A re-conceptualisation of acute spinal care

Mark Hauswald

Department of Emergency Medicine, University of New Mexico, Albuquerque, New Mexico, USA

Correspondence to
Professor Mark Hauswald, Department of Emergency Medicine, University of New Mexico, MSC 08 4620, 1 UNM, Albuquerque, NM 87131-0001, USA; mhauswald@salud.unm.edu

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ABSTRACT

The emergency care of patients who may have spinal injuries has become highly ritualised. There is little scientific support for many of the recommended interventions and there is evidence that at least some methods now used in the field and emergency department are harmful. Since prospective clinical trials are not likely to resolve these issues I propose a reconceptualisation of spinal trauma to allow a more rational approach to treatment. To do this I analyse the basic physics, biomechanics and physiology involved. I then develop a list of recommended treatment variations that are more in keeping with the actual causes of post impact neurological deterioration than are current methods. Discarding the fundamentally flawed emphasis on decreasing post injury motion and concentrating on efforts to minimise energy deposition to the injured site, while minimising treatment delays, can simplify and streamline care without subjecting patients to procedures that are not useful and potentially harmful. Specific treatments that are irrational and which can be safely discarded include the use of backboards for transportation, cervical collar use except in specific injury types, immobilisation of ambulatory patients on backboards, prolonged attempts to stabilise the spine during extrication, mechanical immobilisation of uncooperative or seizing patients and forceful in line stabilisation during airway management.

INTRODUCTION

Almost one million patients are evaluated for spinal injuries every year in US emergency departments alone. Only 2–3% of these patients actually have spinal injuries, most of these are stable and few unstable injuries are actually missed.[1] However, failing to treat an injury that later causes disability is among the greatest fears for emergency providers. Unfortunately few acute treatments for spinal injuries have been subjected to controlled clinical trials and the emergency care of patients who may have spinal injuries has become highly ritualised. Since the evidence that current care is effective is very limited[2] it relies primarily on historical comparisons.[3] The only study that compared patients with blunt spinal injuries who received routine emergency spinal care with those who did not was done internationally and showed that patients who received prehospital care had worse outcomes[4] an association that remained after correction for mechanism of injury. This does not mean that all treatments are useless but it is clear that at least some methods commonly used in the field and emergency department can cause harm. For example, in patients with penetrating injuries standard care is associated with a doubling of the mortality rate.[5] Adoption of newer techniques of spinal care has been slow. One reason is that acceptance of an innovation does not occur until individuals believe that the innovation is reasonable. This requires a theoretical model that is compatible with the proposed change. The generally accepted theoretical model of preventable post injury neurological deterioration is that visible movement of the spine as a unit is an adequate surrogate for movement at the injured site and that movement at the injured site causes unstable segments or sharp bony fragments to ‘cut’ the cord. This leads to an emphasis on ‘immobilisation’ that is, restricting gross motion. I will show that this model violates accepted principles of injury mechanics and elementary physics and propose a re-conceptualisation of spinal trauma to allow a more rational approach to treatment.

To do this I analyse the basic biomechanics, anatomy and physiology, epidemiology and physics involved. I then develop a list of recommended treatment modifications that are more in keeping with the actual causes of post impact neurological deterioration than are current methods.

BIOMECHANICS

The spine consists of a complex structure of interlocking and reinforcing parts. Bones and intervertebral disks are held together by a self-reinforcing system of ligaments and muscles. The entire structure comprises a complex set of energy adsorbing struts. Components fail at about the same level of force, a feature that maximises strength while minimising mass. This means that most injuries are minor (no permanent failures) or catastrophic (multiple irreversible failures including the cord) and hence that the majority of trauma patients will not benefit from emergency spinal care. The normal range of motion is essentially synonymous with the amount of non-destructive distortion tolerated by the structure and tissues. It requires almost no energy to move the spine within this range. Since resistance to movement is near zero in uninjured segments, resistance cannot be significantly less in injured areas and it will generally be greater due to preloading of tissue by oedema, spasm and mechanical impingement. Injury models that ignore these facts give results that are not directly comparable to the clinical situation. These include cadaver models in which iatrogenic injuries have been made after rigour mortis has developed (in which the uninjured segments are more stiff and the injured segments less stiff than they are in life) and models in which movement exceeds the normal range of motion. It is only when the normal range of motion is exceeded that excess energy can cause tissue destruction (and motion) at the damaged segments. This does not mean that bone fragments cannot cut the cord but rather that this will occur when the normal (near zero resistance) range of motion is exceeded and force is directed at the injured site.

