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Experimental Examination on the Effects and Adaptation Condition of the Fibula Excision Method Using the Stress Freezing Method on the Osteoarthritis of the Knee

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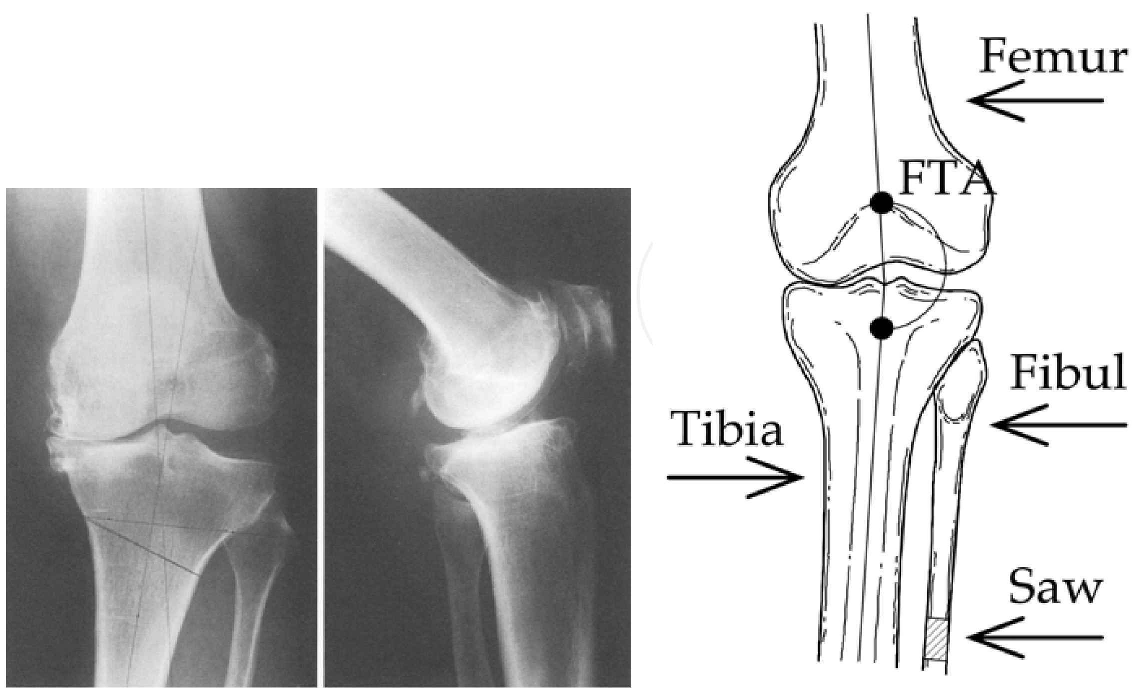
1. Introduction

The knee joint is a joint where arthropathy occurs frequently. Osteoarthritis of the Knee (: Knee OA) is the most important typical joint disease. In the medical orthopedics field, 900 thousand people regularly go to the hospital annually, of which the frequency of senior citizens is high. Conditions of deformations, such those of the cartilage between the knee joints, wearing out are common. Among Japanese people, pain is common on the inside of the knee. Depending upon the advancement of Knee OA, there are times when walking becomes difficult. The diagnosis of Knee OA generally measures leg alignment. Especially FTA, which measures the angle of the femur and the tibia that form the knee joint, provides a guide for the decisive deformation type and operation invasive quantity through measuring fixed quantities. In FTA measurement, a normal knee shows 172°~176°, inside contravariant shape knee arthropathy (O leg) is above 180°, and outside contravariant shape knee arthropathy (X leg) is below 170°. From previous reports of Knee OA types, among Japanese people, inside contravariant shape knee arthropathy (O leg) is common, and among Europeans and Americans, outside contravariant shape knee arthropathy (X leg) is common. When a mechanical factor related to the cause is common, therapeutic reform of the mechanical state becomes the main purpose. Implementation of operations, such as High tibial osteotomy (: HTO), total knee arthroplasty and (: TKA), in addition to minimally invasive surgery (: MIS), is sometimes necessary depending upon the condition.

Fig.1 shows the Osteoarthritis knee method and fibula excision method. The operation considers for four conditions: (1) The skin it is a little ardently, (2) the damage to the soft section organization is only a little, (3) the bleeding quantity is small, and (4) the bone excision is only a little. Operation requires that all above conditions be satisfied. Along with these four conditions, for the patient there are five: (1) operation time is short, (2) after operating, the pain is light, (3) the operation marks must be small and clean, (4) recovery is quick, and (5) economic burden is light. Presently, there is a fibula excision method for one operation technique of MIS. The object of this operation technique system is inside contravariant shape knee arthropathy (O leg). Especially, from the present condition where a large majority of patients are senior citizens, an optimum operation technique system will have the lowest physical strength burden on the patient. In this technique system, the fibula is revised so that the alignment of the legs reaches the normal position. However, the remedy guidelines of deformation characteristic arthropathy are being investigated presently in the Japanese medical orthopedics field. Especially, the occasion where engineering new technology is introduced in the future, reports regarding physicians on site, where engineering knowledge and experience influence the result, are many in number. For example, the excision quantity, detection angle, etc, of specifications and the bone positions of the affected parts examination and operation invasive quantity decisions, etc, are made at the time of planning before the operation.

In this research, the fibula excision method, which is an MIS was examined. This experiment dealt with the knee joint of a normal state and Osteoarthritis of the Knee before the operation and after the operation. The experiment supposed one foot standing and concerned the resultant stress state. Grasp of the mechanical state is important in operation, so this is useful as a mechanical guide at the time of planning before operation. In addition, mechanical examination of this operation system which can lighten physical strength burden with aging patients as a quite urgent characteristic is high.

Therefore, the remaining state of FTA and the meniscus, which are diagnostic guides of Osteoarthritis of the knee, influence the results of clearing for operation. A hybrid experiment used the 3-dimensional stress freezing method and a pressure gauge to examine the effectiveness and application condition of the fibula excision method.



(a) Osteoarthritis of knee method (b) Fibula excision

Fig. 1. Osteoarthritis of knee method and fibula excision method

2. FTA, Mikulicz lineand and osteoarthritis of the knee

2.1 FTA, Mikulicz line

In the knee joint, the inside type (O leg) or outer part type (X leg) in the guide, are used for making a decision. An example is shown in Fig.2 of two Tsugas of FTA and the Mikulicz line. FTA is the angle which consists of the extended shaft direction of the femur and the tibia seen from the front. As for FTA of a normal knee, the range is 173° to approximately 176°. The inside type (O leg) for FTA is above 180°, and the outer part type (X leg) for FTA is below 170°. It is something which the Mikulicz line, the line which ties the thigh antique center and the foot joint center, displays for the leg load line in the standing position. Specifically, this is the line condition of the legs under the arrangement state of the pelvis, femur, tibia and ankle. A normal knee passes by the fog and outside from the center of the knee. As for an O leg, from the center of the knee it passes on the inside. In this research, FTA was utilized, and the leg alignment was decided. Among reports of Knee OA types, in Japanese people, the inside contravariant shape Osteoarthritis of the knee (O leg) is common, and among Europeans and Americans the outside contravariant shape Knee OA (X leg) is common.

