Analysis of Stresses around the Orbit Due to Masseter and Temporalis Muscles Respectively

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Abstract A series of experiment was made for the purpose of clarifying the respective influence in the distribution of stress and internal force, which are produced by the masseter and temporalis muscles in the upper facial skeleton at the action of biting. The experiments were to measure the strains in the macerated skull under static loading. The analyses of stress and internal force were made from the strains measured in the fronto-nasal, fronto-zygomatic, supraorbital and infraorbital regions. They were approximately decomposed according to the force of each muscle. In general, the action of the masseter muscle has a tendency to strengthen the tensile stress, whereas the action of the temporalis has a tendency to strengthen the compressive stress. Basing on the results obtained, some commentaries were done on the functional interpretations in the morphological studies of various authors dealing with the facial skeleton.

INTRODUCTION

It is commonly thought that the form and structure of the facial skeleton are related to the stresses distributed in it. The present author already reported on the experimental analyses of the stress distribution in the human facial skeleton due to the artificially reproduced biting action and discussed on the relationship between the stress and the form of the facial skeleton (ENDO, 1966a, b, 1967a and b). In those reports, the forces of the masseter and temporalis muscles were selected as representing the muscle forces in biting for the simulation of the muscle forces in order to reproduce the main power in chewing action. In the experiment, both kinds of force were applied simultaneously to the skull.

However, in the morphological reports dealing with the structure of the facial skeleton written by various authors, the stress due to the masseter muscle and that due to the temporalis muscle were sometimes separately treated, basing on merely assumption or imagination. Such discussions were often erroneous. It is mainly because the decomposition or separation of the stresses in a single body according to each of the external forces is difficult and also because such an attempt requires sufficient knowledge on the mechanics of the elastic body, especially, in the case of the complicated structure and force system as seen in the bone.

PURPOSE

The purpose of the present investigation is to analyse the influence of each
force of the masseter and temporalis muscles on the stresses in the human upper facial skeleton, which are produced by the biting action, by means of the statical experiment of the macerated skull. It is consequently aimed to establish some biomechanical bases for the morphological discussion on the form and structure of the human facial skeleton in relation to the mechanical influence of the masseter and temporalis muscles.

MATERIALS AND METHODS

Materials consisted of three macerated skulls of the recent Japanese male belonging to the Departments of Anthropology and Anatomy, the University of Tokyo.

The apparatus for simulating statically to the biting action in the macerated skull was identical to that reported elsewhere (ENDO, loc. cit.). In the present investigation, the following external forces were applied to the skull in the apparatus:

1. Force vertical to the plane of the dental arch on an arbitrary tooth \( P_d \).
2. Forces corresponding to those of the masseter muscle of both sides in the case of experiment to investigate the stress due to this muscle \( P_{rm} \) and \( P_{lm} \); forces corresponding to those of the temporalis muscle of both sides in the case of experiment to investigate the stress due to this muscle \( P_{rt} \) and \( P_{lt} \); or both kinds of force in the case of experiment to investigate the stress in the normal biting action \( P_{rm}, P_{lm}, P_{rt}, \) and \( P_{lt} \).
3. Forces corresponding to those produced at the mandibular fossa by the pressure of the condyle in the actual biting action \( P_{ra} \) and \( P_{ta} \).

In the apparatus, \( P_d \) was applied to the skull as an external load and the other forces were produced as the reactions of the apparatus against the skull.

In the case of the set of forces including either one out of \( P_m \) or \( P_t \), the forces become as

\[
\begin{align*}
\sum P &= P_d + P_{rm} + P_{lm} + P_{ra} + P_{ta} = 0 \\
\sum M_i &= 0,
\end{align*}
\]

where \( M_i \) is the moment of each force about an arbitrary point in the skull. Only \( P_m \) or \( P_t \) were arranged as \( P_{rm} = P_{lm} \) or \( P_{rt} = P_{lt} \), when \( P_d \) acted along the median sagittal plane.

In the case of the set of forces including both \( P_m \) and \( P_t \),

\[
P_{rm} = P_{rt} \quad \text{and} \quad P_{lm} = P_{lt},
\]

were conditioned (see ENDO, 1966a). Thus,

\[
\begin{align*}
\sum P_{ij} &= 0, \quad i = r \text{ or } l \quad \text{and} \quad j = m, t, d, \text{ or } a \\
\sum M_{ij} &= 0.
\end{align*}
\]

\( P_d \) was constantly 4.0 kg through the experiment.

