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Biomedical Influences on Spinal Cord Function

by

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Studies were conducted in concert with the Naval Biodynamics Laboratory to evaluate neurophysiological alterations of brain and spinal cord function secondary to impact produced on the Navy's HYGE sled in New Orleans, LA. The Medical College of Wisconsin provided the biomedical engineering and neurosurgical expertise to direct the implantation of electrodes on the spinal cord and on the brain matter of non-human primates for these studies. The animals were transported to our laboratories for implantation and evaluation, and then transportated back to New Orleans for study. The impact studies indicate that substantial neurophysiological alterations occur in the non-human primate in the region of 80 to 100 sled G's in the -x direction. Furthermore, the position of the subject's head is a critical factor during impaction. The neurophysiological and pathological studies following the investigation suggest substantial alterations of the evoked potentials associated with the injuries secondary to the inertial pulse produced by the sled. (CONT'D)

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Parallel studies conducted in donated human surrogate tissues have determined the strength of the ligaments at all levels of the spinal column. In addition, neurophysiological studies conducted in concert with the Naval Biodynamics Laboratory in New Orleans in non-living primates helped to delineate the mechanisms of injury secondary to tension mechanisms. For this purpose, studies using evoked potentials, 14C deoxyglucose, electron microscopy, and conventional pathological investigations of the tissues were also done. In conclusion, the evoked potential technique provides a means for evaluating alterations in neurologic function during impact experiments and is a valuable technique to determine levels of permanent alteration of the tissues.

INTRODUCTION

This research commenced in September of 1977. The studies were directed to delineate the mechanisms of injury to the human brain and spinal cord during impact injury such as that experienced by Navy Air Force personnel and other military personnel during typical military and non-military maneuvers. The program was conducted in concert with the Office of Naval Research and the Biodynamics Laboratory in New Orleans, LA. Our group of biomedical engineers and neurosurgeons provided assistance for the biodynamics program in the evaluation of impact injury to non-human primates. Evoked potentials were used to measure the alterations in neurological function secondary to inertial impact produced on the HYGE sled in New Orleans at -x G levels up to approximately 100. The pathological evaluations were conducted in New Orleans by consultants and Navy personnel, and our personnel at the Medical College of Wisconsin provided the neurosurgical and biomechanical and bioengineering expertise to assist these studies. In addition, basic studies were conducted to evaluate spinal cord injury function in non-human primates and in human cadaveric tissues to determine the mechanical properties and strengths to further understand potential mechanisms of injury in military personnel.

METHODS AND DISCUSSION

Substantial evidence is available, both clinical and experimental, indicating that pathological stretch of the spinal cord is a major factor in the pathogenesis of traumatic myelopathy. This myelopathy, whether permanent or transient, may occur without radiographic evidence or fracture dislocation. The spinal cord lengthens in flexion and it becomes shorter in extension. The recording of specific and non-specific somatosensory evoked potentials and the determination of threshold for cortically induced muscle contractions provides an objective and quantitative means for evaluating conduction in the anterior, lateral and posterior portions of the spinal cord. In monkeys electrodes were chronically implanted over the sensorimotor cortex and nucleus ventralis posterior lateralis of the thalamus, and over the spinal cord. For evaluation of conduction over afferent pathways, electronic pulses are applied transcutaneously to the sciatic nerve or through electrodes implanted in the cauda equina. Evoked potentials are recorded from the various indepth electrodes to evaluate transmission in the pathways. During the impact accelerations produced in non-human primates, the evoked potentials were altered in the specific and non-specific pathways at higher levels of acceleration. At the lower levels of acceleration they were not altered. In the region of 100 G's atlanto-occipital dislocations with total disruption of ligaments in that region occurred. Pathological findings were reviewed in various publications by Dr. Unterharnscheidt (*Unterharnscheidt F: Pathological and neuropathological findings in rhesus monkeys subjected to* $-G_x$ *and* $+G_x$ *indirect impact acceleration. In* *__Mechanisms of Head and Spine Trauma__, A Sances Jr, DJ Thomas, CL Ewing, SJ Larson, and F Unterharnscheidt, eds, Aloray Publisher, Goshen, NY, 1986, pp 565-664*). Methods for conducting these experiments have been published (*Ewing CL, Thomas DJ, Sances A Jr, Larson SJ, eds:* *__Impact Injury of the Head and Spine__, Charles C. Thomas, Springfield, IL, 1983, 654 pp*). Drs. Thomas and Jessop have also published a chapter entitled, *Experimental head and neck injury from inertial forces. In* *__Mechanisms of Head and Spine Trauma__, A Sances Jr, DJ Thomas, CL Ewing, SJ Larson, and F Unterharnscheidt, eds, Aloray Publisher, Goshen, NY, 1986, pp 351-396.*