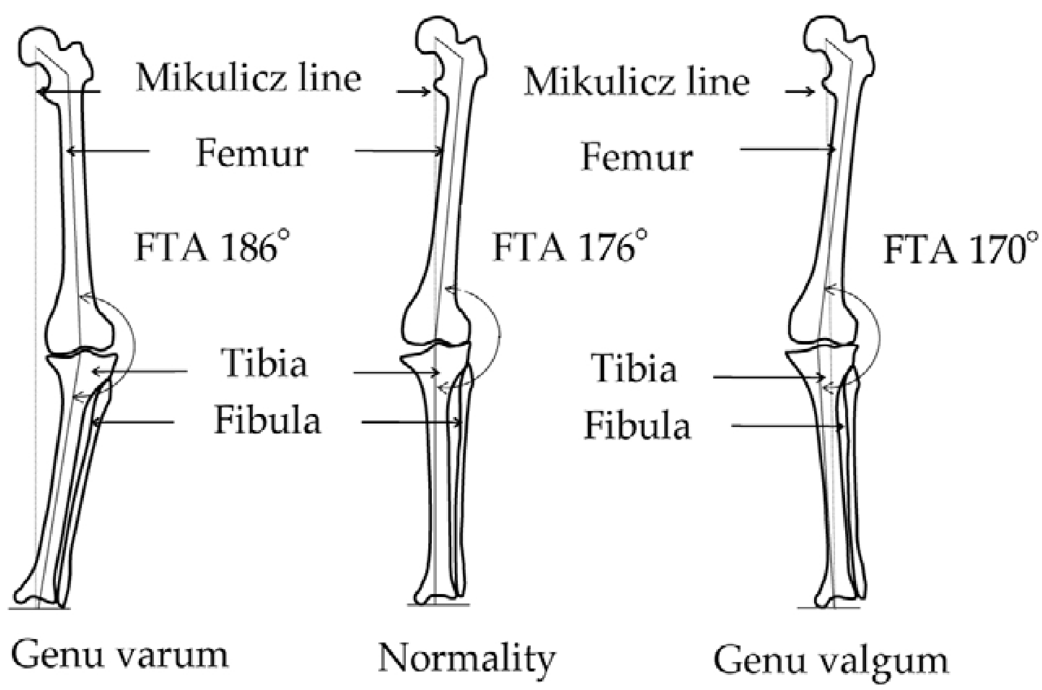


Fig. 2. FTA and Mikulicz line

Osteoarthritis of the knee is classified from appearance and inspection results; inside contravariant shape Knee OA (O leg) and the outside contravariant shape knee arthropathy (X leg). As dangerous factors of emergence there exists: history of external wounds, arthritis, age and obesity as four characteristic items for which Knee OA risk is increased. The emergence ratio becomes high from around 40 years old, and the frequency which emerges in senior citizens is high. As for the male to female ratio of patients, male : female = 1: 4. As a cause, mechanical factors are pointed out (e.g., stress concentrated inside the knee such as an imbalance of muscular strength or becoming fat).

3. Photoelastic theory, experimental model and actual model by epoxy resin

3.1 Photoelastic theory

The similarity rule is generally utilized for model production and analysis method. Production and an experiment must consider and satisfy the following conditions. (1) The experimental model and actual model from examination and supposition must be within the limit of elasticity, (2) Similarity of experimental model and actual model, (3) agreement of load point, load distribution and similarity, (4) similarity to Poisson's ratio ν. Then, when all conditions are satisfied, even with high polymer materials such as the epoxy resin, which was used for the experiment, the stress distribution of actual model of steel, alloy and concrete, etc, agrees. In addition, experimental values which can match the stress values of the actual model by conversion are possible.

However, like this experiment in the case of 3 dimensional photoelasticity, there are times when it does not agree to these under heating. It is necessary to know the characteristics and coping methods of the materials.

(1) the experimental model and examination within the elastic limit of the apparatus are supposed, and (2) the experimental model and similarity of the apparatus, are faults for the stress freezing process with respect to the relationship which utilizes the elastic body of the rubber condition, whereby the elastic coefficient is vitrified because it becomes 1/100, and deformation is easy to become large. In addition, the size of the model differs before the stress freezing and after the freezing, with error due to change in size being easy to occur. There is a deformation revision method as the expedient which removes these faults. This method, expecting the deformation quantity of the specimen beforehand, produces a model of the form which it revises, and stress freezing it is the method for the occasion of making a specified size. With this method, the error which originates in the deformation of geometric form can be made rather small.

As for the photoelastic experiment, other experimental stress analyses inside it are not possible for a single form to discover the pattern of analysis and entire stress distribution of stress simply. On the other hand, an experimental value which utilizes these features has recently become necessary, with experimental stress analysis it is the most effective method.

In addition, the numerical analysis with FEM has become easy, but the experimental data from which photoelasticity in the verification for supporting numerical analysis is of importance.

When analyzing the stress distribution of three dimensional structures, a stress freezing process which utilizes the characteristics of the epoxy resin is generally used, where the epoxy resin reaching a temperature above approximately 120 °C causes a second order transition, and the condition becomes rubber elastic. The load is loaded above this temperature. It makes the temperature fall to approximately room temperature. A distortion state occurs in the rubber elastic range under freezing. As for this distortion removing the load, it continues under freezing. In order to measure this distortion, the model after the stress freezing is sliced into approximately 5mm wide slices. The photoelastic device shown in Fig.3 was used. As for the distortion, which became an isochromatic fringe pattern depending upon the polarized light. Fig.3 shows the construction of the photoelastic device where S is the illuminant, L and L2 are the field lenses, P is the polarizer, A is the analyzer, and Q1 and Q2 are the quarter undulation plates.

