

Review Paper on Penetrating Brain Injury

Ethical Quandaries in the Trauma Bay and Beyond

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Objective: The aim of this review was to review the ethical and multidisciplinary clinical challenges facing trauma surgeons when resuscitating patients presenting with penetrating brain injury (PBI) and multicavitary trauma.

Background: While there is a significant gap in the literature on managing PBI in patients presenting with multisystem trauma, recent data demonstrate that resuscitation and prognostic features for such patients remains poorly described, with trauma guidelines out of date in this field.

Methods: We reviewed a combination of recent multidisciplinary evidence-informed guidelines for PBI and coupled this with expert opinion from trauma, neurosurgery, neurocritical care, pediatric and transplant surgery, surgical ethics and importantly our community partners.

Results: Traditional prognostic signs utilized in traumatic brain injury may not be applicable to PBI with a multidisciplinary team approach suggested on a case-by-case basis. Even with no role for neurosurgical intervention, neurocritical care, and neurointerventional support may be warranted, in parallel to multicavitary operative intervention. Special considerations should be afforded for pediatric PBI. Ethical considerations center on providing the patient with the best chance of survival. Consideration of organ donation should be considered as part of the continuum of patient, proxy and family-centric support and care. Community input is crucial in guiding decision making or protocol establishment on an institutional level.

Conclusions: Support of the patient after multicavitary PBI can be complex and is best addressed in a multidisciplinary fashion with extensive community involvement.

Keywords: ethics, multicavitary trauma, penetrating brain injury, structural racism, transplant

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INTRODUCTION—THE TRAUMA SURGERY PERSPECTIVE

Trauma centers across the country are faced with growing rates of firearm violence with a significant number involving penetrating injuries to the head. These patients present challenging clinical decisions that push trauma centers and staff to the limits of their capabilities. Critical decisions regarding heroic measures to sustain a life, such as an Emergency Department Thoracotomy (EDT), must be made within minutes. At the University of Chicago Medicine's (UCM) Level I Trauma Center, we have seen more than 200 penetrating brain injuries (PBIs) over the last 2 years.¹ The worst cases lead to devastating brain injury, meaning a brain injury that is assessed (by clinicians or surrogates) at hospital admission, or early during intensive care unit care, as an immediate threat to life, or incompatible with acceptable functional recovery. Our clinical decision making varies on a patient-by-patient basis and ranges from early determination of physiologic futility to aggressive resuscitation, including at times, extracalvarial operative interventions and intensive care. This approach has produced a cohort of survivors with varying neurologic outcomes, some of whom recover unexpectedly well, many do not, paralleling anecdotal survivors in the literature.^{2,3}

Nonetheless, anecdotes are not evidence. A Trauma Quality Improvement Program (TQIP) database review of nearly 27,000 civilians with PBI demonstrated that 55% present with severe traumatic brain injury and have >40% mortality.⁴ Independent predictors of mortality were advanced age (> 50 y), prehospital intubation, suicide attempt, and the need for craniotomy or craniectomy.⁴ Another retrospective study suggested that aggressive management may be associated with significant improvement in both survival and organ procurement in civilian PBI; 40% of survivors initially presenting with bihemispheric injuries and 20% with a discharge Glasgow coma scale (GCS) of

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≥ 13.⁵ In this study, the implementation of an aggressive resuscitation policy for all patients with PBI, irrespective of admission GCS, increased the survival rate from 10% to 46% within 3 years. The authors suggest that outcomes may not be predictable in the early stages of care.⁵ Another study of 119 patients with a GSW to the brain combined GCS and pupillary response to demonstrate a predictably high mortality rate of 64% with fixed and dilated pupils and a GCS of 3. However, 19% of this cohort survived with a favorable outcome at 6 months based on Glasgow outcome score (GOS).⁵ The data on pupillary response as predictor of mortality is mixed in PBI. This may be due to confounding factors such as sympathomimetic/parasympatholytic drugs, bullets causing direct oculomotor nerve pressure from a localized hematoma, and optic nerve or direct ocular trauma, which deviates from uncal herniation seen with a space-occupying lesion in blunt traumatic brain injury.⁶⁻⁸