Energy deposition is very different during and after a crash. An injury sequence usually involves rapid deposition of very large amounts of energy. In addition, during the 'accident' episodes of energy deposition tend to be repetitive—as when an unrestrained driver goes through a window and then bounces across the vehicle and road. Since energy is absorbed during each impact, the maximum energy deposition and hence injury, will tend to occur early in the sequence. This is obvious for a restrained driver, whose head will be subjected to the greatest deceleration during the initial impact and will then undergo a series of decreasing oscillations[6] but even a direct blow can generate repetitive linear accelerations that are hundreds of times greater than gravity.[7] Energy depositions during extrication and emergency care are orders of magnitude less than that of the primary or secondary impacts. In fact it generally takes 2000–6000 Newtons of force to fracture the cervical spine[8] whereas even hanging a 4 kg head off the treatment table will only generate about 40 Newtons. (Gravity exerts a force of 9.8 N). Energy deposition during treatment will be far less than that during the crash sequence even after the spinal injury has occurred.

ANATOMY AND PHYSIOLOGY

Mechanically severing the cord causes irrevocable injury but both temporary and permanent neurological damage also result from other mechanisms. It is well understood that patients may deteriorate after the acute injury despite the most careful care.[9] Neurological deterioration may be caused by tissue hypoxia which in turn may be from global hypoxia, damage to the blood vessels feeding the cord itself, microvascular injury or compression by oedema. Cord injury from hypoxia or direct contusion causes a complex series of physiological changes that can result in apoptosis and cell death.

The current theory of post accident neurological deterioration functionally assumes that spinal instability is an all or nothing phenomenon, that unstable injuries lose all their resistance to movement. But this is clearly not true. Steadman's dictionary defines spinal instability as 'the inability of the spinal column, under physiological loading, to maintain its normal configuration [which] may lead to damage to the spinal cord or nerve roots or to painful spinal deformity.'[10] Most spinal injuries are actually biomechanically stable, at least in the short term. Some of these patients will become biomechanically unstable over time as tissue oedema resolves and if the injured part is subject to prolonged periods of gravitational force, but this does not change the fact that initial immobilisation-directed treatment will not affect their ultimate outcome.

EPIDEMIOLOGY AND LONG TERM TREATMENT

As a general principle, reduction of tissue hypoxia is the most important basic factor in trauma management. This often requires sophisticated treatments such as advanced airway management, blood transfusions and surgery that are only available in hospital. Delaying definitive care to provide spinal 'stabilisation' can harm even those patients who have biomechanically unstable partial spinal injuries and cannot help the large majority of trauma patients who have either intact spines or irreversible injuries. Fortunately many cord injuries improve as oedema resolves. This means that the assumption that care or the lack of it in a specific case caused improvement or deterioration is generally unwarranted and does not provide evidence for or against current practice. Patients at risk for spinal trauma are likely to have other critical injuries that require urgent management. Those with cord injuries are particularly prone to hypoxic tissue damage in the immobile and de-sensate areas below the spinal injury.[11] In fact decubiti are a leading cause of morbidity and mortality in these patients. Both the potential soft tissue damage and the possibility of delay in critical care provision mean that harm as well as potential benefit from spinal treatment needs to be considered.

