ANTLER STRESS IN THE NASAL BONE REGION OF MOOSE

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ABSTRACT: We used holographic nondestructive testing (HNDT) to study the impacts of antler-transmitted dynamic and shock-type forces which potentially affect development of the nasal region in moose skulls. Four different nasal region structures were used, and differences in the stability of the types studied were observed. The results were compared with deer skulls of different pedicle structure, and significant differences in biomechanics were found. Comparison between fresh- and dry- bone biomechanics showed that dry bones may be used for biomechanical studies of thick-boned structures.

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The deciduous antlers of deer (Cervidae, Gray 1821) are primarily used for display and defence purposes connected with status determination during the rutting period (Bubenik 1990). The structural pattern of an antler is genetically determined, its mass also reflecting the nutritional status and age of an animal (French *et al.* 1956, Smith *et al.* 1987).

In the nasal bone region of moose a structural variation including incomplete internasal suturation and extra bones, divided into four types (normal,extra-bone, perforated and open), has been observed in the European moose (Nygrén 1986, Nygrén *et al.* 1990). Korablev (1988) has also reported extra bones in the nasofrontal area as well as in other moose skull sutures.

Typically in recent moose, the nasal bones are short and the antler pedicle structure of adult males is almost horizontal. However, in young animals the antlers may start to grow more or less as upward-diverging protuberances of the frontal bones. The pedicles are connected by 14-25 mm thick frontal bone halves which articulate medially by an 24-28 mm thick, deeply interdigitated interfrontal suture (Fig.1A). The vomer is a less than 30 mm deep and 300 mm long groove running from the interpremaxillary suture up to the palatino-pterygoideal junction, giving support to the cartilaginous mobile part of the nasal septum. In the moose this cartilage is well developed, being up to 100 mm in height rostrally (Fig.1B). Caudally, it reaches the interfrontal junction and the ectoturbinates. In most cases, there is no ossification of the nasal septum close to the nasofrontal and internasal suture. This is, however, frequently observed in the open nasal bone type and in some of the perforated ones (Nygrén *et al.* 1990).

In Quaternary *Alcinae* Jerdon, which show a similar pedicle structure but also a shorter facial part of the skull with longer nasal bones contacting the premaxillary bones, only normal nasal bones have been observed (Azzaroli 1981). In the nasolacrimal fissure, or "anteorbital vacuity" of *Cervalces americanus (Scotti)* Scott (1885) reports an extra bone or several bones articulating with the nasal, frontal and maxillary bones. Similar bones are frequently seen in recent European moose bulls, though never in cows (Nygrén *et al.* 1990). They seem to grow in size with age.

We studied the influence of a dynamic antler-transmitted force simulating the torque caused by gravity and antler mass. Similarly, a shock-type force resembling those caused by random impacts provided by the environment on one antler was studied to find critical areas of bone surface moving faster than their surroundings. We compared the results obtained with moose skulls representing all the four nasal bone structures with the results from one cervid skull with the typically vertical pedicle structure (roe deer, *Capreolus*

