscitation of severe burns. *Ann N Y Acad Sci.* 1968;150:874–894.
2. Friedrich JB, Sullivan SR, Engrav LH, et al. Is supra-Baxter resuscitation in burn patients a new phenomenon? *Burns.* 2004; 30:464–466.
3. Engrav LH, Colescott PL, Kemalyan N, et al. A biopsy of the use of the Baxter formula to resuscitate burns or do we do it like Charlie did it? *J Burn Care Rehabil.* 2000;21:91–95.
4. Cancio LC, Chavez S, Alvarado-Ortega M, et al. Predicting increased fluid requirements during the resuscitation of thermally injured patients. *J Trauma.* 2004;56:404–413.
5. Pruitt BA, Jr. Protection from excessive resuscitation: "pushing the pendulum back." *J Trauma.* 2000;49:567–568.
6. Ivy ME, Possenti PP, Kepros J, et al. Abdominal compartment syndrome in patients with burns. *J Burn Care Rehabil.* 1999;20:351–353.
7. Ivy ME, Atweh NA, Palmer J, et al. Intra-abdominal hypertension and abdominal compartment syndrome in burn patients. *J Trauma.* 2000;49:387–391.
8. Maxwell RA, Fabian TC, Croce MA, Davis KA. Secondary abdominal compartment syndrome: an underappreciated manifestation of severe hemorrhagic shock. *J Trauma.* 1999;47: 995–999.
9. Block EF, Dobo S, Kirton OC. Compartment syndrome in the critically injured following massive resuscitation: case reports. *J Trauma.* 1995;39:787–791.
10. Tremblay LN, Feliciano DV, Rozycki GS. Secondary extremity compartment syndrome. *J Trauma.* 2002;53:833–837.
11. Tsoutsos D, Rodopoulou S, Keramidas E, et al. Early escharotomy as a measure to reduce intraabdominal hypertension in full-thickness burns of the thoracic and abdominal area. *World J Surg.* 2003;27:1323–1328.
12. Lagerstrom CF, Reed RL 2nd, Rowlands BJ, Fischer RP. Early fasciotomy for acute clinically evident posttraumatic compartment syndrome. *Am J Surg.* 1989;158:36–39.
13. Hobson KG, Young KM, Ciraulo A, Palmieri TL, Greenhalgh DG. Release of abdominal compartment syndrome improves survival in patients with burn injury. *J Trauma.* 2002;53:1129–1133.
14. Cullinane DC, Jenkins JM, Reddy S, et al. Anterior ischemic optic neuropathy: a complication after systemic inflammatory response syndrome. *J Trauma.* 2000;48:381–386.
15. Evans LS. Increased intraocular pressure in severely burned patients. *Am J Ophthalmol.* 1991;111:56–58.
16. Vallejo A, Lorente JA, Bas ML, Gonzalez Y. Blindness due to anterior ischemic optic neuropathy in a burn patient. *J Trauma.* 2002;53:139–141.
17. Walton W, Von Hagen S, Grigorian R, Zarbin M. Management of traumatic hyphema. *Surv Ophthalmol.* 2002;47:297–334.
18. Castro E, Seeley M, Kosmorsky G, Foster JA. Orbital compartment syndrome caused by intraorbital bacitracin ointment after endoscopic sinus surgery. *Am J Ophthalmol.* 2000;130:376–378.
19. Yung CW, Moorthy RS, Lindley D, Ringle M, Nunery WR. Efficacy of lateral canthotomy and cantholysis in orbital hemorrhage. *Ophthal Plast Reconstr Surg.* 1994;10:137–141.
20. Lee LA, Nathens AB, Sires BS, McMurray MK, Lam AM. Blindness in the intensive care unit: possible role for vasopressors? *Anesth Analg.* 2005;100:192–195.