Ultrastructural Changes of the Cochlea After Oral and Maxillofacial Firearm Wounds

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Background: There have been reports that maxillofacial firearm wounds could induce hearing loss. The effects on the ultrastructure of the cochlea and cochlear nerves after oral and maxillofacial firearm wounds are still unclear. This experiment investigates the ultrastructural changes of the cochlea and cochlear nerve after oral and maxillofacial firearm wounds.

Methods: Twenty dogs were wounded by steel spheres or detonators to establish animal models of oral and maxillofacial firearm wounds. At different times after trauma, the wounds were examined and the specimens of the cochlea and cochlear nerve were taken to study the ultrastructural changes.

Results: The ultrastructural changes of the cochlea and cochlear nerve at 1 hour after trauma were cilia disorganization, edema of the nerve, and mitochondrial denaturalization. At 6 hours, there was extensive degeneration in the cochlea and cochlear nerve, cilia falling off of hair cells, and dissolution of the nerve sheath structure.

Conclusions: The ultrastructure of the cochlea and cochlear nerve after injury is severe, but in the early period the injury is reversible.

Key Words: Maxillofacial, Firearm wounds, Cochlea, Ultrastructure.

ear regions were irrigated with 3% glutaraldehyde through opened cochlear and vestibular windows. The specimens of the temporal bones were fixed in 3% glutaraldehyde for 24 hours, and then decalcified with 10% of ethylenediamine tetraacetic acid (EDTA) for 14 to 24 days. The cochlear axis and cochlear nerves were separated from the temporal bones under the anatomic microscope. The specimens of the modiolus were collected for scanning electron microscopic (SEM) observation. The specimens of the cochlear nerve were collected for transmission electron microscopic (TEM) observation.

The four control animals were killed and treated the same way as previously described 1 hour after anesthesia, except for the trauma.

RESULTS
Wound Parameters
The impact velocity of the missile wound was measured in all animals in group A. There were no significant differences between the average value of impact velocity and injury energy of animals killed 1 hour after wounding \((1,417.5 \pm 67.2 \text{ m/s}, 724.5 \pm 131.2 \text{ J})\) and 6 hours after wounding \((1,429.7 \pm 72.1 \text{ m/s}, 738.1 \pm 114.1 \text{ J})\). The values of the explosive energy of animals in group B were not measured.

Macroscopic Observation of Wounds
In group A, gross examination of the maxillofacial wounds of the animals showed that the bullet entered the left side of the face and came out of the bottom of the mouth on the right side of face. The entrance wounds averaged 0.5 cm in diameter and the exit wounds 1.5 cm in diameter. There was a comminuted fracture of the mandible with a defect averaging 3.0 \(\times\) 1.5 cm\(^2\). There were extensive contusions of the skin and muscular tissues around the wound track. The wounds had extensive hemorrhage and hematomas. The average distance from the midpoint of entrance wounds to the external auditory meatus was 3.5 cm. No fractures of the base of skull and temporal bone were found. The external auditory canal, drum membrane, and ossicular chain of the wounded animals were intact. There was no rupture of the cochlear and vestibular windows. Only one animal, where the distance from midpoint of the entrance wound to the external auditory meatus was 2.5 cm, had a hematoma and hyperemia of the middle ear mucosa in the left middle ear.

In group B, extensive lacerated wounds in the left cheek and masseter muscle region were observed. The diameter of the wound of the skin and the soft tissues reached 4.0 cm. The contused wound averaged 5.5 cm at 6 hours with the wound cavity shaped like a funnel. There were burnlike changes at the wound borders of the skin. The muscle was black and red for approximately 0.5 cm and there was no contraction and/or hemorrhage when the muscle was incised. Comminuted fractures of mandible in the wound region were found, but no obvious bony defect was observed. Rupture of the drum membrane was found in two dogs. Hyperemia of the mucosa of the tympanic cavity and small amounts of hematotympanum were observed but there were no other abnormalities.

Scanning Electron Microscopy of the Surface Structure of the Cochlea
In the control group, stereocilia of the outer hair cell on the basilar membrane of the cochlea was normal. Stereocilia of three rows of outer hair cells in the base and second turns were lined up in order, in a “V” shape. Stereocilia were all erected parallel without obvious break or defect; a few stereocilia of the third row of outer hair cells in base turns were disarranged. The cuticular plate was even, smooth, and glossy. At 1 hour after injury, the cilia of the second and third row of outer hair cells were oblique, severely separated, falling, and inosculated with complete or partial shedding of the stereocilia. The wound area involved the base and the second turns. Cuticular plate was normal (Fig. 1). At 6 hours after injury, the area with injured stereocilia was widened and involved the base and middle turns; damage in the top turn was also found. The stereocilia of the three rows of outer hair cells were all falling, inosculated, crossing, and detached (Fig. 2). Swelling of the cuticular plate appeared. The explosive wound group (Group B) was damaged even worse. The injury affected the base, middle, and top turns. The stereocilia of the three rows of hair cells were all falling and inosculated; the stereocilia of the hair cells obviously fell off.