IN SUMMARY

1. Far more patients will be treated than eventually turn out to have injuries to their spine.
2. Most patients who do have spinal injuries are mechanically 'stable' at least in the short term—stable in that significant force would need to be applied to the injured site to cause further damage.
3. Completely unstable injuries—ones that have essentially no more resistance to movement than do the uninjured segments generally cause irrevocable injuries during the 'accident' sequence.
4. Unfortunately all of these patients are at risk for side effects of treatment.

PHYSICS

Analysis of the physics involved in spinal care allows the development of a more scientifically valid theory to guide therapy. In Newtonian physics motion over a distance (d) is one component of energy (E), the other being force (F): $E=Fd$. Force is defined as mass (m) times acceleration (a): $F=ma$. To change a physical system, energy must be deposited or equivalently mechanical work must be done.[12] In the case of biomechanical injury during a vehicle crash, the head, neck and body de-accelerate at different rates. The resultant kinetic energy is transferred to the injured part causing direct and indirect tissue damage. These principles mean that movement cannot cause injury by itself because force must be involved to generate (or change the form of) energy. This has important implications for the medical literature which has concentrated on attempts to measure and decrease post injury motion without considering the amount of force that is needed to cause the movement. This approach does not necessarily result in minimising the energy of the system or hence the amount of potential tissue damage. The goal of post impact spinal care must be to minimise energy deposition to the tissues that were injured, this requires that force and hence energy be minimised at the injured site. In other words the total energy of the system needs to be minimised and/or the energy that is generated during care needs to be absorbed by sites away from the injured tissue.

IN SUMMARY

1. Reducing visible spinal movement does not necessarily reduce movement at the injured site both because movement at uninjured sites requires minimal force and because force applied at the injured site may not cause gross movement of the rest of the spine.
2. Mechanical work at the injured site will by definition be minimised by minimising force and energy there.
3. Mechanical work can increase injury but movement per se cannot.

The above principles allow the development of a rational, scientifically based approach to the care of the potentially spinally injured patient which will at times be different from current treatment. Prehospital and emergency department care should focus on minimising force and hence energy deposition to the parts of the spine likely to be injured. Movement within the normal range of motion is much less important because it by definition requires essentially no force and will hence occur at uninjured segments. Global hypoxia should be aggressively treated. Local tissue hypoxia should be avoided. Delays to definitive treatment should be minimised. This approach can be used to guide analysis of several specific treatment interventions.

The use of a comfortably firm, high friction surface for transport is rational. Comfortable means, by definition, that it would not cause tissue hypoxia.[13] High friction means that the energy generated during transport will be dissipated over a large area. Hard slippery 'backboards' expedite extrication but are terribly unsuited for prolonged use. Their low friction surface requires that all the energy generated during transport is absorbed by direct restraints such as straps and lateral supports. Because these attach to the patient in areas that have different resistance (the head is much less compressible than the torso) some of the energy will inevitably be deposited across the injured site. Tightly fastening the restraints will decrease this energy deposition but at the expense of constricting the patient and potentially causing hypoxia.[14] Using a device such as a vacuum board that allows energy generated during transport to be dissipated over a large area is increasingly popular and may be ideal. Hard backboard use in the field for short transports is debatable but there is no reason to keep patients on them longer than necessary. They clearly should not be used during long prehospital transports or for intrafacility transports to avoid tissue damage. If backboards are used patients should be removed from them immediately upon arrival at the hospital. Delaying to 'clear' the spine is irrational since patients who actually do have spinal injuries will be moved to a soft surface as soon as the diagnosis is made.

Lateral supports for the head and body do make rational sense. Straps or buttresses will absorb force that might otherwise be deposited on the injured area. Supports against flexion are also reasonable but much less useful since vertical deceleration during transport and hospital care is rare and because when applied tightly to the torso they can increase the work of breathing.