Thus, three kinds of the application of external forces were carried out to the skull. This means that the first experiment produced the biting action exclusively by means of the masseter muscle; the second experiment did it only by means of the temporalis muscle; the third did it by means of both the muscles, being roughly similar to the actual biting action. The former two biting actions never happen under the normal living condition. But these procedures are use-
ful in order to analyse the component of stress of the respective muscle. The loading of the skull described above is schematically illustrated in Fig. 1.

The stress itself in the bone is very hard to be observed, because the bone is anisotropic and heterogeneous. But the strain is measurable which has a close relationship to the stress even under such conditions. Hence, the direct object for the analysis in the present investigation is the strain.

Strains were measured by means of the electric wire strain gauge SHINKOH S121 by amplifying through SHINKOH LT. The accuracy of the measurement of strain was $1 \times 10^{-6}$. The gauge was glued onto the skull by the adhesive cement of nitrocellulose, SHINKOH K-4. The measuring points on the skull are shown in Fig. 2. These points were arranged along and 3 mm inside the orbital margin and around the margin of the cross-sections of $N_1$, $Z_2$ and $MZ_1$ which were determined in order to obtain the statical character of the fronto-nasal, fronto-zygomatic and infraorbital regions respectively. The gauges in these cross-sections were directed in parallel to the longitudinal axis of each region. For the explanations readers are referred to the previous report (ENDO, 1966a). In the cross-sections, the point

Fig. 1. Three kinds of force application for the analyses of stress.

Above, for the analysis of stresses due to the masseter muscle; middle, due to the temporalis muscle; below, due to both the muscles, i.e., due to the biting action approximated to the living body. Canvas sheets are attached instead of the muscles for producing simulated muscular forces. Signals, see in text.
RESULTS

Measurement of strain

It was already reported elsewhere (Endo, 1966a) that the strain in the upper facial skeleton varied to some degree from experiment to experiment, from individual to individual, and from tooth to tooth loaded.

The definite character of the strain at a certain point was, nevertheless, obvious. Sometimes the difference in strain in different time of practice of the experiment was obscure, probably owing to the error in the experimental procedure. But when the experiment was repeated, the tolerable tendencies of the strain distribution in three cases of the application of the forces could be recognized.

The high magnitude of the strain at an arbitrary point of the upper facial skeleton is generally seen in the loading on a tooth of the same side as the measuring point. The importance of the strain in relation to the strength of structure of the facial skeleton may be thus limited to the case of the loading on the teeth of the measuring side. The following results are concerned, therefore, with the strain when the load was applied onto the teeth of the measuring side.

General view The distribution of strains in the case of the application of the force corresponding to that of the masseter muscle, that of the force corresponding to the temporalis muscle and that of the forces of both the muscles, in general, showed approximately the same pattern and no fundamental difference between them. Only the magnitude of strain was variable. These facts indicate that the deformation of the structure of the upper facial skeleton is principally the same in these three cases. As a whole, the strains in the case of the application of the force corresponding to the masseter muscle tended to shift towards the tension, and on the contrary, the strains in the case of application of the force corresponding to that of the temporalis tended to shift towards the compression. The strain in the case of application of the forces corresponding to both the muscles became roughly the mean of the above-mentioned two values.

Orbital margin Strains along the orbital margin obtained in the case of application of the forces corresponding to those of both the muscles were distributed as shown by the broken line in Fig. 3 in an exemplary case. This kind of the strain distribution was already reported and dis-
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cussed elsewhere (ENDO, 1966a).

In the case of application of the force corresponding to that of the masseter muscle, the compressive strains along the supero-medial to medial margin and the margin from the lateral region to the infero-lateral corner were decreased as compared with the above case. On the other hand, the tensile strains along the lateral half of the superior margin and the medial half of the inferior margin were increased, especially, the strains in the former reached to a remarkable magnitude as compared with the other strains. In the case of application of the force corresponding to that of the temporalis muscle, the strains tended to shift reversely. The compressive strains were increased, whereas the tensile strains were decreased. Curiously, the strain at the infero-lateral corner was decreased in these two cases.

Nearly the same results on the difference between the latter two cases were already obtained by KASHIMA (1965).