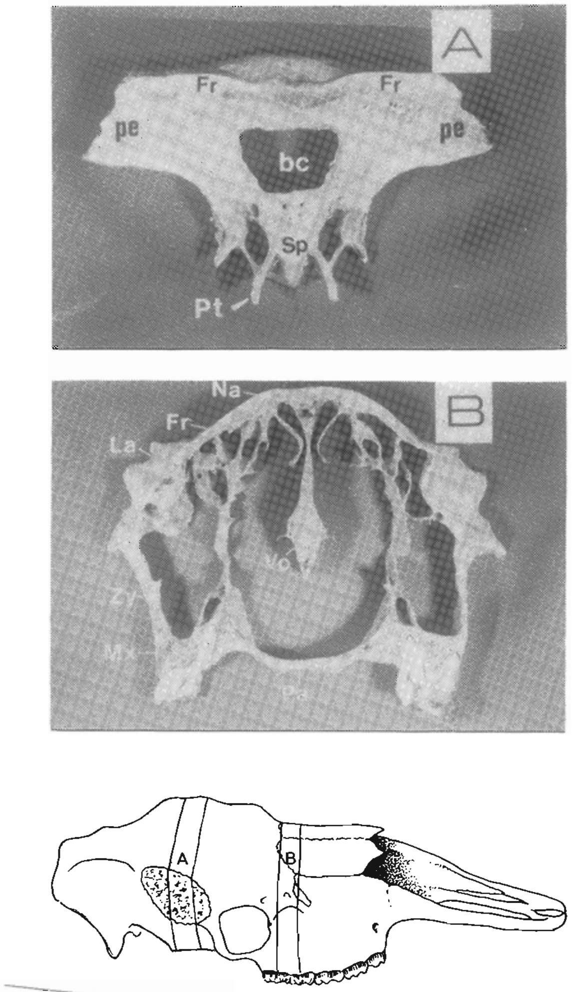

Fig. 1. Transversal sections of adult male European moose skull. (A) Through the pedicles and (B) through the nasofrontal junction. Fr:frontal bone, La:Lacrimal bone, Mx:Maxillary bone, Na:Nasal bone, Pa:Palatine bone, Pt:Pterygoid bone, Sp:Sphenoid bone, Vo:Vomer bone, Zy:Zygomatic (jugal) bone, bc:brain cavity and pe:antler pedicles.

capreolus L.) and from a deer skull representing the most common oblique pedicle structure (sika deer, *Cervus nippon Temminck*), to see whether any species- specific differences in force impact patterns existed which might help us to understand why the moose nasal region shows variations unknown in other cervid species.

The biomechanics of the mammalian skull has already been studied by using pressure or bending transducers (Dessem 1985) and with the aid of the light diffraction pattern produced by birefringent coating media (Demes 1985). In this study, however, we decided to use the holographic nondestructive testing method (HNDT), which has been employed in testing objects of various shapes and sizes (Smidth 1969, Collier *et al.* 1971). The method is known to be free of sensor errors and to bee capable of giving an instantaneous picture of surface deformations even in the case of a detailed and complicated object.

MATERIAL AND METHODS

The skulls of a 5,5 year-old moose with a normal nasal bone structure, a 3,5 year-old with an extra-bone nasal bone structure, an 8,5 year-old with a perforated nasal bone structure, and a 9,5 year-old with an open nasal bone structure were used for this study, as well as the skulls of a 3 year-old roe deer buck and of a 6,5 year-old sika stag. All were defleshed and dried like normal museum specimens. A two year-old moose bull wounded by wolves was decapitated and also studied firstly without skinning and defleshing, and then in a defleshed and dried condition.

All of the skulls were fixed on a stand by their occipital condyles and foramen magnum. A static force not exceeding 13 ±5 N was used to draw the antlers apart from each other. Secondly, a shock-wave type force was generated by hitting an antler lightly with a hard object. In the fresh, unskinned moose head, 12 points of the bone were sampled by driving screws with flat white heads into bone through the soft tissues. The movements of the screw heads caused by the bone-transmitted force studied were recorded by holography. After the skull had been cleaned and dried, the sampling screws were fastened in their original places and the skull was holographed again. The stress patterns on the bone surfaces were recorded by using double exposure holographic interferometry (Smidth 1969, Collier *et al.* 1971). The principal setup is presented in figure 2. The resolution of the method used is 0.347 micrometer of surface displacement.

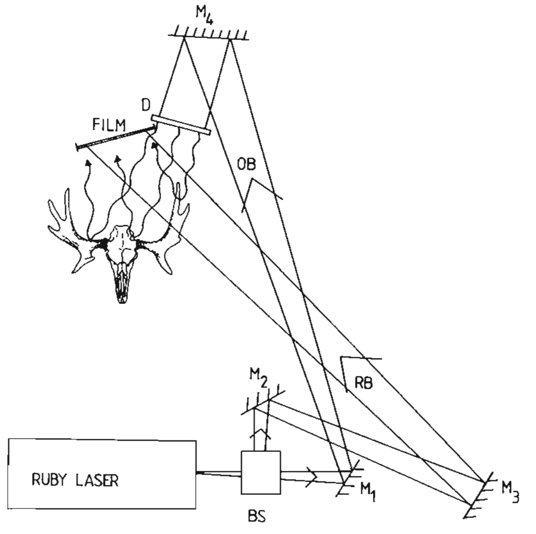

Fig. 2. Double-beam laser system used for the holographic interferometric studies. OB=object beam, RB=reference beam, BS=beam splitter, D=diffuser and M_1-M_4=mirrors.

RESULTS

In the skull of the normal nasal bone type, a symmetrical fringe pattern united in the nasion but not seen on the interfrontal junction was produced by the dynamic force (Fig. 3A). The pattern produced by the shock-type force was asymmetrical, with fringes crossing the interfrontal suture. There was a separate oval center of fringes near the nasion (Fig. 3B). Other nasal bone types showed asymmetrical fringe patterns and higher fringe densities than the normal type, when the dynamic force was used. In the extra-bone type (Fig. 4A), the line density was lowest whilst in the punctured type (Fig. 4B) it was intermediate, and in the open type (Fig. 4C) highest.