There is also the question of whether patients with either isolated or multicavitary PBI should undergo cardiopulmonary resuscitation or even EDT. A recent multicenter study of patients with PBI receiving cardiopulmonary resuscitation alone demonstrated a dismal 2.1% survival rate (with 74% of these discharged to rehabilitation or home), but a 10.3% organ donation rate.⁹ There are no best practices or updated evidence-informed guidelines to inform clinical decision making for PBI with concomitant traumatic arrest, need for EDT, or other invasive resuscitation efforts in noncompressible cavitory or torso hemorrhage. The Western Trauma Association and the Eastern Association for the Surgery of Trauma practice management guidelines do not exclude PBI or devastating brain injury as an indication for EDT.^{8,9}

Prediction models may also reflect local resuscitation practices and biases in addition to actual physiologic and neurologic reserve. A recent systematic review conducted by members of our group found a limited amount of clinically meaningful publications¹⁰, and the now 20-year-old PBI guidelines are of minimal contribution in resolving the aforementioned quandaries.¹¹ These clinical conundrums are even more difficult when dealing with pediatric patients presenting with PBI.

Other difficult discussions exist regarding how resuscitative efforts, or multicavitary surgical interventions, including EDT, may affect the viability of organs for donation. This surfaces especially challenging conversations regarding organ procurement within a community that remains deeply skeptical, with reason, of a health care system that does not always appear to provide equitable care to all. Mistrust is rooted in a historic precedent of organ procurement from within their community—without clear benefit to members of that same underserved community. This Review Paper includes expert opinions based upon the best available evidence from multidisciplinary team members who contribute to these decisions at one representative trauma center in the United States. Representative discussions are included from the disciplines of trauma surgery, neurosurgery, critical care intensivists, pediatric surgery, ethics, transplant surgery, and from community representatives.

THE NEUROSURGICAL AND NEUROCRITICAL CARE PERSPECTIVE

Early in the clinical course accurate prognostication can be exceedingly difficult, and decisions to limit aggressive resuscitation can lead to neuronihilism and self-fulfilling prophecies of poor outcomes, frequent death and the generation of “clinical scoring metrics” that predict the same.

While surgical intervention may not be recommended, careful assessment by a neurointensivist is crucial to clinical decision making and aggressive neuroresuscitation, if warranted. Imaging of arterial and venous structures (by computed tomography angiography and venography, respectively) after the initial noncontrast brain computed tomography further assists in prognostication. Particular attention should be focused on identifying traumatic intracranial aneurysms or venous sinus thromboses that may need intervention.¹² A period of treatment and observation may be necessary in order to gain accuracy and confidence in prognostication. In some cases, this period also allows for timely referral to organ donation organizations, ensuring patients and families are given sufficient opportunity to consider donation after stabilization, if and when possible.

Extracranial brain matter should not be dogmatically considered to portend a devastating outcome; in some cases, it may actually function as an autodecompressive mechanism precluding brain herniation, although this is mostly a hypothesis. For example, 1 study from South Africa demonstrated a 45% to 57% survival rate in patients presenting with brain matter “ooze” after PBI.¹³ Other studies found that independent predictors for poor outcomes and death included low postresuscitation GCS, fixed pupils, and projectile trajectories that cross multiple lobes or course through deep structures. These factors were also shown to be important in the recently validated Survival After Acute Civilian Penetrating Brain Injuries Score (SPIN; a logistic regression based, risk stratification scale for hospital and 6-month survival after civilian PBI). This study found that the 3 dominant predictors were pupillary reactivity, motor GCS, and INR.¹⁴ When imaging findings have been considered, deep bihemispheric or posterior fossa GSWs are associated with increased mortality. One exception was that bihemispheric frontal GSWs, or lack of transventricular (deep) trajectory, had similar good outcomes compared with unihemispheric injuries in one study.⁵ Transventricular injuries can be devastating for 2 reasons: proximity to deep structures (basal ganglia, thalamus, or brain stem) and the intraventricular hemorrhage itself.

In the absence of adequate empirical data from civilian cohorts with imminently life-threatening PBI, our practice is motivated by the guiding care principles outlined in Table 1. The above difficulties highlight the need for the early convergence of a multidisciplinary team that includes (but is not limited to) trauma surgeons (both as surgeons and surgical intensivists), and neurosurgeons, but importantly includes neurointensivists and neurointerventionalists as needed. Consideration of the different expertise that each group brings, as well as the expressed wishes of the patient and family when known, will offer the best opportunity for a positive outcome. Saliiently, the multidisciplinary team must engage in shared decision making with surrogates in a concerted fashion. Our recommendations and overview of the literature are presented in Table 2.