Fronto-nasal region An exemplary case of the distribution of the longitudinal strains over the N1 cross-section in this region is shown in the diagram N1 in Fig. 4. All the diagrams in this figure show the distribution in loading on the left first premolar. The magnitude of the strains in the case of the application of the force...
Fig. 4. Distributions of the longitudinal strains over the cross-sections of N₁, Z₂ and MZ₁.

Mt, in the case of the application of the forces corresponding to the actions of the masseter and temporalis muscles; M, in the case of the masseter muscle; T, in the case of the temporalis muscle.
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corresponding to that of the masseter muscle was slightly shifted towards the tension as compared with the case of both the muscles. On the contrary, the strains in the case of application of the force corresponding to that of the temporalis muscle were slightly shifted towards the compression.

**Fronto-zygomatic region** The longitudinal strains over Z2 cross-section in this region (Fig. 4-Z2) were also shifted towards the tension in the case of application of the force corresponding to that of the masseter muscle as compared with the case of both the muscles. The strains in the case of application of the force corresponding to that of the temporalis muscle were shifted towards the compression. In this region the shifts were marked.

**Infraorbital region** The magnitude of the tensile strains normal to the upper part of MZ1 cross-section in the case of the application of the force corresponding to that of the masseter muscle was remarkably increased, as compared with the case of both the muscles. But the magnitude of the strain at the lower end of the cross-section in the former case was not markedly different from the magnitude of the latter case. In three specimens, both the strains were roughly same, or difference

Fig. 5. Schematical illustration of the internal forces around the orbit in man.

Above, internal forces due to the action of the masseter; middle, due to the actions of the masseter and temporalis muscles, i.e., due to the biting action in the living body; below, due to the action of the temporalis muscle.

C, compressive force; T, tensile force; ?, unknown; M, bending moment; N, Z2 and MZ, supposed cross-sections.
between them seemed to fall within the range of error.

In the case of application of the force corresponding to that of the temporalis muscle, the strains in the upper part were markedly shifted towards the compression as compared with the case of both the muscles. Also the magnitude of the strain in the lower end of the cross-section was not markedly different from the magnitude of the latter case.

**Stress concentration**

The distribution of strain mentioned above is approximately parallel to that of stress from the theoretical viewpoint. The concentrations of tensile stress in the regions of the lateral part of the supraorbital margin and the medial part of the infraorbital margin are markedly more pronounced due to the action of the masseter muscle than that of the temporalis muscle. The stress concentration in the fronto-nasal region may be slightly more pronounced by the action of the temporalis than that of the masseter.

**Internal forces**

In the morphological papers dealing with the mechanical aspect of the form of bone, there were often seen the discussions using the concept of the "force". Under the static condition, the force in a body has always another force with the same magnitude having the reverse sense in the same direction. Thus they form a couple of forces: action-reaction. As to discuss the mechanical condition of a body by means of the concept of the force, we must deal with the couple of forces. The couple is usually termed "stress" in another usage, "Schnittkraft" (cross-sectional force) or "Internal force". The last is used in the present report. There are three kinds of internal forces: the axial force (compression or tension), shearing force and bending moment.

In the present investigation, it is hard to calculate the value of the force from the strains obtained. However, it is possible to estimate the approximate distribution of the internal forces from the strains as was done elsewhere (Endo, 1966a).

But the present investigation is chiefly concerned with the axial force and bending moment, because the experimental results were insufficient for making out the shearing force. The axial force and the bending moment estimated as below are schematically shown in Fig. 5.

**Fronto-nasal region** The longitudinal strains distributed over N1 cross-section in the case of application of the forces corresponding to those of both the muscles indicate that the fronto-nasal region is intensively acted on by a compressive force and a bending moment having the horizontal but obliquely directed axis in the biting action. This estimation was already reported elsewhere (Endo, loc. cit.). The distribution of the same kind in the respective external forces corresponding to the action of the masseter muscle and that of the temporalis muscle suggest that the compression may be a little more intensively produced by the action of the temporalis muscle than that of the masseter muscle.