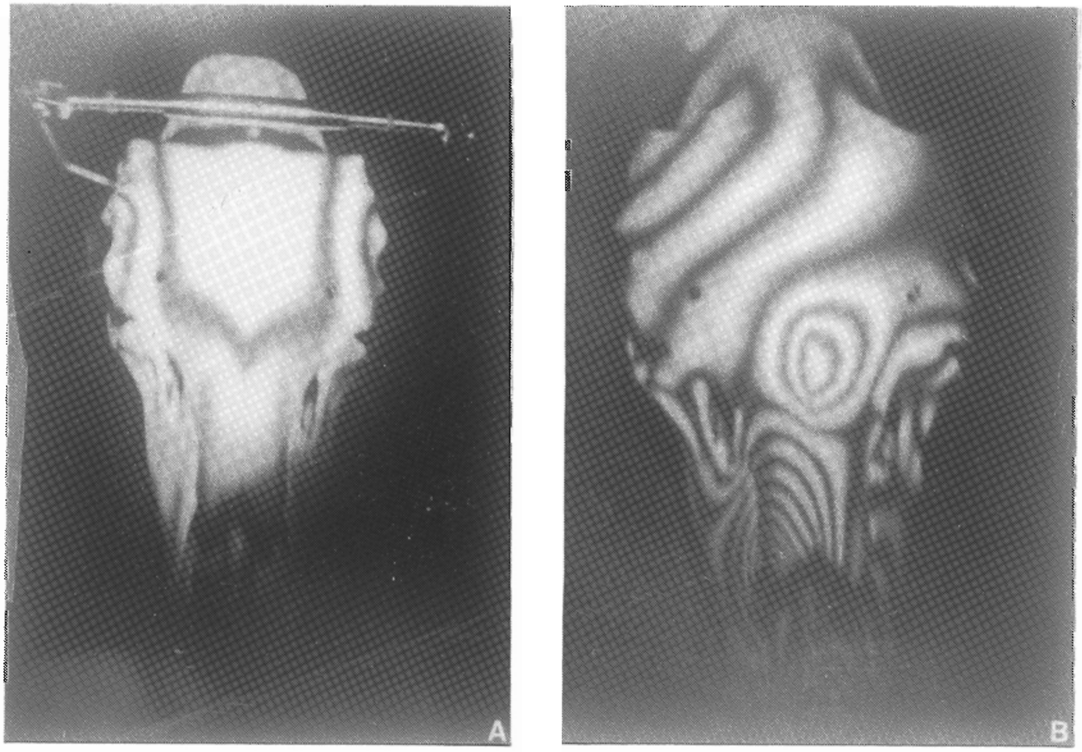

Fig. 3. Interference pictures of a skull with normal nasal bones. A=dynamic force, B=shock-type force.