TABLE 1. Early Guiding Care Principles for PBI

- (1) Limit early and potentially premature neuroprognostication prior to hemodynamic stabilization
- (2) Optimize individual patient outcome
- (3) Reasonable allocation of scarce resources
- (4) Incorporate patient-respecting, end-of-life practices including organ donation as part of the continuum of compassionate care to patient and family

TABLE 2. Recommendations and Overview of the Literature

Source	Definition of DBI	Types of BI	Observation Period	Prognostication	Stance on Donation
NCS Souter et al	Immediate threat to life and where early WOLST is being considered	Unspecified	Appropriate initial resuscitation; 72 hours and based on SDM	Prognostication based on individualized assessment of risk rather than on clinical scoring systems	Notification of DBI patient donor status during the resuscitative period, if done, should not alter resuscitative efforts
UK Harvey et al	Assessed at hospital admission as an immediate threat to life or incompatible with good functional recovery AND where early WOLST is being considered.	Unspecified	Appropriate initial resuscitation; 24–72 h. Decisions On the basis of clinical characteristics and SDM	Age, conscious level at presentation, physiological status, extent of brain injury identified by imaging, and comorbidities. Disease-specific prognostic schemes	Consideration begins when a patient continues to deteriorate and WOLST is being considered, or when it appears likely that a patient will meet brain death criteria.
CAEP Healey et al	Follow NCS and UK definitions	Unspecified	Appropriate initial resuscitation; Decisions On the basis of clinical characteristics and SDM	Early prognostication has known limitations and can be inaccurate.	A potential donor is someone who has a very high chance of death but in whom active care continues or suitability for donation has not yet been established. Refer to organ donation organization prior to WOLST
2001 Trauma Guidelines	Not defined	PBI	Not addressed	Features to take into account include age, mode of injury, weapon type, neuroimaging, ICP, GCS, pupils hypotension, coagulopathy	Not addressed
UChicago Guidelines	Brain injury assessed (by clinicians or surrogates) at hospital admission, or early during ICU care, as an immediate threat to life, or incompatible with acceptable functional recovery, or where WOLST is being considered as a response to predictions of poor neurologic function or unacceptable quality of survival	PBI	Appropriate initial resuscitation; multispecialty clinical triage team. Decisions based on clinical characteristics and SDM	Ominous features: Coma with absence of midbrain/pontine reflexes, or with rapid rostrocaudal progression. Radiographic evidence of major (often bihemispheric) craniocerebral disruption with brain stem herniation, or direct disruption	Aggressive systemic resuscitation is recommended until donation status is determined. Further management tailored to clinical goals and SDM

BI indicates brain injury; CAEP, Canadian Association of Emergency Physicians; DBI, devastating brain injury; ICP, intracranial pressure; ICU, intensive care unit; NCS, Neurocritical Care Society; SDM, shared decision making; UK, United Kingdom statement; WOLST, withdrawal of life sustaining therapies.

THE PEDIATRIC PERSPECTIVE

Since 2020, firearm-related injury is the leading cause of death of children and adolescents aged 1 to 19 years.¹⁵ In the United States, ~8000 children and adolescents sustain gun inflicted injuries every year with 3.5% of those involving a GSW to the head.¹⁶ Pediatric data from 2003 to 2012 as reported in the National Trauma Data Bank (NTDB), show a mortality rate of 45%.¹⁷ In 2020, there were 77 pediatric gun violence deaths in Illinois and 1358 across the United States.¹⁸

The St. Louis Scale for Pediatric Gunshot Wounds to the Head, is a useful decision tool for pediatric patients sustaining PBI. Predictive patterns of injury that portend a favorable clinical outcome include absence of a transventricular trajectory, <3 lobes involved, ≥ 1 reactive pupil on arrival, absence of deep nuclei and/or third ventricular involvement, and initial ICP <30 mm Hg.^{19,20} It is important to note that a favorable clinical outcome was defined in these studies as a GOS of 4 or 5. While this definition of a favorable outcome can be debated, pediatric patients with PBI have better outcomes compared with their adult counterparts, potentially due to high neurological plasticity and the robust developmental potential in children, potentially mandating an aggressive approach.²¹