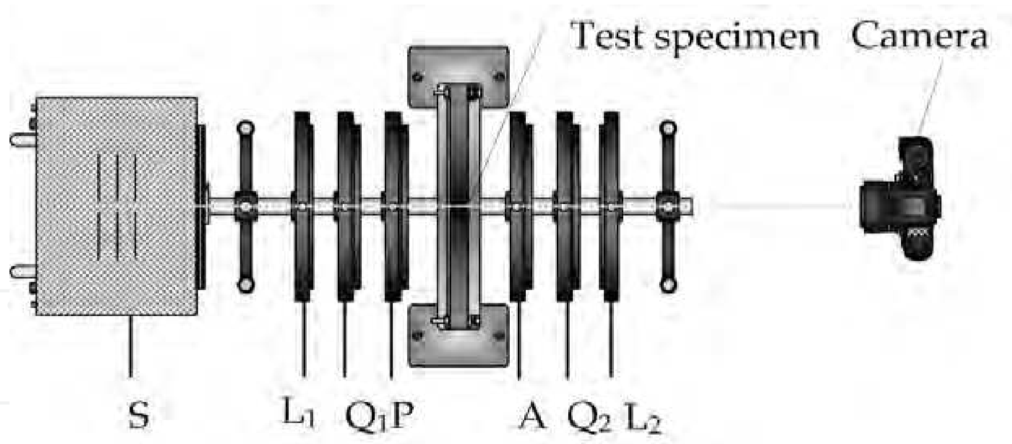


Fig. 3. Circular polariscope

Fringe order and the relationship of principal stress which occurs becomes (1).

$$N = \alpha t(\sigma_1 - \sigma_2) \quad (1)$$

Here, for the N fringe order, t is the thickness of sliced specimen, α is the photoelastic sensitivity, and σ_1 and σ_2 are the principal stresses inside the slices.

In addition, with respect to free boundaries, the σ_1 each of σ_2 becomes 0. Therefore, through (2) the stress state can be known.

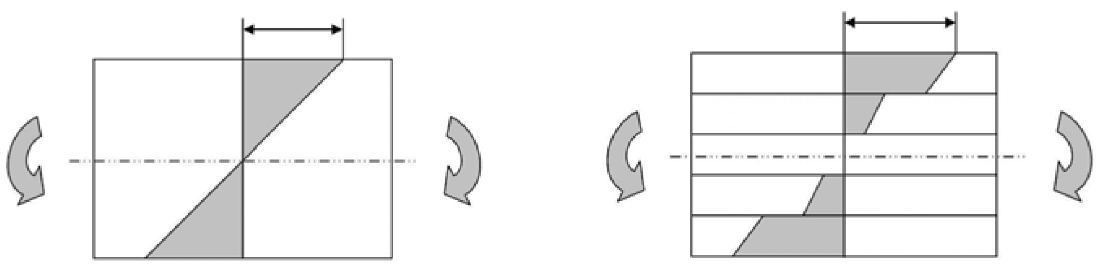
$$\sigma = N/\alpha t[\mathrm{MPa}] \quad (2)$$

3.2 Material error of relation between experimental model and actual model

The epoxy resin of the photoelastic material used as the test material is an isotropic homogeneous body, but the organism bone (sponge bone and fine bone, from marrow constitution) is an anisotropic heterogeneous body. Due to this, error occurs in the comparison analysis of the material and the heterogeneous material of which Young's modulus, *E*, is homogeneous. Depending on this, examination becomes necessary by use of epoxy resin concerning the quantitative error of the bone.

Concerning this, Nishida allotted the epoxy resin of Young's modulus, *E*, which differs by layer, and a bend experiment which imitated the bone was performed. The design of the experiment is shown in Fig.4. As a result of the experiment, the error of Young's modulus, *E*, was calculated to be 10% when the experiment was performed on a solid monolayer structure. As the quantitative error is small, quantitative reproducibility can be expected. In addition, for the dynamic quality of the bone, due to a characteristic difference and personal equation, for the femur of an adult male 30~50 years of age, an average tension of 137.30MPa, an elastic limit of 100.82Mpa, and a recovery factor of the distortion due to stress relief with extension of 0.0125 have been reported as representing 95% or more.

As for the bone, to think of the body as being composed of photoelastic material and use a photoelastic experiment is favorable. This method, which is a powerful experimental analysis method in stress distribution visualization of the whole bone, was adopted on the basis of these reports. In addition, mechanical characteristics of the silicon rubber which was used in this experiment showed a hardness of JIS A43, a tensile strength of 2.2MPa, and a growth rate of 170%.



(a) homogeneous (b) unhomogeneous

Fig. 4. Difference between experiment and model

3.3 Experimental summary

3.3.1 Test material and test pieces

In this research, experimental analysis which used three-dimensional stress freezing was performed. A specimen model of the framework which forms the left side of the knee joint ,including the femur, tibia and fibula, was produced using actual equipment and material, making use of the medical organism skeletal model,. The test material selected was an epoxy resin (mixed weight ratio; ARALDITE B CT200: HARDENER HT901=100: 30). The normal temperature (25°C) and high temperature (128°C) against mechanical quality are shown in Table 1.

Organism bone is generally formed by marrow, etc, which does not bear stress from the fine adrenal cortex section and the porous spongin section, and furthermore, shows rigidity. Therefore, it is not possible to handle the homogeneous body, and in addition, the modulus anisotropy of elasticity and strength regarding the same adrenal cortex section must be considered. However, the aforementioned has reproducibility concerns, and error in this research is due to the layer system, so a 3 dimensional photoelastic experimental model was produced as a solid structure.

	Normal temperature [25°C]	High temperature [125°C]
Modulus of longitudinal elasticity *E* (MPa)	2940	13.62
Modulus of transverse elasticity *G* (MPa)	1131	4.59
Poisson's ratio ν	0.30	0.48
Photoelastic stress sensitivity α (mm/ N)	0.1	4.0

Table 1. Properties of the epoxy resin

3.3.2 Experimental method

In this research, the skeletal structure of the knee joint was reproduced, making use of a specimen model of the framework which forms the left side of the knee joint, including the femur, tibia and fibula. The framework for reappearance consisted of the knee joint of the femoral model and the fibula combined with the tibia model. In order for more accurate vertical load to be imposed, the muscular part was produced using silicon as the jig. In the case of stress freezing, 107.8N was loaded as a freezing load. In reappearance of joint cartilage, clay for ceramic art with a hardness of HS29 (Sculpey III American poly- form the corp.) was used. The specimen model is shown in Fig. 5, and the load device is shown in Fig. 6.

After the stress freezing ended, for the standing position state, especially when the FTA was maintained, slices of a 5mm thickness were made. Slices were made from the front of the knee, with the inside as a standard. The slice direction is shown in Fig. 7 (a), and a slice is shown in Fig. 7 (b) and (c).