**Fronto-zygomatic region** The strain distribution over Z2 cross-section in the case of both the muscles points out that the
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part near the cross-section is acted on mainly by a relatively strong bending moment. Considering the magnitude of the extreme fibre strains on both sides, the bending moment has its axis almost normal to the facial surface of the bone as seen in Fig. 3-15 in the previous report (Endo, 1966a). Strains in the case of each of the muscles indicate that a tension is produced in addition to the bending moment by the masseter, and a compression by the temporalis. These facts were also detected by Kashima (1966). In the same side as the loaded tooth, both the axial forces almost nullify each other in biting action due to the simultaneous action of both the muscles. As the respective bending moment due to the masseter and temporalis has approximately the same direction and sense, the resultant bending moment is increased on the contrary.

**Infraorbital region** From the strains over MZ1 cross-section it is concluded that the infraorbital region is acted on mainly by a bending moment in the case of both the muscles. This region may also be comparable to a sort of the beam acted on by the bending moment. But the region is considerably wide (high), and consequently the simulation to a beam is theoretically limited, especially with respect to the axial force. Nevertheless, the strains in the respective case of the masseter and temporalis indicate that the axial force on this cross-section becomes more tensile due to the masseter, whereas more compressive due to the temporalis. These facts are also indicated by the distribution of strains along the orbital margin. These occurrences of the axial force may be produced by the approximately vertically directed bending moment which may be understood from the difference in the sagittal inclination of the direction of these muscles: the masseter is posteriorly tilted and the temporalis, anteriorly.

**DISCUSSION**

With respect to the statics of the elastic body, there are three kinds of concept on the force. They are the external force, internal force (Schnittkraft) and stress. The external force is the force in the usual meaning; the internal force is produced by the external force within a body as a couple of forces and has three kinds as mentioned before; the stress, being shearing or normal, is a couple of forces over the unit area of an arbitrary cross-section. These three concepts must be definitely distinguished when concerned with the statics of structure to avoid the confusion of argument. For example, Ehara (1969 and 1970) recently developed the detailed discussion on the structure of the superior and lateral orbital regions of the primates in relation to the force of the chewing muscle, but he made some unsuitable and incorrect interpretations owing mainly to the lack of definite distinction of these kinds of force, although he attempted to make a very attractive argument. Besides, this kind of inference is rather little successful. The argument must be developed on the basis of the results obtained from the mechanical experiment, as is always done in the field...
of the engineerig. Mechanics of the body is not so simple as is deduced from the observation of the form and structure as well as from the consideration.

Most of authors concerned in former times, Görke (1904) above all, considered that the upper facial skeleton was subjected to the vertical compression between the forces on the teeth and from the temporalis muscle and that it resisted against this compression principally with three columns. However, as already pointed out by the present author (Endo, 1966a), the upper facial skeleton is principally the rigid frame structure having the closed spaces of the orbits and piriform aperture. In the case of the rigid frame the internal force most decisive on its strength is the bending moment, not the tension or compression. Furthermore, even in the case of the long bone the same is true, as repeatedly asserted by Pauwels (1948 etc.) and Kummer (1959 etc.). The remarkable occurrence of the bending moment in the long bone was observed in simulative experiments by many authors such as Pauwels (loc. cit.), Kummer (loc. cit.), Kimura (1966) and Knief (1967). All in all, the discussion on the mechanically viewed structure of the facial skeleton is unfitting or even erroneous without paying attention to the action of the bending moment. Görke (loc. cit.), Sicher and Tandler (1928), Tappen (1953) and Ehara (1969 and 1970), all lost sight of the bending moment in their discussions, especially in the discussion in terms of the force (may be internal).

Again, when a rigid frame is acted on by the external force, bending moments were produced all over the structure except for few special cases. In the facial skeleton in biting action, whether it is acted on dominantly by the force of the temporalis or by the force of the masseter, the bending moments are always produced, being similarly distributed as described before. Subsequently the distribution of stress is also similar, only the magnitude of the stress is to a certain degree different. Moreover, the stresses in a single elastic body under the static condition can not be theoretically separated from region to region according to each external force such as the forces of the masseter, of the temporalis, on the biting tooth and on the mandibular fossa in this case. The external force has always the reaction and the both are balanced. Most of the above authors made such a mistake.

The tension can be also produced in the facial skeleton as is often done in the rigid frame structure. On this point Tappen (1953) had keen eyes to suggest the presence of the tension in the infraorbital and zygomatic regions.

