J. Biomechanics, Vol. 3, pp. 551–555. Pergamon Press, 1970. Printed in Great Britain

THORACIC FORCE-DEFLECTION STUDIES IN LIVING AND EMBALMED PRIMATES*†

DAVID L. BECKMAN, MARVIN F. PALMER and VERNE L. ROBERTS
Biosciences Division, Highway Safety Research Institute, University of Michigan, Ann Arbor, Mich. 48105, U.S.A.

Abstract—In order to evaluate the validity of the use of the cadaver in making estimates of the living human response to cardio-thoracic impact a series of tests were performed under similar conditions comparing the force-deflection response of the anaesthetized and the embalmed Rhesus monkey. Twelve primates (100 tests) were subjected to controlled thoracic impact with a Remington Humane Stunner while seated in a sled held firmly in place. Tests on 8 of the monkeys were performed while they were anaesthetized and again 30 days after being embalmed. Four monkeys were tested only after embalming. X-rays were used to evaluate rib fractures.

Results showed clear significant differences between anaesthetized primates and those tested 30 days after being embalmed. Forces developed under the same test conditions were 132 per cent higher for the embalmed primates compared to anaesthetized monkeys under static test conditions at maximum displacement and 25–50 per cent higher under dynamic testing conditions for all but the initial part of the tests. The results of these studies indicate that the mechanical characteristics of the primate thorax are dramatically affected by death and/or subsequent embalming procedures.

INTRODUCTION

THE EFFECTS of death and the embalming process on the force-deflection characteristics of the primate thorax have been investigated in 12 Rhesus monkeys. Various reports have supported the use of the cadaver for mechanical tests (Roberts and Lissner, 1966; Patrick *et al.*, 1966) while others have suggested the possible interference of changes in tissue stiffness (Life and Pince, 1967). Results of this study extend previous work on the physical characteristics of the primate thorax (Beckman and Palmer, 1969; Beckman and Palmer, 1970).

METHODS

Twelve Rhesus monkeys (100 tests) *Macaca mulatta*, male, 4–5 kg (body weight) deeply anaesthetized with Sernylan (Phencyclidine hydrochloride) and Na-pentabarbital or embalmed and held for 30 days were used to make a comparison of thoracic force-displacement characteristics between the living and embalmed state.‡ Eight primates were tested while anaesthetized and the tests repeated 30 days after the embalming procedure. Four monkeys were tested only after embalming to determine whether prior testing while anaesthetized affected subsequent results. Each primate was tested several times—once using a static test and at several velocities—34–35, 45, 55–56 and 65–66 ft/sec. Impactor mass was held constant at 0·8 lb. The sequence in which the tests were run was varied in order to avoid prejudice from possible effects of repeated testing. In addition, two anaesthetized and one embalmed primate was tested 15 times using identical blows to determine whether repeated testing itself changed the force-deflection response.

**Received* 12 *June* 1970.
†Presented at the 4th Annual *ASME* Biomechanics Conference, June 1–2, 1970 in Washington, D.C.
‡These experiments were conducted in accordance with 'Principles of Animal Care' established by the National Society for Medical Research.

It was found that there was no significant change or effect of repeated testing at moderate forces.

Primates were seated in a solidly fixed stationary sled and hit in the chest (mid sternum) with a 1 in. flat metal plate fired by a modified Remington Humane Stunner, Model 412A (Fig. 1). This was modified so that a tubular sleeve which served as the striker fitted over the stunner rod and was consequently fired as a relatively free missile. A force transducer and an accelerometer were attached to the sleeve. The movement of the striker was measured by means of a photocell arrangement. Checks on the accuracy of the force measurements were made with a crystal load cell placed behind the sled. Velocity and displacement measurements were checked by high speed photography. Signals were recorded on a Honeywell Medical Electronic System and Tektronic oscilloscopes. The embalming procedures were performed by a qualified technician using standard accepted methods 30–40 days before testing. Those primates tested before being embalmed were X-rayed and results indicated that there were no rib fractures. Results expressed in Figs. 2–6 were based on values from anaesthetized primates which served as controls compared to embalmed primates with or without previous testing.