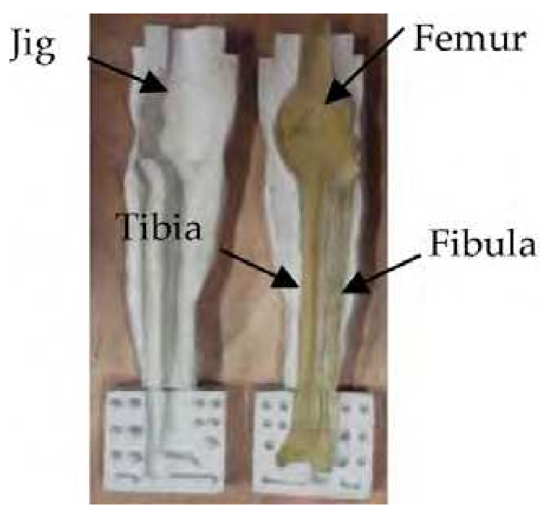


Fig. 5. Model specimen

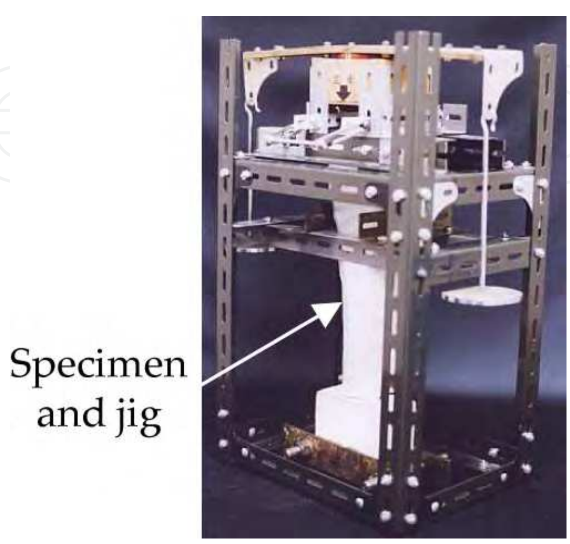
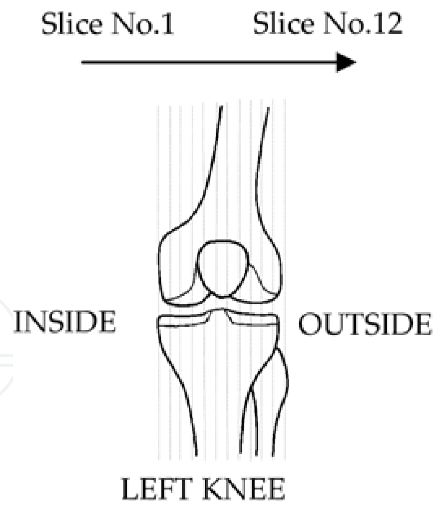


Fig. 6. Load device



(a) Slice position

(a) Slice of femur

(b) Slice of tibia

Fig. 7. Model slice

4. Relation experimental results converted to actual model

As for stress distribution, if the apparatus and the figure are similar, the distribution is the same regardless of material. However, as it is a model experiment, when Young's modulus, E, differs, conversion of the obtained experimental value and the stress value of the apparatus are necessary. Therefore, a photoelastic material of which the Young's modulus, E, of the apparatus was known was inspected.

Concerning this, a system for the conversion of the stress value obtained from the experiment to the stress value of the actual bone is plural, and was implemented into the program conversion. Here, subscript experiment values: *ex* is the value of the actual bone: *a*.

4.1 Experimental value for the calculation method regarding the stress value of the actual bone

As an outline, the case of a plane surface stress state is written. The ratio, L, of length of the actual model and the experimental model is expressed by (3).

$$L = \frac{Actual\ size}{Experimental\ size} \tag{3}$$

The relation of (4) gives the length ratio, L, of the error ratio and load, W, of the respective stress value, σ, for the model. Depending on this, the stress value for the error ratio, K, of the actual model and the experimental model becomes (5).

$$K = \frac{\sigma_a}{\sigma_{ex}} = \frac{W_a}{W_{ex}L^2} \tag{4}$$

$$\sigma_a = K \cdot \sigma_{ex} \tag{5}$$

Generally, for a three dimensional photoelastic experiment, if Poisson's ratio, v, is almost identical to the experimental result and analogy is for conversion to the apparatus such that:

$$\nu_{ex} \cong \nu_a$$

In the three dimensional problem, it designates the ratio of the length of the model as L_{ratio}, as shown in (6).

$$L_{ratio} = \frac{Experimental\ size}{Actual\ size} = \frac{L_{ex}}{L_a} \tag{6}$$

where the area ratio, A_{ratio}, and specific volume, V_{ratio}, are given by (7),

$$A_{ratio} = L_{ratio}^2,\ V_{ratio} = L_{ratio}^3 \tag{7}$$

and the load ratio, W_{ratio}, given by (8) becomes similar,

$$W_{ratio} = \frac{Experimental\ load}{Actual\ load} = \frac{W_{ex}}{W_a} \tag{8}$$

so that the stress ratio, σ_{ratio}, (9) can be given by:

$$\sigma_{ratio} = \frac{\sigma_{ex}}{\sigma_a} = \frac{W_{ex}}{W_a}\left(\frac{L_{ex}}{L_a}\right)^2 \tag{9}$$

For conversion to the stress ratio σ_{ratio}=1, knowing a more accurate stress value is desirable, so it is necessary to consider the experimental load well. In addition, after drawing up a stress distribution chart, because the experimental load is computed from Fringe Order, the experimental stress value, σ_{ex}, of the actual bone stress value, σ_a, can be calculated by (10).

$$\sigma_a = \sigma_{ex}\frac{W_{ex}}{W_a}\left(\frac{L_{ex}}{L_a}\right)^2 \tag{10}$$

4.2 Experiment value and the calculation method which uses Young's modulus *E* of the experimental model and Young's modulus *E* of the actual bone

The stress value of the actual bone is able to be calculated by the experimental value and the proportional system which uses Young's modulus, *E*. If the actual bone and the experimental model are similar figures, the same stress distribution is given regardless of material. However, when Young's modulus differs, conversion is necessary for the obtained experimental value to give the stress value of the actual bone.

Therefore, for the photoelastic material which is used it is necessary to know the Young's modulus, *E*, of the actual bone which we would like to inspect. Table 3 shows the mechanical characteristics of the femur and tibia. The mechanical characteristics of the epoxy resin are shown in Table 3. For the stress freezing process, Young's modulus, *E*, of the epoxy resin at the time (freezing) of high temperature was used. Therefore, Young's modulus, *E*=13.62[MPa].

	Young's modulus *E* [GPa]	Yield stress [MPa]	Ultimate stress [MPa]
Femur	17s 2	111s 12	129s 6
Tibia	20s 2	124s 8	147s 9

Table 2. Mechanical properties of mechanical characteristics of femur and tibia

	Young's modulus *E* [MPa]	modules of rigidity *G* [MPa]	Poisson's ratio ν	photoelastic sensitivity α [mm/ N]
Normal temp.	2940	1131	0.30	0.10
High temp.	13.62	4.59	0.48	4.00

Table 3. Mechanical properties of the epoxy resin

Proportional system (11) can be converted into formula (12), which substitutes the known Young's modulus, *E*, and experiment stress value, σ_{ex}, respectively, and gives the stress value of the actual bone, σ_a.

$$\sigma_{\max ex} : E_{ex} = \sigma_{\max a} : E_a \tag{11}$$

$$\sigma_{\max a} = \frac{\sigma_{\max ex} \cdot E_{ex}}{E_a} \tag{12}$$

5. Importance of the meniscus

The importance of the meniscus was considered in this experiment. Types I-III were set and compared. The FTA was set at 176°, that of the normal knee, and the meniscus was reproduced using the two materials of silicon rubber and polyurethane resin. In the same way, the meniscus completely wore through, and the femur and the tibia and fibula reached a state where they contacted directly. The laboratory conditions are shown in Table 4, and the experimental parameters are shown in Table 5.