There are few evidence-based guidelines to inform resuscitation decisions in children suffering from PBI with concomitant multicavitary injuries or traumatic arrest. The ACS-COT recommends using adult guidelines for ED thoracotomy in pediatric patients.²² It may be difficult to cease resuscitation of a pediatric patient given the natural tendency to try to “do everything” to save a child’s life, leading one to consider extended indications for performing an EDT.²³ Pediatric patients are able to maintain vital signs even in severe shock states, and this too may lead to an overuse of EDT in patients who are unlikely to survive.²⁴ While a 2015 systematic review on the topic addresses these issues, the authors do not include patients with PBI thus limiting the conclusions that can be drawn in this pediatric population.²⁵

The clinical determinants for brain death in the pediatric population are similar to those for adults with the addition of a second exam 12 or 24 hours after injury depending on age.²⁶ This diagnosis is difficult for anyone, but the intensity of grief for families is reportedly highest for unexpected deaths such as head injuries.²⁷ After the determination of death by neurologic criteria, it may be empowering to be offered the option of organ donation in situations where hemodynamic stability has been restored. Such discussions, as challenging as they are, when situated within the appropriate cultural and social context, may, in fact, facilitate the grieving process and may be therapeutic for families.^{28,29}

THE ETHICAL PERSPECTIVE

The importance of invoking sound medical ethics in the decision making for the patient with PBI cannot be overstated. Often, as trauma is a disease of time, it is impossible to enact a multidisciplinary, negotiations-based approach in determining the medical and ethical benefits of aggressive management strategies.³⁰ However, the 4 classical ethical principles³¹ remain relevant in guiding decision making in PBI: 1) Beneficence mandates that our primary duty as physicians is to act to benefit the patient before us. The primacy of beneficence should be highlighted, particularly in situations where the local population served by the medical center may lack trust in the institution. 2) Nonmaleficence is the ethical responsibility to avoid harming

our patients. An example of harm may be interpreted as proceeding with an EDT when futile. Conversely, not proceeding with surgical intervention, even with a drastic maneuver such as EDT, may be considered the same if this denies the patient any hope of survival or an attempt at neurological recovery. 3) The principle of justice obliges us to equitably distribute benefits, risks, costs, and resources. If we are perceived to intervene solely to “preserve organs” for donation, that places us in the position of using the patient before us to benefit someone else. This is contrary to most ethical positions that argue in favor of treating persons in an equitable fashion. It could also raise tremendous concerns of a breach of trust within the community we serve in that we could be accused of “using” patients to benefit others. 4) Autonomy may initially not be applicable, given the absence of decision-making capacity of the patient. This becomes increasingly relevant, though, as family or surrogate presence increases. In the absence of surrogate presence, emergent decisions are made in favor of preserving life and according to “best interests” considerations. Once family or surrogate decision makers are identified, shared decision making can take place, informed either by prior expressed wishes or substituted judgment.

Clinical teams recognize that transitioning from the therapeutic goal of saving the patient’s life to the goal of facilitating organ donation can lead to potential or perceived conflicts of interest. Specifically, it is advisable to decouple conversations about neurological death criteria testing or treatment limitations from the family approach regarding organ donation. An approach for consent to the gift of organ donation should only occur after the family has understood the diagnosis of brain death or the reasons for suggested limitation of artificial support, then undertaken in collaboration with an independent specialist for organ donation.

In view of the ethical considerations above, we believe that it is critical to place the primary focus of decision making on what could possibly benefit the individual patient before us. If there is a reasonable possibility of survival, then decisions should be made to maximize that possibility while still being open with families about the potential risks. Quality of life after survival is also a very important social and ethical concern dependent on patient and family values, with poor neurological outcomes potentially leading to significant long-term emotional angst and/or financial ruin in the United States. When the alternative to intervening for a patient is death, the strength of arguments against harming patients (nonmaleficence) necessarily are reduced. We believe that wider issues of justice cannot truly be addressed during emergency decision making as such considerations require time and extensive discussions that may not be feasible in emergency decision making with families. Nevertheless, a necessary prerequisite in addressing disparities in the provision of care relates to engaging with the specifics of the served community (refer to the “community perspective” below).