RESULTS

Thoracic force-deflection tests on the anaesthetized and the embalmed primate have been carried out under static conditions and at 4 different velocities. Results of static tests (Fig. 2) show dramatic differences between anaesthetized and embalmed monkeys. For each measured chest wall displacement the forces developed during tests with embalmed primates were significantly higher than controls with forces for embalmed primates 132 per cent higher at the point of maximum deflection.

Dynamic tests showed a similar trend (Figs. 3–6). After the initial 0·3 in. chest deflection forces were significantly higher for the embalmed compared to the anaesthetized monkeys when at an initial impactor velocity of 34–35 ft/sec (Fig. 3). In all but the initial deflection, forces from the embalmed tests were 27–42 per cent higher. Tests run at the next higher impactor velocity, 45 ft/sec. showed the same trend after initial displacements of 0·3 and 0·6 in. with forces from embalmed primates up to 32 per cent higher than control values (Fig. 4). Similar trends were seen for tests run at 55–56 ft/sec (Fig. 5) with forces up to 27 per cent higher for the embalmed tests. Tests run at the highest velocity, 65 ft/sec, were consistantly different with all forces for the embalmed tests significantly higher than for the anaesthetized primates. Values for the initial 0·3 in. displacement were 32 per cent higher from embalmed tests compared to controls and generally maintained this difference (Fig. 6).

Repeated trials were run on 3 monkeys to evaluate the effects of repeated testing on sub-

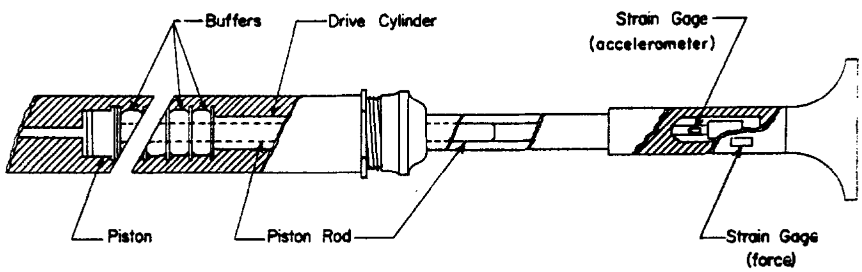

Fig. 1. Diagram of the striker or impactor. A Remington Humane Stunner was modified for use in these studies.

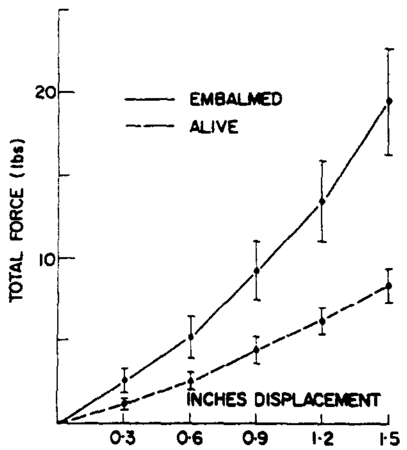

Fig. 2. Composite data taken from 8 anaesthetized and 12 embalmed monkeys under static conditions.

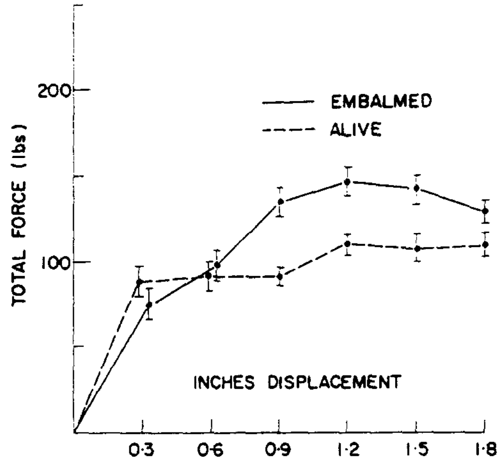

Fig. 4. Composite data from tests run at an initial impactor velocity of 45 ft/sec from 7 anaesthetized and 12 embalmed monkeys.