Examples of a photoelastic stripe photograph and a stress distribution chart (principal stress difference at a point of contact) of the femur are shown in Fig. 8. That of the tibia is shown in Fig. 9.

In Fig. 8 and Fig. 9, Types I and II show almost similar stress distribution states. From the fact that the state of the alignment of the normal knee of FTA 176° was reproduced, a normal contact state of the femur, tibia and fibula was established. It was achieved when the meniscus was approximately 60% moisture, much like a sponge which contains water. In addition, there are dynamic functional characteristics of stability for the joint which are quite important for load support, absorption and joint impact load regarding lubrication. For example, in absorbing approximately 20% of the loads which operate the knee joint at the time of knee joint extension, it is thought that it transmits approximately 50%. In addition, it has an influence on the dispersion of the load where the meniscus direction on the outside is thicker than on the inside of the knee joint.

On the one hand, in Fig. 9, Type III can be seen to differ from Type I and II for stress distribution state. In the femur there was a centralization of stress in the contact section, and in the tibia influence in the frame work section was also observed. From this, the meniscus which is between the knee joint not only dispersed the stress of the contact section of the knee joint , but concerning the frame work section, it was found that it plays an important role in bone transmission, e.g., the centralization of stress is eased. A dynamic concentration of stress became a centralized load because it in fact occurred due to a centralized load, and regarding the knee joint, it was found to be in a state where deformation is promoted. In addition, the deformation characteristic of knee OA was the formation of bone spikes, however, it is understood that they were formed due to excessive stress. Type III of the stress distribution state and the stress value reached a higher degree to ease the excess stress, and it is presumed that the location of the bone spike was formed for the purpose of expanding the contact surface area.

Type	FTA	Material of meniscus
I	176°	Silicone rubber
II		Polyurethane
III		No

Table 4. Parameter of Types

Resin	Hardness (JIS A)	Tensile strength (MPa)	Elongation (%)
Silicone rubber	43	2.2	170
Polyurethane	60	15	430

Table 5. Properties of silicone rubber and polyurethane resin

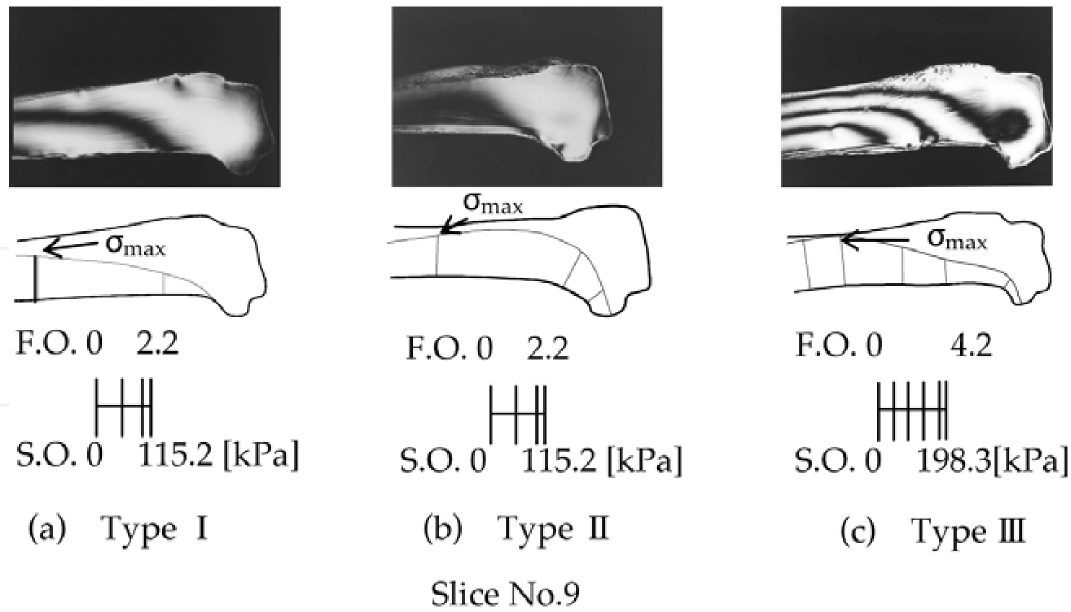


Fig. 8. Isochromatic fringe pattern (Femur)

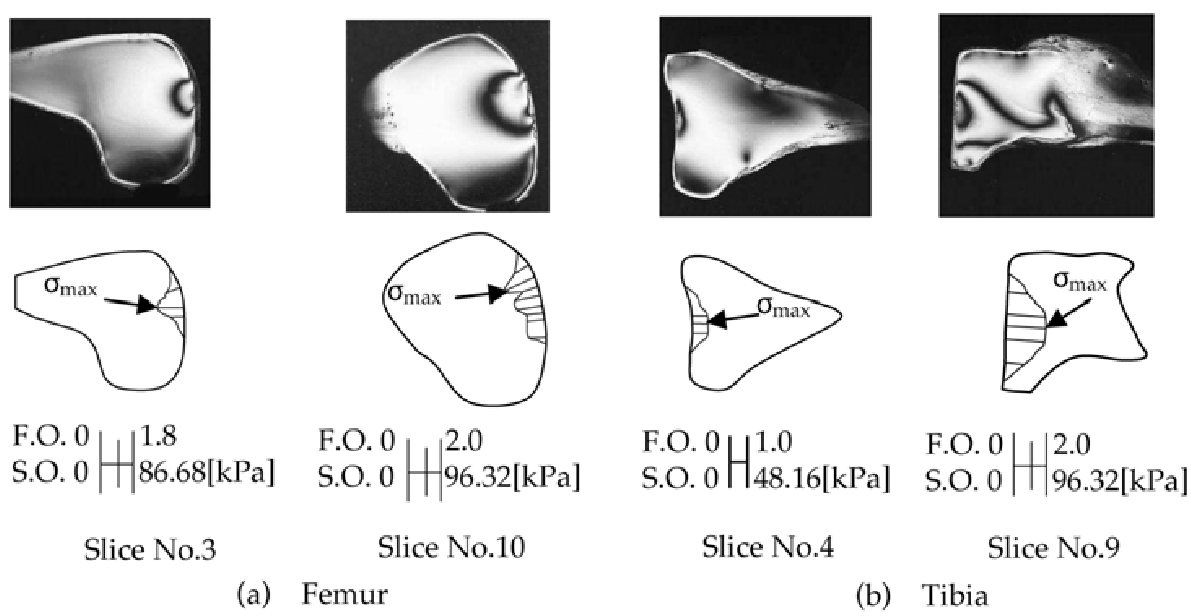


Fig. 9. Isochromatic fringe pattern (Tibia)

6. Examination of the effectiveness of the fibula excision method - Experimental parameter -

In this research, the fibula excision method was examined. The experiment dealt with the knee joint of a normal state, Osteoarthritis of the Knee before and after operation and supposed one foot standing and was concerned with stress state. The state of FTA and remaining meniscus, which are a diagnostic guide of the Osteoarthritis of the knee. In this research examines the influence which these give to an Osteoarthritis of the Knee and operation.