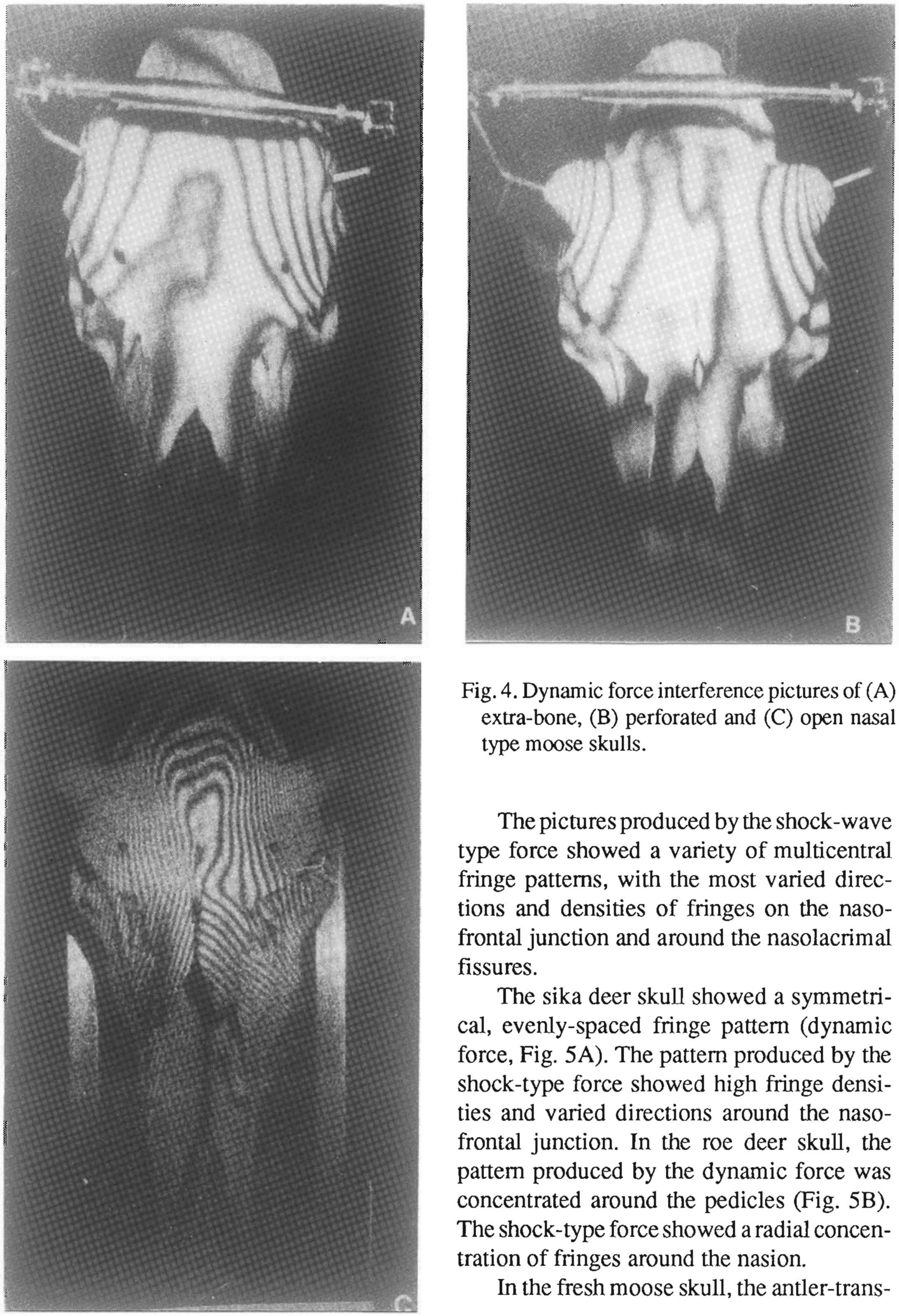

Fig. 4. Dynamic force interference pictures of (A) extra-bone, (B) perforated and (C) open nasal type moose skulls.

The pictures produced by the shock-wave type force showed a variety of multicentral fringe patterns, with the most varied directions and densities of fringes on the nasofrontal junction and around the nasolacrimal fissures.

The sika deer skull showed a symmetrical, evenly-spaced fringe pattern (dynamic force, Fig. 5A). The pattern produced by the shock-type force showed high fringe densities and varied directions around the nasofrontal junction. In the roe deer skull, the pattern produced by the dynamic force was concentrated around the pedicles (Fig. 5B). The shock-type force showed a radial concentration of fringes around the nasion.