Besides, many authors such as Görke (loc. cit.) and Sicher and Tandler (1928) underevaluated the action of the masseter muscle, which exercises the markedly large influence over all part of the upper facial skeleton. The importance of this influence was also pointed out by Tappen (1953).

**Supraorbital region**

The considerable magnitude of the tensile stresses is produced in the region
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along the lateral part of the supraorbital margin as already reported by the present author (1960, 1965 and 1966a) and also by KASHIMA (1965, 1966a and b). Hitherto, this fact was almost unaware among the morphologists. The presence of these tensile stresses indicates that GÖRKE's scheme for the interpretation of the internal forces in this region is incorrect. This tensile stress is markedly strengthened by the action of the masseter muscle as described in the present paper.

As already reported (ENDO, 1966a), this tensile stress is produced by the bending moment which becomes to disappear around the mid-point of the margin, where a sort of the point of inflexion is seen. The region medial to the above is subjected to the reversely sensed bending moment. Subsequently, the compressive stresses appear along the margin, whereas the relatively intensive tensions of principal stress as the extension of the tensile stresses along the lateral part of the margin appear around the region of the Arcus superciliaris. The same kind of the occurrence of the tensile stress was of course observed also in the skull of Gorilla (ENDO, loc. cit.). This occurrence in the primates is also suggested by EHARA (1970) from his morphological study. All these tensile stresses are produced by the deformation of the orbital frame due to the external shear between the force acting on the tooth and the forces of both the muscles (ENDO, 1965). Only the force of the masseter plays the most important role, at least, in the case of the human skull.

**Fronto-nasal region**

This region, being columnar in shape, is acted on by the remarkable compression as well as the remarkable bending moment as reported by the present author (1965 and 1966a). On the former point, the idea of the compressive pillar (Druckpfeiler) is correct. This compression is produced by the actions of both the muscles. But almost all the reports except for that by KASHIMA (1966) neglected the occurrence of the bending moment in this region, which is rather of more importance.

Going into further details, however, the distribution of the longitudinal strains over N1 cross-section show some difference from the simple inclination of the magnitude due to a bending moment as is sometimes distinct (ENDO, 1966a) and shown in Fig. 4. This distribution may indicate the association of the other factors. The stress concentration in the notched part may be slightly produced. On the other hand, the nasal root is supported by two processes of the maxilla. Subsequently, two different bending moments are transferred into this region, and this column is too short to be compared with the beam. Thus the stress distribution may be somewhat different from the typical pattern. Besides, KASHIMA (1965, 1966a and b) asserted that the central part of the facial skeleton is acted on by the horizontal compression approximately along the frontal plane and that subsequently the nasal root is subjected to this compression. This may be related to the peculiar distribution of strains over N1 cross-section which is often observed and seen in Fig. 4. His
opinion may be correct. But in his experiment the load on the teeth was symmetrically applied. This condition of the force is unusual in the biting of the living body. Consequently, the strain distribution obtained from his experiment may be to a certain degree different from that in the living body. In the former case, the strains related to the transverse deformation of the facial skeleton, which is common in the latter case, may disappear.

**Fronto-zygomatic region**

The present and previous results indicate that the internal force which acts on this region is principally the bending moment, and the axial force may be very weak or almost absent in biting action. If the force of the temporalis muscle markedly exceeds that of the masseter muscle, a compression is produced. In the contrary case, a tension occurs. But they must be considerably weak as compared with the bending moment. Therefore, this region can be compared with a beam subjected to the bending moment. On this point, most of the interpretations on the mechanical character of this region made by various authors such as GÖRKE (*loc. cit.*), BENNINGHOFF (1925), and TAPPEN (1953) are incorrect.

However, TAPPEN (*loc. cit.*) indicated the presence of the tensile force due to the masseter muscle, which appears by overcoming the compression due to other forces, from his results on the split-line orientation. His opinion is more progressed than the simple opinion that this region is a sort of the compressive pillar or column. With respect to the stress, in fact, the tensile stress is produced at least in the lateral half of this region by the bending moment and perhaps the weak tension. As against the opinions of TAPPEN (*loc. cit.*) and EHARA (*loc. cit.*), the bending moment producing the tensile stress is provoked by both the masseter and temporalis muscles as shown in the present investigation, whenever the latter originates only from the high region near the *Linea temporalis*. The same is the case of the Gorilla (ENDO, 1966a), and this fact implies that the same may be seen in the other primates skull relatively similar to that of Gorilla in shape. The absence of the idea of the bending moment seems to cause the mechanically curious interpretation by EIHARA (*loc. cit.*), although he reached to an opinion of the presence of the tension in the lateral part and of the compression in the medial part in primates skull. As against his assumption, the tensile stress is produced not mainly by the tension due to the masseter muscle but principally by the bending moment related to the deformation of the frame around the orbit. And this deformation is provoked by the action of both the muscles. On this point his interpretation is incorrect.