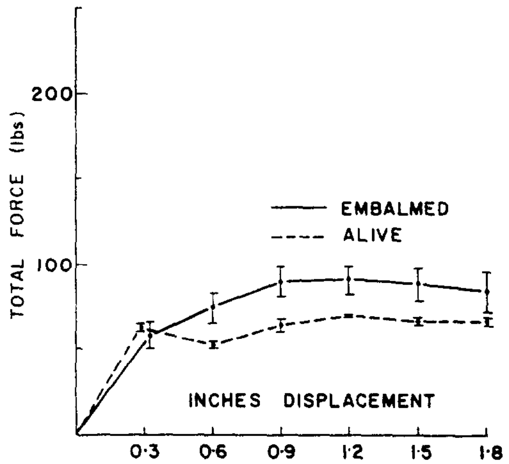

Fig. 3. Composite data from tests run at an initial impactor velocity of 34–35 ft/sec from 5 anaesthetized and 8 embalmed monkeys.

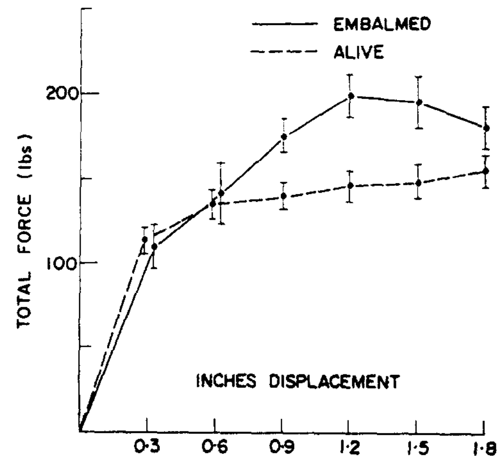

Fig. 5. Composite data from tests run at an initial impactor velocity of 55–56 ft/sec from 8 anaesthetized and 10 embalmed monkeys.

sequent force-deflection curves. Results from 15 similar repeated tests on 3 monkeys showed less than a 10 per cent difference over the range of the tests for anaesthetized primates and less than 3 per cent difference for the embalmed state. These differences were presumably due to variations in impactor velocity since the variations were at random.

DISCUSSION

The results of these studies show that the embalmed primate thorax is significantly stiffer than that of the control anaesthetized monkey. The forces developed during static tests were 132 per cent higher in embalmed primates at 1·5 in. displacement. Under dynamic test conditions all but initial displacement values from the embalmed primate were 25–50 per cent higher than controls. Additional preliminary work on the baboon supports these results.

It is apparent that direct comparisons

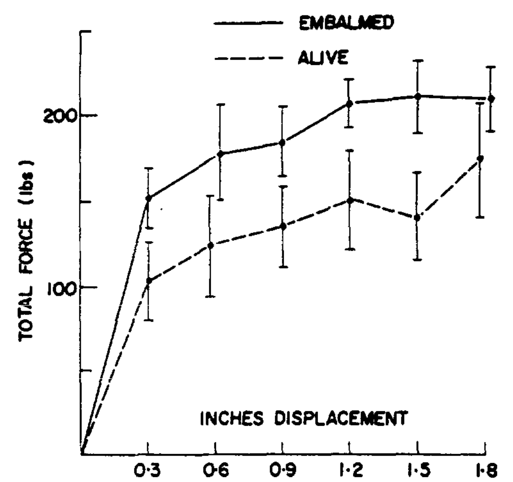

Fig. 6. Composite data from tests run at initial impactor velocity of 65 ft/sec from 4 anaesthetized and 5 embalmed monkeys.

between primate work and full scale cadaver tests cannot be made. Obvious differences in body mass, the effects of the arms and shoulders, and head and neck have not been considered. All tests presented here have been limited to a consideration of the properties of the thorax alone.

The effects of embalming on the force-displacement characteristics are due to tissue changes after death and perhaps also due to the effects of embalming fluid on the tissue itself. In addition, the presence of embalming fluid in the lungs may have had some effect. The ribs may also have become somewhat stiffer although it has been shown that embalming has little effect on the mechanical properties of the skeleton (McElhaney *et al.*, 1964).