In this experiment, concerning the stress rate, a comparison and examination of a meniscus and the inside of a contravariant shape knee arthropathy (O leg) was done after using the fibula excision method. At that time, the remaining state of the FTA and the meniscus were considered when the laboratory conditions were decided, as shown in Table 3.

Furthermore, the fibula excision method reproduced a state where a 10mm frame work section of the fibula was excised in Types D and E.

Type	FTA	Meniscus	Operation
A	176°	All	No excision
B	186°	All	No excision
C	186°	Half	No excision
D	186°	All	excision
E	186°	Half	excision

Table 6. Parameter of Types A)E

7. Examination of the effectiveness of the fibula excision method -A ~ E type results-

7.1 Mechanical state of a normal knee joint of Type A: Normal knee (FTA176º/extensive meniscus remains)

The isochromatic fringe pattern and stress distribution chart of an example of Type A are shown in Fig. 10 (a) the femur, and (b) the tibia. As for the scale, the upper is the fringe order (: F.O.) and the lower is the stress value (: S.O [kPa]). On the vertical axis are the most compressed stress points, the σmax, and the slice No. are given on the horizontal axis in Fig. 11.

In the femur of a Type A normal knee, regarding Fig. 10, an almost equal stress distribution was shown on the inside and outside. Regarding Fig. 10 (b) of the tibia, on the tibia side, the stress was higher on the inside than on the outside. As for the FTA of 176°, it is thought that this kind of distribution was shown because some of it was transferred to the outer part type (X leg). Regarding Fig. 11, for a normal knee joint, the load was easily imposed on the outside, and the difference of stress which occurred inside and outside was small. Therefore, it was stabilized dynamically. Especially, when the emergence of Knee OA is considered, concentration of stress is difficult to obtain, and wear of the meniscus is thought to not advance.

As for the result, in a healthy knee, for stress to be distributed outside, it must agree with the assumed idea in the orthopedics field that a nearly equal stress distribution is desirable (sharing a load 40 percent inside and 60 percent outside). As the stress value is low overall and the range is wide, the load which falls on the knee joint is efficiently dispersed, making a normal knee joint is stable.

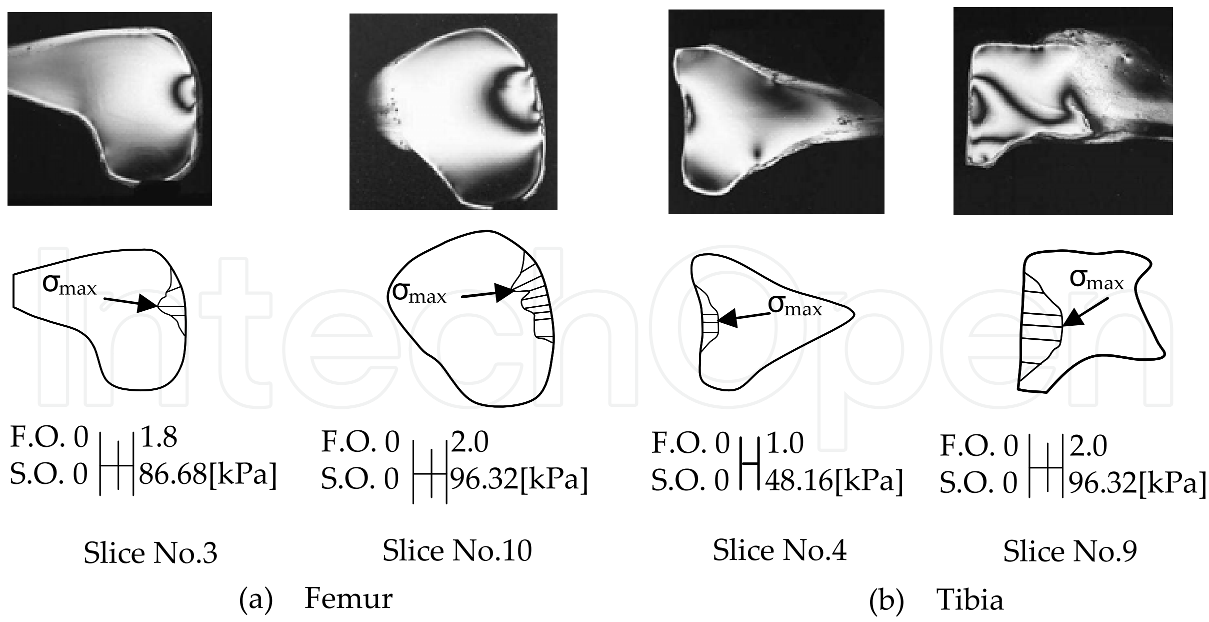


Fig. 10. Isochromatic fringe pattern of Type A

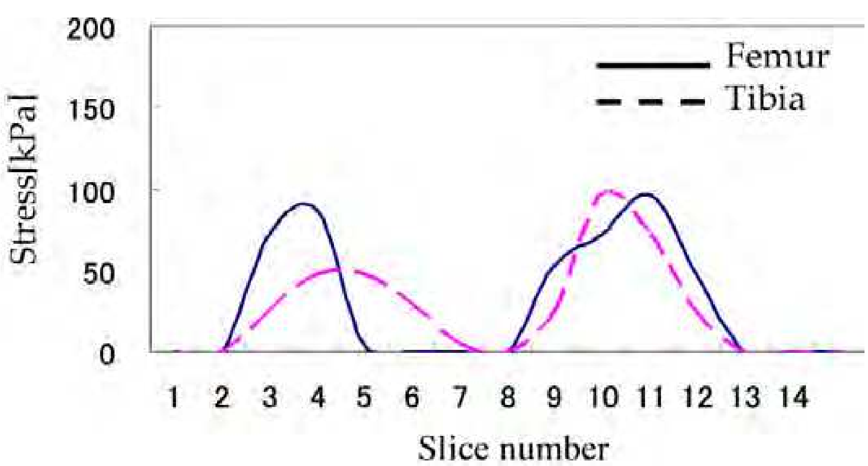


Fig. 11. Stress distribution of Type A

7.2 Contravariant shape knee arthropathy among minor Type B: Osteoarthritis of the knee (FTA186 º/ extensive meniscus remains)

The isochromatic fringe pattern and stress distribution chart of an example of Type B are shown in Fig. 12 (a) the femur, and (b) the tibia. As for the scale, the upper is the fringe order (: F.O.) and the lower is the stress value (: S.O [kPa]). On the vertical axis are the most compressed stress points, the σmax, and the slice No. are given on the horizontal axis in Fig. 13.