BENNINGHOFF (*loc. cit.*) and TAPPEN (*loc. cit.*) asserted clearly the parallelism between the split-line and the line of principal stress. But there have been strong objections from the field of biomechanics against this opinion (PAUWELS, 1949; EVANS and GOFF, 1957). In a rough sense, however, the present author is also affirmative
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As TAPPEN (loc. cit.) indicated, the region below the orbit is acted on by the tensile stress. The whole infraorbital region can be compared with a short and wide beam subjected mainly to the shearing force and bending moment, as reported elsewhere (ENDO, 1966a). The occurrence of this bending moment based on both the masseter and temporalis muscles is described in the results of the present investigation. But the tensile stresses in the region of the infraorbital margin becomes remarkably intensive by the action of the masseter muscle probably due to the bending moment of another kind. This fact affirms the statement of TAPPEN (loc. cit.). In his illustration the split-lines in this region seem again roughly parallel to the lines of the absolutely maximum stress of the principal stress.

Provided also that the surface relief "Reliefmodellierung" or "-struktur" by VOGEL (1965) is parallel to the orientation of the split-lines as he asserted, his statement on the pathway of the Sutura zygomatico-maxillaris becomes of interest. As is seen in Fig. 4-17 and 18 of the report of the present author (ENDO, 1966a), most of the sutures in the upper facial skeleton are located in the regions which correspond to the point of inflexion of a member of rigid frame structure. This is also the case of the Sutura zygomatico-maxillaris. At the point of inflexion, two groups of the line of stress cross each other at a right angle. As previously illustrated (ENDO, 1966a and b), in the infraorbital region of the human skull the tensile stress points from supero-

to the presence of rough parallelism so far as the upper facial skeleton is concerned (ENDO, 1966a, b and 1967) and so is KASHIMA (loc. cit.), although the exact parallelism can be denied both theoretically and experimentally. This problem is still unsolved.

Provided that the above-mentioned rough parallelism is true, the split-lines in this region must be separated into two groups: the split-lines corresponding to the tensile stress from the medial part of the zygomatic process of the frontal bone passing through the latero-central part of the fronto-zygomatic (lateral orbital) region to the region adjacent to the origin of the masseter; and the split-lines corresponding to the compressive stress beginning in the region near the orbital margin at the level just below the Sutura frontozygomatica and passing through along the lateral part of the infraorbital margin. Thus, these lines may become roughly parallel to the lines of principal stress (those of the absolutely maximum) which are concluded from the strain distribution. As the present author reported (ENDO, in press), this region is very similar in shape to the beam of uniform strength. In this kind of beam, the majority of the lines representing the absolutely maximum stress of principal stress is parallel to the longitudinal axis of the beam. Consequently, there is rather little contradiction against the parallelism, in spite of the fact that the orientation of all the split-line is almost parallel to the longitudinal axis of the zygomatic bone.

Infraorbital region

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medial to infero-lateral direction whereas the compressive stress does from infero-medial to supero-lateral direction. But these directions in the Gorilla are considerably different as seen in the former report, roughly corresponding to the different orientation of the split-line shown by TAPPEN (1957). Besides, the remarkable width of this region may make more complicated stress distribution than that at the point of inflexion of the beam. On this point VOGEL's report may be of interest in regard to the difference in distribution of stress in various structures of the facial skeleton among catarrhine primates. But it seems that this kind of stress distribution does not depend directly on the action of each muscle but on the stiffness and arrangement of various parts of the facial skeleton.

**SUMMARY**

The following brief results were obtained from the experimental analysis of the stress in the human facial skeleton by means of the loading on the macerated skull simulated to the biting action:

1. As to the orbital margin, the intensive tensile stresses are produced along the lateral part of the supraorbital margin and the medial part of the infraorbital margin. They are largely due to the action of the masseter muscle. Intensive compressive stresses along the other parts of the margin depend more largely on the action of the temporalis muscle.