Other factors which most likely enter into the results may include the position of the glottis and the point in the respiratory cycle during the test; the viscera below the diaphragm may also influence the shape of the curves. In addition the amount of moisture in the skeleton most likely has an influence on its deflection characteristics (Greenburg *et al.*, 1968).

The complete force-deflection curves are not presented in this paper but are carried out to 1·8 in. chest wall deflection which approaches one half the anterior–posterior diameter of the thorax. The extent of the deflection of the thorax was variable which prevented a statistical analysis and summary graphic presentation. The total work (area under the force-deflection curve) was not calculated except in individual cases; these demonstrate (Fig. 7) that equal amounts of work were involved whether primates were anaesthetized or embalmed.

The shape of the force-deflection curves is dependent on factors of (1) elastance (2) frictional resistance and (3) effective mass or inertia. The first factor, elastance, as measured by the static tests, remains comparatively low (Fig. 2) reaching a maximum at 1·5 in. deflection of less than 20 lb of total force. The other two factors are functions of the striker velocity which decreases rapidly after initial contact. The effective mass of the chest wall moved by the striker increases during the displacement; this increase may be partly countered by the deceleration of the striker with a consequent decrease in the second factor, frictional resistance. The net result of this may partly explain the initial rise followed by a relatively flat curve.

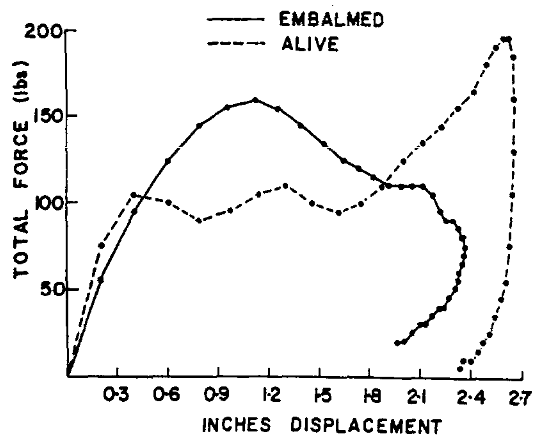

Fig. 7. Typical example of a complete force-deflection curve at an initial impactor velocity of 44 ft/sec.

Acknowledgements—Donald Baslock and William F. Price have provided the technical assistance for this work.

This work was supported by USPHS Grant GM-16912.

REFERENCES

Beckman, D. L. and Palmer, M. F. (1969) Response of the primate thorax to experimental impact. *Proc. 13th Stapp Car Crash Conf.*, pp. 270–281. Society of Automotive Engineers, New York.

Beckman, D. L. and Palmer M. F. (1970) Thoracic force-deflection studies in primates. *J. Biomechanics* **3**, 223–227.

Greenburg, S. W., Gonnzalex, D., Gurdjian, E. S. and Thomas, L. M. (1968) Changes in physical properties of bone between *in vivo*, freshly dead and embalmed condition. *Proc. 12th Stapp Car Crash Conf.*, pp. 271–279. Society of Automotive Engineers, New York.

Life, J. and Pince, B. (1967) Comparative responses of small and medium sized primates, both live and embalmed, to impact stress. *Proc. 11th Stapp Car Crash Conf.*, pp. 136–153. Society of Automotive Engineers, New York.

McElhaney, J., Fogle, J., Byars, E. and Weaver, G. (1964) Effect of embalming on the mechanical properties of beef bone. *J. appl. Physiol.* **19**, 1234–1236.

Patrick, L. M., Kroell, C. K. and Mertz, H. J. (1966) Forces on the human body in simulated crashes. *Proc. 9th Stapp Car Crash Conf.* (Edited by M. K. Cragun), pp. 237–259. Society of Automotive Engineers, New York.

Roberts, V. L. and Lissner, H. R. (1966) A correlation between cadaver and *in vivo* results. *Proc. 8th Stapp Crash Conf.*, pp. 134–146. Wayne State University Press, Detroit.