Transmission Electron Microscopy of the Cochlear Nerve
In the control group, the cochlear nerve fiber was intact; stratification of the myelin sheath was clear and in good order. Microtubules and microfilaments in the axon were obvious and distributed evenly. There was no abnormality in
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Fig. 2. The area with injured stereocilia was widened and involved the base and middle turns; damage in the top turn was also found. The stereocilia of the three rows of outer hair cells were all falling, inosculation, crossing and detached. Swelling of the cuticular plate appeared (SEM, original magnification 1,500×).

Fig. 3. Edema in the axon, decreased but evenly distributed microtubules and microfilaments, and swelling of mitochondria with breakage and disarrangement of the cristae in the myelin sheath were observed (TEM, original magnification 10,000×).

Fig. 4. Lysis, vacuolization degeneration, medullary degeneration of the mitochondria and edema of ply in the myelin sheath appeared (TEM, original magnification 10,000×).

Fig. 5. Cochlear nerve in the explosive wound group was damaged even more; dissolution of the structure in nerve sheath was frequent (TEM, original magnification 10,000×).

DISCUSSION

Stereocilia and the cuticular plate of cochlear trichobothrium cells and the cochlear nerve play important roles in the sensing, discrimination, and conduction of sound information; defects or disruptions can cause hearing impairment. Tinnitus, dizziness, and decreased hearing in patients with firearm wounds to the maxillofacial region have been reported in literature and observed in patients. Because the inner ear is sensitive to the shock wave, research about inner ear injury is mainly focused on the effects of blast injuries on hearing impairment. There are a few experimental reports about inner ear damage after oral and maxillofacial firearm injuries. Schwann and endothelia cells of the capillaries in the stroma were normal. At 1 hour after injury, there was edema in the axon, decreased but evenly distributed microtubules and microfilaments, and swelling of mitochondria with breakage and disarrangement of the cristae in the myelin sheath (Fig. 3). At 6 hours after wounding, lysis, vacuolization degeneration, medullary degeneration of the mitochondria, and edema of ply in the myelin sheath appeared (Fig. 4). In one specimen, structure of the myelin sheath became obscure, edema, and patchy lysis. The medullary degeneration of mitochondria within cochlear nerve was found. The cochlear nerves in the explosive wound group (group B) were damaged even worse; dissolution of nerve sheath structure was frequent (Fig. 5). Collapsed structure of the myelin sheath was found in one specimen (Fig. 6).
wounds. In our experiments, the effects of oral and maxillofacial firearm wounds on the injury and ultrastructural changes of the cochlea and cochlear nerve were investigated and should be of clinical significance. We established animal models of high-velocity missile and blast wounds to study the ultrastructure pathologic changes of cochlea and cochlear nerve associated maxillofacial firearm wounds. There were obvious ultrastructure pathologic changes observed, which induced disturbance, coalescence, fusion, crossed and lost stereocilia of the cochlear hair cells, edema of surface panel of the cochlea, and degeneration, edema, and mitochondrial denaturation within myelin sheath structures of the cochlear nerve. Our experimental results not only show a reasonable explanation for clinical cases of maxillofacial firearm wounds with auditory impairment, but also provide an experimental basis for clinical management of auditory damage in maxillofacial firearm wound care. The main mechanisms for the damage to the neighboring organs caused by high-velocity missile wounds include a crush-and-stretch injury from the temporary cavity, injuries from the pressure waves, injury of the impacting vibration effect and injury from hemodynamic changes. With explosive wounds, the important mechanism of injury is caused by a shockwave including changes of pressure on tissues such as high and negative pressures. In our experiment, hemostasis and tracheal intubation were performed immediately after wounding to exclude the ultrastructure damage of the cochlea and cochlear nerve from the influence of blood loss and hypoxia. Unlike the results of intact sound transductive structures in high-velocity missile wounded dogs, there were two dogs with broken drum membranes in the explosive wound group (group B). The ultrastructural damage to the cochlea and cochlear nerve in explosive wounded dogs were more severe than high velocity missile wounded dogs. This result showed that the shockwave may be the most important injured factor that caused auditory impairment in maxillofacial explosive wound.

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**REFERENCES**


**Fig. 6.** Collapsed structure of the myelin sheath of cochlea nerve was found in one specimen (TEM, original magnification 10,000×).