2. The fronto-nasal region is subjected to the intensive axial force and bending moment produced by the action of both the muscles. But the axial force may be produced slightly less by the masseter than the temporalis.

3. The fronto-zygomatic region is acted on mainly by the bending moment due to the actions of both the muscles. The action of the masseter produces a tension to a certain degree, whereas that of the temporalis does a compression. The simultaneous action of both the muscles in biting action makes these forces cancel each other to become approximately null.

4. The infraorbital region is subjected to a bending moment produced by both the muscles. In addition, the action of the masseter muscle produces a tension in the region of the infraorbital margin, probably due to another bending moment.

**LITERATURE CITED**


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眼窩周辺の応力における咬筋と
側頭筋の各影響の分析

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顔面頭蓋に関する形態学的論文には、しばしばその力学的構造を論じているものが見られる。そのような議論には、材料力学あるいは構造力学の立場からみて、一般的に不正確な記述が多き、またはしばしば誤った解釈が展開されている。この種の議論においては顔面頭蓋に対して välgeの時働く一覧の力が、ひとつの力系としてとらえられず、別個にとらえられて、それらによって生ずる骨格断面の力（内力）あるいは応力の分布を各力に対応する断面に分割する傾向がある。正確にいえばこの方法自体が誤りである。しかし、あらかじめ近似としては成立することもある。

筆者（ENDO, 1965, 1966a, b）は、すでに、ひとつの系としての咬合のときの頭骨に加わる外力群下に生ずる顔面頭蓋応力の実験的解析を行った。これに述べたように議論に対応するため、これに、実験によって咬筋の作用による応力成分と側頭筋の作用による応力成分の分析を試みた。

実験に使われた資料は現代日本人成人男子顔頭骨3個体である。実験においては、まず生体において咬むときと働く咬筋と側頭筋の力を静力学的に近似推定し（ENDO, 1965a），そのいずれかの力あるいは両方の力と顔間筋部に加わる力，歯を加わる力との間で平衡させた。これらの力を頭骨に加えて，そのとき生ずる頭骨の眼窩周辺の各性状を測定した。測定された歪にもとづいて咬むときに生ずる応力状態を知り，その応力の各筋の力による成分を近似的に分析した。この実験の結果は、したがって，従来行われてきた形態学の立場からの顔面頭蓋の形態の力学的解析に対して，力学の立場から批判と基礎を与えるものである。

結果を要約すると次の通りである。

1. 一般的に，咀嚼のとき顔面頭蓋眼窩周辺に生ずる応力あるいは内力の分布様式には，咬筋の力によるそれとの間に側頭筋の力によるそれとの間にも大きな差はなく，ただし応力値・内力値には変化がある。

2. 眼窩上縁－外側頸部には線に沿って引張応力が生ずるが，この応力は咬筋の力に負うところが大きい。この応力は眼窩上縁ならびにラーメン構造の変形により生ずるものである。直接的にはこの部分の曲げモーメントに由来する，位置が近いかなて側頭筋の張力に直接由来すると考えるのは，少なくともヒトの場合は誤りである。

3. 前頭－鼻部 この部分には垂直接線力と水平で斜め方向に軸をとる曲げモーメントが働く。軸力については側頭筋の力の影響が強い。しかし，構造に与える影響は曲げモーメントの方が全体に強いのが通説である。したがって，曲げモーメントが無視された従来の形態学的研築は誤ったところが多い。

4. 前頭－頸骨部 この部分では外側面にほぼ沿って変形を起こす曲げモーメントが主である。軸力については，咬筋の力を引張りと側頭筋の力による圧縮が同時に生ずるため，このふたつの力が相殺してほぼ消失する。したがって，この部分においては，変形力や圧縮力の存在を重視して議論することは誤りである。

5. 眼窩下部 この部分には曲げモーメントと剪断力が生じ，そのため眼窩下縁に侧頭筋に引張応力が現われる。更にこの部分には咬筋の力によって，別の曲げモーメントに由来すると思われる引張が生ずる。以上の結果にもとづいて，GÖRKE（1908），BENNINGHOFF（1925），TAPPEN（1953，1957），EHARA（1969，1970）等の顔面頭蓋の形態学的研究における力学的解析を論評した。