In Fig. 12 (b), the tibia, the stress distribution inside the peak of the tibia is narrower than that of Type A. The meniscus extensively remained, but the FTA was 186°. It is thought that 60% of the stress was distributed outside the knee. When walking where impacts occur over time, like the of ascent or descent of a stairway, it is expected that high stress occurs inside the knee. If during this the FTA is not normal, the meniscus cannot disperse the load equally, it is presumed that the change in FTA is strongly related to the wear and deformation of the meniscus.

From the graph in Fig. 13, in the femur, as for stress inside and outside, they were almost the same as in the tibia stress outside. We assumed that in an O leg high stress occurs inside, but, from the result, the cartilage remains even with the O leg, and with the point which only a dead load is loaded, it does not mean that stress is distributed to the inside and outside.

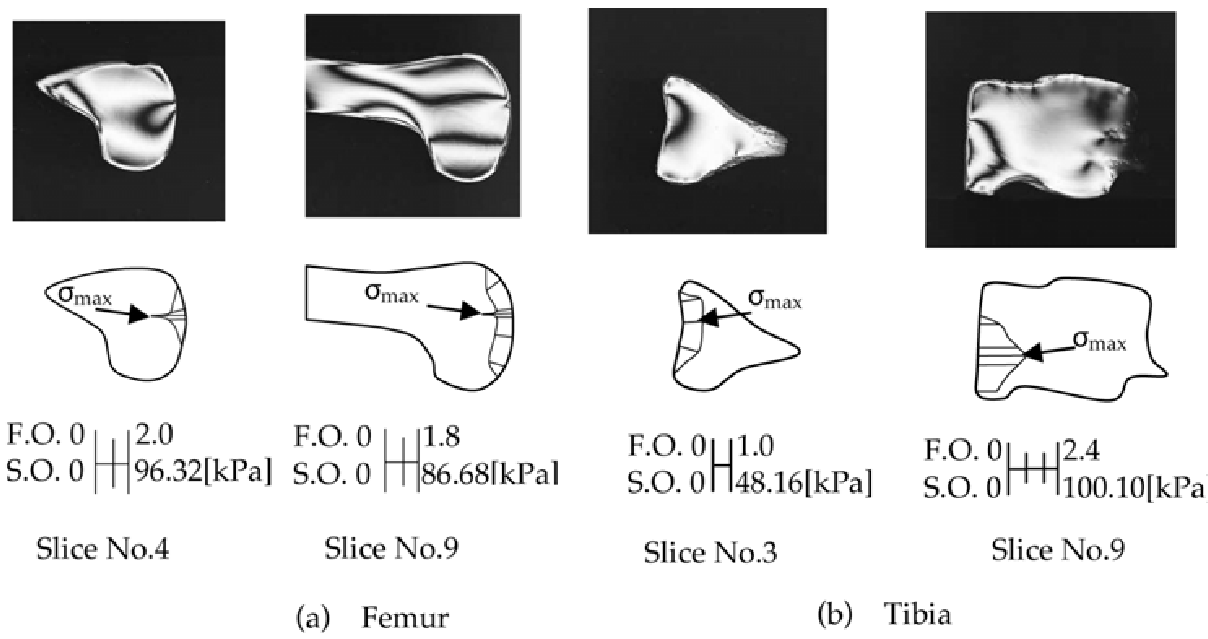


Fig. 12. Isochromatic fringe pattern of Type B

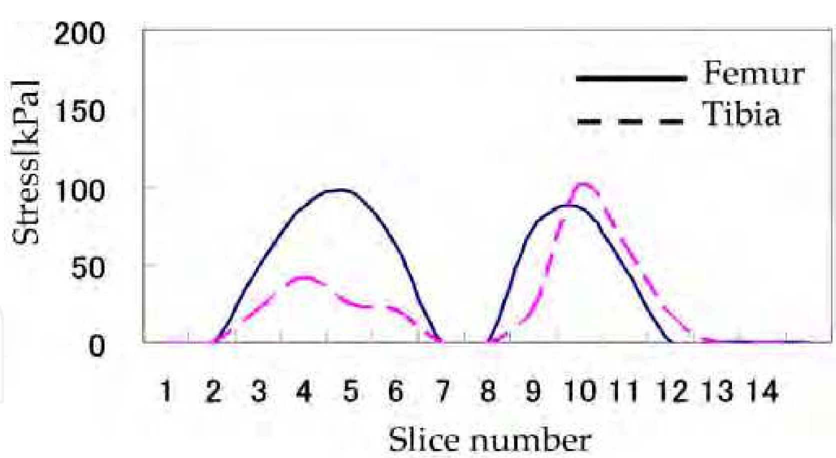


Fig. 13. Isochromatic fringe pattern of Type B

7.3 Type C: Seriousness osteoarthritis of the knee (FTA186°/ on ly outside meniscus remains)

The isochromatic fringe pattern and stress distribution chart of an example of Type C are shown in Fig. 14, the femur, and Fig. 15, the tibia. As for the scale, the upper is the fringe order (: F.O.) and the lower is the stress value (: S.O [kPa]). On the vertical axis are the most compressed stress points, the σmax , and the slice No. are given on the horizontal axis in Fig. 15.

Concentration of stress of higher-order was verified for Type C from Figs. 14 and 15, which show inside the knee where the meniscus disappeared. As for this, the load dispersion role of the meniscus was not fulfilled, and it is thought that the stress was concentrated.

In the tibia in Fig. 16, concentration of stress of higher-order was verified originally in the condylar between bulging sections which existed on the center of the tibia, which did not cause direct contact. This is related to the occurrence of bone spikes which are a feature of Knee OA. These contact states have been expressed as two peaks, one of which is on the left side in the graph. When the meniscus wears, the bones collide, are damaged, and when bending and stretching, the motion causes pain. In the inside contravariant shape knee OA, the result is exemplified by the pain, which agrees with the opinion within the orthopedics field that spikes occur in the condylar between bulging section of the tibia.