THE TRANSPLANTATION PERSPECTIVE

Trauma surgeons play a critical role in our health care system—both in saving lives of trauma patients or the lives of future organ recipients. In the United States, there are more than 410 persons that die each day from trauma and 20 patients that die daily awaiting transplantation.^{32,33} This amounts to 140,000 and 7000 yearly deaths, respectively. In 2020, 24% of organ donors to our regional Organ Procurement Organization (OPO) (Gift of Hope Organ and Tissue Donor Network) were due to traumatic mechanisms. One deceased donor has the potential to save or enhance the lives of more than 25 individuals awaiting

organs.³⁴ Regulatory statutes mandate all hospitals to refer all deaths and imminent deaths to the local OPO as a Condition of Participation in government financed Medicare programs. Even patients that have expired after failed resuscitation who are not considered for organ donation are referred for evaluation for tissue and cornea donation.³⁵

Organ donation has been identified as a valid secondary outcome in patients with fatal PBI, with organ donation rates as high as 71% after implementation of aggressive donor care protocols, including hormone replacement therapy.^{7,36} Lack of appropriate resuscitative efforts or early termination in patients suffering from PBI may lead to lower organ procurement rates. The presence of a multidisciplinary team and in-house coordinators from OPOs may lead to substantial improvements in donation rates.³⁷ It is important to consider that, even when a patient's condition is deemed unsalvageable, that the trauma surgeon may still impact the lives of multiple potential recipients and should consider ongoing resuscitation in a protocolized manner.

This approach allows families to potentially honor their loved one's request to save and improve the lives of others while recognizing the important societal value of these efforts. A detailed cost analysis is out of the scope of this review, and it involves complexities such as the cost of trauma resuscitation in the setting of severe PBI which has not been explored; however, 1 fact in favor of socioeconomic benefit comes from the Centers for Medicare & Medicaid Services. These data show it costs between \$65,312 and \$180,000 per year to maintain a patient on dialysis versus ~\$20,000 a year for immunosuppression therapy after transplant.³⁸⁻⁴⁰

An important way to positively impact donation outcomes, particularly in Chicago's South Side communities, is to support the timely notification for potential organ donors in order for OPOs to complete effective culturally competent, family-requested conversations and clinical donor management. Organ donation outcomes also improve when communities believe they have opportunities for transplantation as well as donation. Barriers have historically existed at every step to solid organ transplantation, in particular for Black patients, women, and economically marginalized individuals, which represent a significant proportion of our patients on the South Side.⁴¹ Following novel OPO harmonized Best Practices is one way to mitigate these inequities.⁴²

THE COMMUNITY PERSPECTIVE

Intentional gun violence disproportionately affects communities of color. For patients with PBI who suffer traumatic arrest, EDT may be attempted to prolong life and/or provide opportunities for organ transplantation. However, this scenario is fraught with challenges for communities of color for historical reasons.⁴³

Consequences of diseases most often have a disparate impact on communities of color. Inequities in critical infrastructure and key resource sectors have arisen from intentional, deleterious and institutionally based policies and practices.⁴⁴ This has resulted in disparities often referred to as the social determinants of health.⁴⁵ These factors have resulted in a population-based disproportionate burden of trauma as well as chronic medical conditions in African American communities. Such a social construct fosters the intergenerational beliefs, values, customs, and behaviors of communities of color. There is also a heightened risk for victimization by fraud, waste, and abuse. The historical mistreatment and exclusion of African

Americans by the US health care system by design, as well as the lack of access to culturally appropriate care contributes to health care disparities.⁴⁶

As a local example of mistrust, the lack of access to adult Level 1 trauma care on the South Side of Chicago from 1991 to 2018 was a source of frustration and anger for many on the South Side. Community protests led the UCM to launch an adult level 1 trauma center in May 2018.⁴⁷ This trauma center now cares for over 4700 injured patients per year (40% penetrating trauma), dramatically illustrating the need for such a center and reinforcing reasons for historic community distrust.