Cervical collars are probably not a rational method of early spine care. They do decrease visible motion but they work by transferring force from the mid-cervical spine to their ends and will thus theoretically increase some high and low cervical injuries. In addition they provide an axial distractive force and are hence contraindicated in injuries that are unstable to distraction.[15] They increase intracranial pressure and decrease cerebral perfusion[16] and make it difficult to examine the neck or manage the airway.[17] If used alone they do protect some injuries, which is why they are used for long term rehabilitation but acutely they add little to other means of stabilisation such as lateral supports.[18] I suggest that they should only be used when the nature of the injury is appropriate—which cannot be determined prior to imaging.

'Standing backboards' are perhaps the most obvious example of irrational ritualised care. Ambulatory patients are highly unlikely to have an unstable spinal injury. When sitting from a standing position, rotation occurs at the hip joint. Strapping a standing patient to a hard slippery board and then laying it down causes a distractive force across the entire spine. The reasonable thing to do is put the back of the gurney up, assist the patient to sit on it and gently lower the back. They can then be transported on a comfortable surface with straps or supports as needed.

The focus on reducing visible movement is least rational when treating an uncooperative or seizing patient. Tightly strapping these patients down does nothing to reduce the force they generate and in many cases will increase it if they panic or fight the restraints, either voluntarily or involuntarily. These patients may need to be calmed down, sedated or paralysed but transport without 'immobilisation' is much preferable to increasing their leverage by tying them up.

Airway management of patients in whom spine injuries cannot be excluded is controversial. All methods of advanced airway management put force across the cervical spine and move it. In fact bag valve mask ventilation moves the spine, and hence delivers more energy to it, than careful intubation does.[19] However, the movement remains within the normal range of motion and requires little energy overall. Most authors recommend in line 'stabilisation' in an attempt to minimise visible movement but this may make intubation more difficult[20] and can increase the amount of force delivered.[21] In fact, immobilising the head directs more of the force during intubation to the neck. Having an assistant hold the head and manipulate the airway if necessary may make intubation easier and is generally reasonable but if they must apply significant force to keep the head immobile this means that an equal or greater force is being applied by the operator and this violates the basic principle that force across the injured site should be minimised. If the head must be repositioned to successfully manage the airway, this is preferable to a 'tug-of-war' between the person holding the head and the one doing the intubation. In line traction should be condemned for the same reasons that overly aggressive in line stabilisation is and because it applies a distractive force much like a cervical collar does.

LIMITATIONS

Acutely biomechanically unstable spine injuries that have not already caused irreversible injuries are the only ones that can benefit from emergency care. These are very rare. As a consequence, adequately clinically testing any therapy is extremely expensive. Relying on tradition does have advantages. It is easy to remember, non-controversial and minimises medical legal risk—at least in the short term. Change is only worth doing when the estimated benefit exceeds the risk and additional cost. In the long run the relatively simple recommendations above are likely to meet these criteria by simplifying spine care, decreasing time to definitive care and minimising additional injury during transport and in the emergency department.

CONCLUSION

I use the term 'theory' as both an explanatory and a predictive model but in this case one that is accepted as elementary Newtonian mechanics. Within the context of spinal care neither the 'theory' that motion causes injury or the one discussed above has been 'proven' but the fact that the former violates aspects of Newtonian mechanics means that it is at best only partially correct. In that motion which occurs at the injured site does obviously increase injury it is a valid explanatory model but it is incomplete and in some cases leads to standard therapies that can be safely discarded. Specific treatments that are irrational when examined from basic principles include the following: the use of hard 'backboards' for transportation, cervical collars except in specific injury types, immobilisation of ambulatory patients on backboards, mechanical immobilisation of uncooperative or seizing patients and forceful head stabilisation during airway management. Eliminating these treatments will decrease time to definitive treatment,

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reduce the risk of ischaemic tissue damage and simplify airway management. It will make emergency care more comfortable for patients and decrease iatrogenic injuries. Re-conceptualising the guiding principle of acute spinal care in terms of minimising energy deposition rather than minimising visible motion may allow more rapid adoption of newer treatment modalities. Given that this is an area in which acceptance of even minor changes has been exceptionally slow[22 23] there is a potential to greatly improve patient care.

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