In the fresh moose skull, the antler-trans-

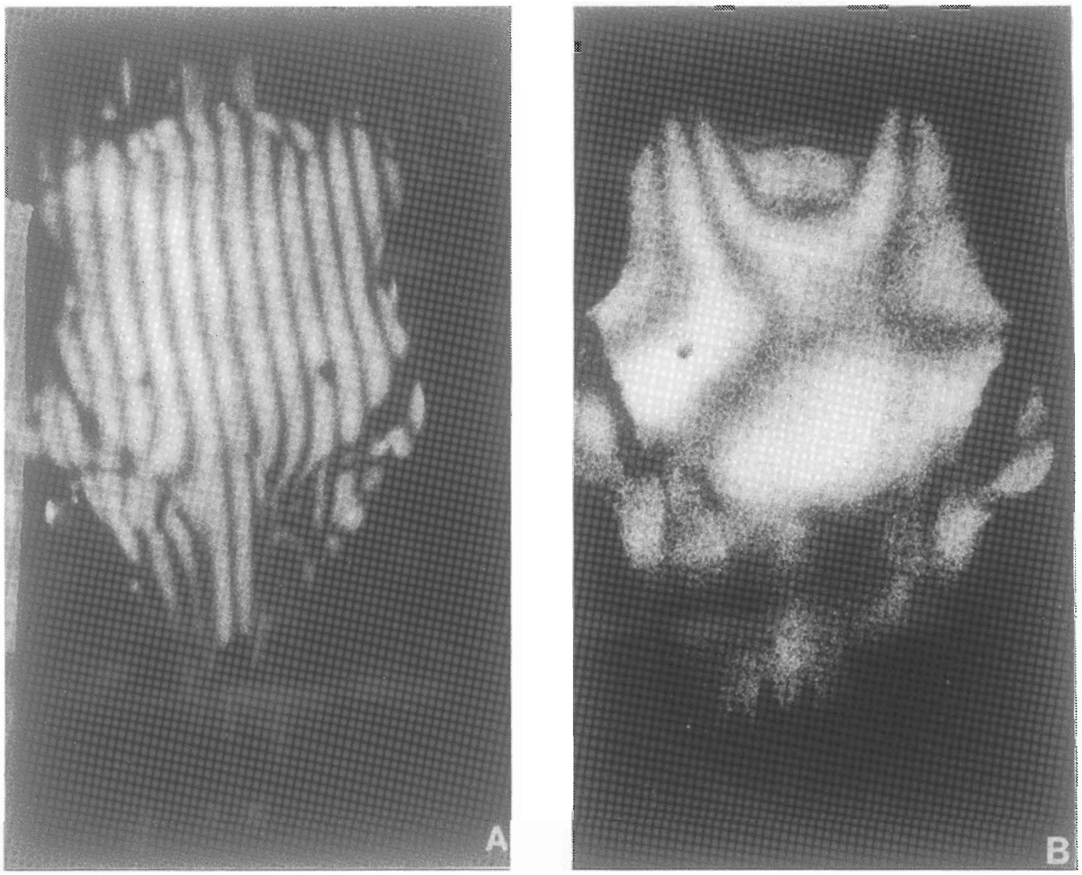

Fig. 5. Dynamic force interference pictures of (A) sika deer and (B) roe deer skull.

mitted forces produced fringe patterns on all of the screw heads. For the majority of the screws, the line direction remained the same after cleaning and drying, except for those fastened on the nasal bones. The line density decreased from fresh to dry.

DISCUSSION

Deformations caused by the small antler-transmitted forces used in this study were seen all over the moose and sika deer skull roof surface (Ossae frontales, parietales, nasales and lacrimales). Small torque forces focused on roe deer antlers seemed mostly to affect the immediate surroundings of the pedicles, leaving other parts of the skull undeformed. This biomechanically different response may be caused by the different pedicle and antler orientation and respective frontoparietal supporting structures. Except for the few deer species with vertical pedicles and antlers, like the roe deer, muntjac (Muntiacus sp) and brocket deer (Mazama sp), most of the deer species are obviously adapted to the fact that the torque forces created or transmitted by their antlers bend and stretch the skull laterally. In sika deer, the dynamic force was distributed very evenly. The whole skull roof structure seems to be involved in eliminating the effects of this seasonal stress. In the moose, the torque force created by the horizontal, massive antlers whose centre of gravity is far from the skull bones, may be greater than in any of the other living deer species. In the extinct giant deer (Megaceros sp), this dynamic stress may have been equal or even greater than in European moose. Their nasal bone region shows no variation comparable to that in moose. This may be due, among other structural arrangements, to the longer nasal bones which make rigid contact with the frontal, maxillary and premaxillary bones.

The nasal septum is, in principal, similar in all of the three deer species studied. The shallow and long vomer articulates with the premaxillary and maxillary bones but not with the caudal third of the hard palate (Fig. 1B). The septal structure is flexible and does not offer rigid support to the nasofrontal region.

The moose nasal regions with normal and extra-bone nasal bone structure show greater stability than those with the perforated or open type. The latter type showed greatest instability. In the case of both force types used, the greatest bone surface movements were observed around the nasofrontal junction.

These movements, coinciding in the area where the mammalian neurocranium with growth priority fuses with the later-developing splanchnocranium (de Beer 1937), indicate a zone of stress with a risk of dysostoses and fractures. The dorsal ossification of cartilaginous nasal septum and conchae found in the open nasal bone type (Nygrén *et al.* 1990) may indicate a repair process occurring after failure of the nasal region suturation, intended to strengthen this biomechanically critical area. However, fusiform spindle-shaped blastems reported by Markens (1975), which were presumed to take part in the suturation process in human and rat skull bones, have not been observed in moose embryos.

According to the fringe patterns observed by screw sampling the moose skull, the fresh skull was more flexible than after subsequent defleshing and drying. This test also showed that the direction of the fresh bone surface movement may be studied by using dry museum samples, provided that the osseous structures studied are well ossified and suturated.

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