It is within that historical context, and the accurate belief that those same communities continue to have worse health outcomes, that African American patients and families are often reluctant to trust that they are offered equitable care.⁴⁸ However, considering the history of intentional and systematic dehumanization and commoditization of African Americans by the US health care system, it is incumbent upon us as physicians to see this not as a failure of patient trust, but a failure of physician trustworthiness.⁴⁹ Even those of us who find this history appalling must accept that we have inherited its legacy and work within our communities to rebuild trust and restore justice. Anything less compounds the generational trauma inflicted by a history of racist medical malpractice and injustice.⁵⁰

Given the concerns of mistrust, engagement with communities of color about this issue of resuscitation following devastating PBI, including situations of traumatic arrest, should be undertaken. We must empower members of the African American community and many others who remain systemically disenfranchised to both determine and control their health care destiny. To accomplish a positive health outcome, accurate and timely communications delivered by trusted community partners are essential.⁵¹⁻⁵⁴ These community partners should be recognized as local leaders most representative of the patient population served by regional trauma centers. They can be identified through patients, families, and local organizations and are invaluable in providing input into community-centric protocols, clinical practice guidelines and injury prevention research. The aim is to ensure confidence surrounding the decision to perform interventions as well as the quality of care received. Education and targeted communications regarding misinformation, myths, and rebuilding trust with providers are essential. Additional training with respect to cultural and structural competency and implicit bias in the context of the individual and family unit is critically important to dismantle intrinsic and historic structures of harm.

CONCLUSIONS

In summary, and in agreement with previously referenced international recommendations, we offer the following statements:

1. For patients with significant cardiorespiratory instability and where urgent surgical intervention or aggressive resuscitation is considered in the face of possible physiologic futility, emergency triage decisions are best made on a case-by-case basis, by a team composed of trauma surgery, neurosurgery and neurocritical care, when feasible. Initial attempts at resuscitation are always targeted in the interest of saving the life of the patient rather than based on other considerations, such as potential organ donation.
2. Urgent, evidence-based guidelines and consensus statements are needed given that the rate of PBI continues to rise in the

United States. These guidelines should be created in a multidisciplinary fashion with the engagement of community partners.

3. A sufficient period of observation [which remains poorly defined in the PBI literature, but is no < 72 h for anoxic brain injury^{45,46}] coupled with appropriate neurosurgical/neurocritical support is recommended prior to attempts at definitive neuroprognostication.
4. A potentially dismal neurologic outlook may be expected in patients with the following features despite early aggressive targeted measures (based on the authors judgment and reviewed literature):^{1,3-6}
 - Clinical exam:
 - i Coma with absence of midbrain and pontine reflexes.
 - ii Coma with rapid rostrocaudal progression and no exam confounders.
 - Radiographic evidence of major (often \geq bihemispheric), nonfrontal craniocerebral or unilateral posterior lobe disruption:
 - i Brain stem herniation, coning, or direct brain stem disruption.
 - ii Trajectory coursing through deep nuclei.
 - iii Transventricular course \pm blood in the ventricles.
 - iv Prognostication with any certainty based on cerebrovascular complications is premature at this stage.
5. For pediatric PBI patients, the St. Louis Scale for Pediatric Gunshot Wounds to the Head can be used to suggest favorable prognostic features as follows:
 - Clinical exam:
 - i \geq 1 reactive pupil on arrival.
 - ii Initial ICP <30 mm Hg.
 - Radiographic findings:
 - i Absence of a transventricular trajectory.
 - ii <3 lobes involved.
 - iii Absence of deep nuclei and/or third ventricular involvement.¹⁸

*It is important to note that a favorable clinical outcome was defined in this study as a GOS of 4 or 5.¹⁸
6. For patients with devastating PBI, appropriate end-of-life care, including evaluation for organ donation, should be discussed with surrogates and incorporated early in the management plan.
7. Physiological support should be maintained until all the following are in place and shared decision making with surrogates is complete:
 - The patient receives an appropriate period of observation for neuroprognostication based on clinical circumstances.
 - A decision for withdrawal has been made or the patient meets neurological criteria for death.
 - The patient has been referred to the regional organ donation organization.
 - Conversation regarding organ donation has been facilitated, where appropriate.
8. Prospective audit of patients admitted with PBI should be regularly undertaken to revisit triage decisions, patient outcomes, resource allocation, and end-of-life practices including organ donation. Ethics consult teams, when available, should be involved in these reviews. Input on iterative quality improvement should always be undertaken with the assistance and guidance of formalized relationships between the academy, health care systems, and our community partners.

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