RESULTS

The Medical College of Wisconsin provided the neurosurgical and biomedical engineering expertise required for electrode implantation and evaluation of the neurophysiologic alterations observed in these studies. The section entitled "Publications" delineate our findings. In addition, parallel studies were conducted in our laboratory to determine alterations in spinal cord function secondary to a closed tension model which was developed by our staff. With tension the evoked potentials are altered secondary to the mechanical alterations (*Cusick JF, Myklebust J, Zyvoloski M, Sances A Jr, Houterman C, Larson SJ: Effects of vertebral column distraction in the monkey. J Neurosurg 57:651-659, 1982; and Cusick JF: Analysis of the spinal pathways. In Impact Injury of the Head and Spine, CL Ewing, DJ Thomas, A Sances, Jr, and SJ Larson, eds, Charles C. Thomas Publisher, Springfield, IL, 1983, pp 286-301*). Parallel studies were conducted on fresh human surrogates obtained through our body donor program at the Medical College of Wisconsin. The strength of the disks, bones, ligaments, etc., were evaluated to provide a background for comparing the studies obtained in the non-human primate with the living human (*Sances A Jr, Myklebust J, Kostreva D, Cusick JF, Weber R, Houterman C, Larson SJ, Maiman D, Walsh P, Chilbert M, Unterharnscheidt F, Siegesmund K, Ho K, Ewing C, Thomas D: Pathophysiology of cervical injuries. Proc 26th Stapp Car Crash Conf, Society Automotive Engineers, Warrendale, PA, 1982, pp 41-70; Cusick JF, Myklebust J, Zyvoloski M, Sances A Jr, Houterman C, Larson SJ: Effects of vertebral column distraction in the monkey. J Neurosurg 57:651-659, 1982; Sances A Jr, Myklebust J, Larson SJ, Cusick JF, Weber R: The evoked potential - a biomechanical tool. In Impact Injury of the Head and Spine, CL Ewing, DJ Thomas, A Sances, Jr, and SJ Larson, eds, Charles C Thomas Publisher, Springfield, IL, 1983, pp 231-285; Sances A Jr, Yoganandan N, Maiman DJ, Myklebust JB, Chilbert M, Larson SJ, Pech P, Pintar F, Myers T: Spinal injuries with vertical impact. In Mechanisms of Head and Spine Trauma, A Sances Jr, DJ Thomas, CL Ewing, SJ Larson, and F Unterharnscheidt, eds, Aloray Publisher, Goshen, NY, 1986, pp 305-348; and*

Pintar F, Myklebust JB, Yoganandan N, Maiman DJ, Sances A Jr: Biomechanics of human spinal ligaments. Ibid, 1986, pp 505-527). In addition, ^{14}C deoxyglucose was used to determine alterations in the pathways of the non-human primate during this procedure (*Myklebust J, Sances A Jr, Maiman D, Pintar F, Chilbert M, Rauschning W, Larson S, Cusick J, Ewing C, Thomas D, Saltzberg B: Experimental spinal trauma studies in the human and monkey cadaver. Proc 27th Stapp Car Crash Conf, Society Automotive Engineers, Warrendale, PA, 1983, pp 149-161).*

The structure and function of the tissues were evaluated with electron microscopy and with LKB cryomicrotome capable of sectioning large specimens, either human or animal tissues, for accurate delineation of cyto-architectual alterations following induced trauma in the experimental animal. Biomechanical studies were conducted in compression, flexion and extension in human cadaveric cervical spines and the thoracolumbar spines (*Sances A Jr, Myklebust J, Houterman C, Weber R, Lepkowski J, Cusick J, Larson S, Ewing C, Thomas D, Weiss M, Berger M, Jessop ME, Saltzberg B: Head and spine injuries. AGARD Conf Proc No. 322 on Impact Injury Caused by Linear Acceleration: Mechanism, Prevention, and Cost, Koln, Germany, April 26-29, 1982, pp 13-1 - 13-34).* Approximately 900 ligaments were evaluated at all levels of the spinal column with tension to determine the strength and properties. In addition, the force on the neck was determined with vertical drops conducted with human surrogates (*Sances A Jr, Yoganandan N, Maiman DJ, Myklebust JB, Chilbert M, Larson SJ, Pech P, Pintar F, Myers T: Spinal injuries with vertical impact. In Mechanisms of Head and Spine Trauma, A Sances Jr, DJ Thomas, CL Ewing, SJ Larson, and F Unterharnscheidt, eds, Aloray Publisher, Goshen, NY, 1986, pp 305-345).*

CONCLUSIONS AND RECOMMENDATIONS

Conclusions of this study indicate that the strength of ligaments in the spinal column of the human vary with the anterior longitudinal ligament being approximately the strongest followed by the joint capsules, the posterior longitudinal ligament, and the ligamentum flavum. The posterior ligaments are more elastic than the anterior. Studies conducted in the non-human primate in concert with the Biodynamics Laboratory indicate substantial alteration of neurologic function, with permanent alteration at the atlanto-occipital junction with accelerations of 100 sled G's (-x). Below these levels, in the region of 40 to 50 G's, minimal alterations of evoked potentials, an indicator of neurologic function, were observed. These studies suggest that scaling is required to determine comparisons between the human and non-human primate. Furthermore, the initial position of the head of the non-human primate was a factor in the injury mechanism. When the head was rotated to the side, injuries were more easily sustained at the relative G levels in contrast to having the head face full forward. The neurophysiologic studies conducted by the Medical College of Wisconsin in concert with the Biodynamics Laboratory in New Orleans, indicate that injuries are most likely due to tension forces on the neural tissues as documented by the morphological findings. In summary, the evoked potential appears to be a viable method for evaluating alterations in neurological function during dynamic testing. The evoked potential is useful in determining the levels of injury in the living human. Furthermore, the initial position of the head-neck complex plays a substantial role in the injury mechanism. In addition, the direction of the force vector is important.

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