First rib fracture due to cervical hyperextension:
A clue to solving a Colorado ski fatality

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Introduction
A 41 year-old female (171.5cm 66kg) advanced skier was downhill skiing when she apparently lost control, diverted off the side of a trail into a group of trees, and sustained fatal trauma. No person witnessed the accident. Nylon rope was tied between the trees forming a perimeter border alongside the ski trail. The forensic analysis addressed whether her injuries resulted from hyperflexion/compression mechanism consistent with head impact into a tree or hyperextension mechanism consistent with underside chin contact with the rope.

Methods
Autopsy revealed bilateral laminae fractures at C3 with associated spinal cord trauma, right first rib fracture, and multiple chest trauma including fractured sternum, anterior 4\textsuperscript{th} rib, bruised right atria and left ventricle, and left lung edema and hemorrhaging. The scalp, skull, and brain were unremarkable and there was a semi-circular bruise and laceration under the chin. Medical and scientific literature was reviewed regarding first rib fractures, cervical spine fractures, and injury secondary to cardio pulmonary resuscitation (CPR). The total injury pattern was reviewed and each injury evaluated for its most probable mechanism. The accident site was inspected and the snow depth and rope height was scaled from photographs taken on the date of the accident. A 3-dimensional scale model was generated to assess skier kinematics and point-of-rest.

Results
The fracture of the sternum, the 4\textsuperscript{th} rib (anterior fracture) and pulmonary and cardiac contusions resulted from CPR consistent with multiple chest trauma reported in the medical literature as the result of prolonged resuscitation attempts (Baubin M, et al., 1999; Powner DJ, 1984).

The anatomical location of the first rib protects it from trauma and consequently first rib fractures are rare. The fracture sight of right 1\textsuperscript{st} rib was on the posterior aspect near its origin on the vertebral column. It has been shown in a case study report (Theriot, et al., 1984) that fracture of the first rib can occur as a result of forces transmitted through the scalene muscles resulting from hyperextension of the neck (Figure 1).

Figure 1. Diagrammatic representation of first rib fracture injury mechanism.
This force can be accentuated or exacerbated by lengthening muscle contraction. Points of fracture most commonly noted are at the subclavian groove or the neck of the rib (the site of fracture in this case). The above referenced case study reports this first rib fracture mechanism associated with facial trauma. The subject of this report sustained laceration and contusions of the chin, which is consistent with contact with the rope barrier.

Posterior element fracture of the cervical spine has been reported in the medical literature to result from both hyperflexion and hyperextension mechanisms (Allen, et al., 1982). Deep muscles of the back with origins and insertions on the posterior elements of the cervical spine have been proposed to cause trauma during hyperflexion due to excessive tension of these muscles. Tension of the deep back muscles would then generate a force between the posterior elements causing trauma to their attachments to the vertebral body, at the lamanae. Hyperextension of the cervical spine causes contact between the spinous processes (see Figure 1), which can cause fracture of the attachment of the spinous process and the vertebral body. The trauma to the cervical vertebrae could not completely distinguish between a hyperflexion/compression or hyperextension injury mechanism. Examination of the scalp, skull, and brain were unremarkable thereby not suggestive of head impact, however a head contact mechanism could not be completely ruled out due to several cushioning factors (ski hat, backpack).

The three-dimensional scale model was used to evaluate skier kinematics and point-of-rest and determine whether her injuries resulted from an impact with a tree or a contact with the rope. Both scenarios were analyzed. The physical proximity of the point of rest, trees, and rope showed that impact with the tree was physically unfeasible and highly unlikely.

Discussion
There was no mechanical explanation for the first rib fracture other than hyperextension, especially in absence of any shoulder or upper back trauma. The laceration on the underside of the chin indicated likely rope contact and a moment arm that created an extensor moment as the skier’s body passed under the rope and snapped the head rearward. The C3 fracture and first rib fracture were caused primarily by hyperextension. The right-side first rib fracture also indicated some left lateral flexion consistent with the C3 posterior element fracture, which was greater on the left side. Knowledge of the hyperextension scalene muscle pull mechanism for first rib fractures assisted in the ultimate determination that the primary applied force to the skier was hyperextension, consistent with being caught underside the chin by the rope. Determining whether the applied force was extension versus flexion had significant legal implications.

References

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