Depending, in order for the bone not to contact, it is necessary to perform a remedy which revises FTA and excises the bone spike. The stress which occurs in the knee joint from the abovementioned conditions of Knee OA differs. The stress which occurs in the knee joint from the abovementioned conditions of OA also differs. Especially, as the cartilage wear causes concentration of stress, contact in the condylar between bulging sections occurs, and it is important to prevent wear of the meniscus. FTA is related to the wear of the meniscus, and it is thought that the revision of FTA is connected to preventive methods.

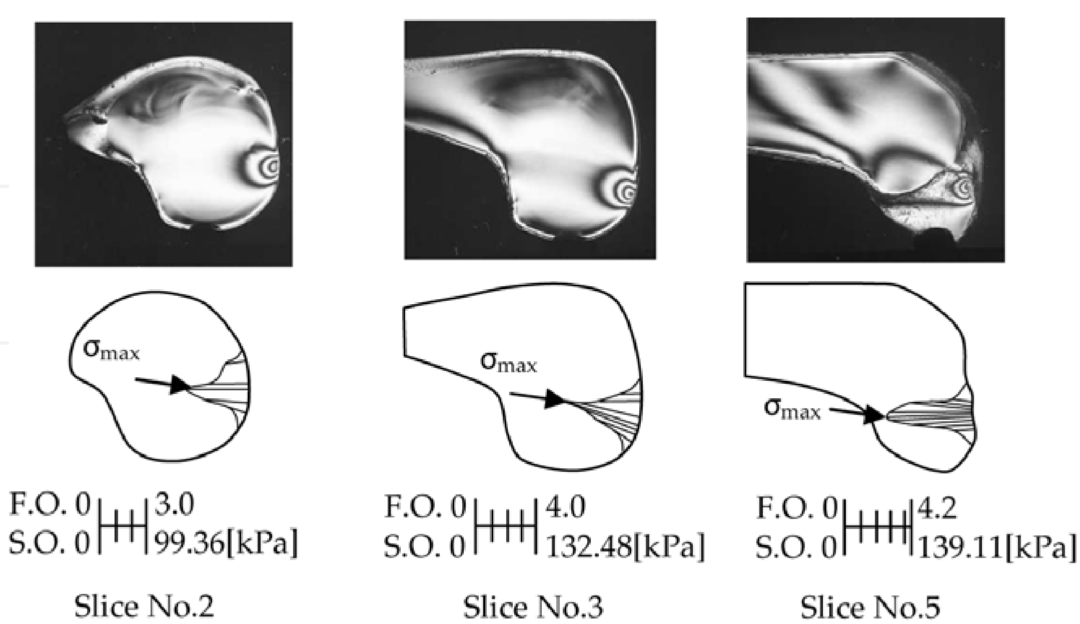


Fig. 14. Isochromatic fringe pattern of Type C (Femur)

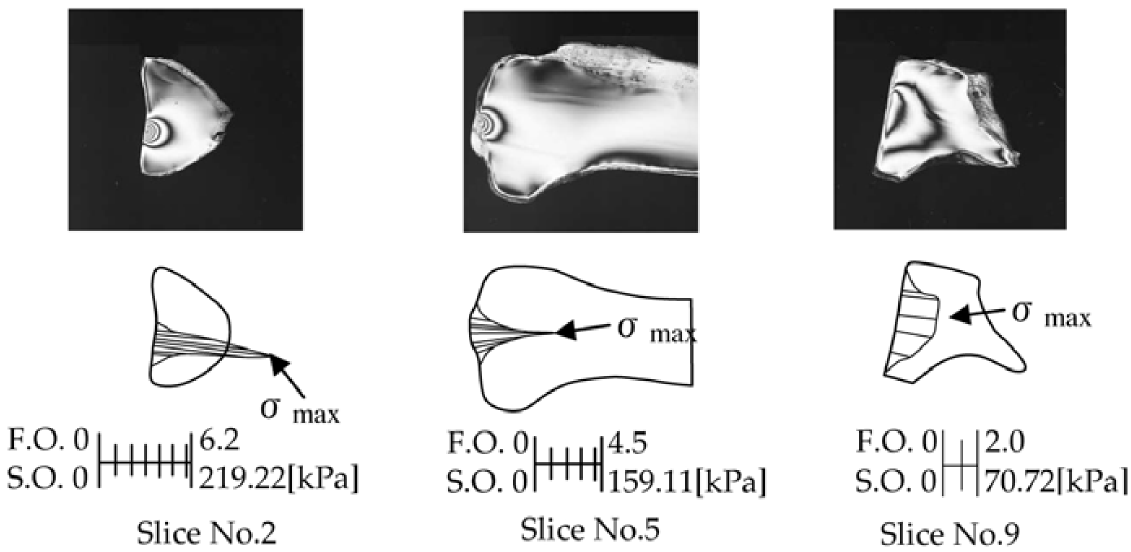


Fig. 15. Isochromatic fringe pattern of Type C (Tibia)

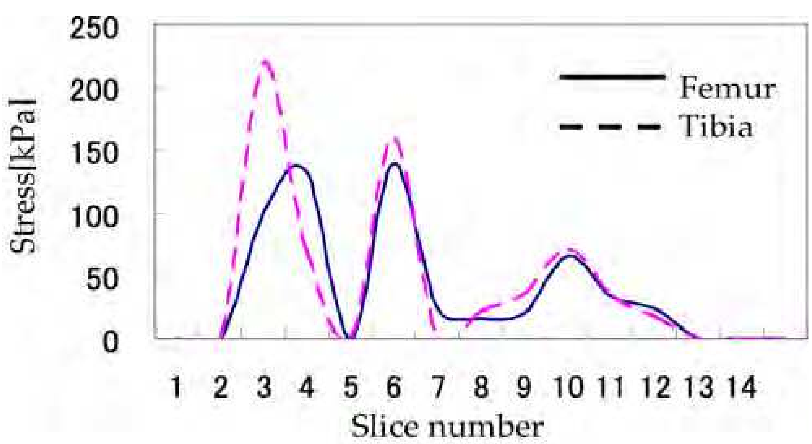


Fig. 16. Stress distribution of Type C

7.4 Type D: After the operation of the fibula excision method for minor OA (FTA176 º/ meniscus extensive remains)

The isochromatic fringe pattern and stress distribution chart of an example of Type C are shown in Fig. 17, the femur, and Fig. 18, the tibia. As for the scale, the upper is the fringe order (: F.O.) and the lower is the stress value (: S.O [kPa]). On the vertical axis are the most compressed stress points, the σmax, and the slice No. are given on the horizontal axis in Fig. 19.

From Figs. 17 and 18, for Type D the stress was distributed equally inside and outside the knee. From Fig. 19, the stress value and stress distribution state were similar to the normal knee (Type A), and were mechanically stability. Correction of FTA was indicated by removal of a fibula. Therefore, the mild OA knee became mechanically stable by the fibula excision method, achieving a mechanical position equal to the normal knee. Depending on the case, the fibula excision method effectiveness is suggested in cases of minor OA knees.

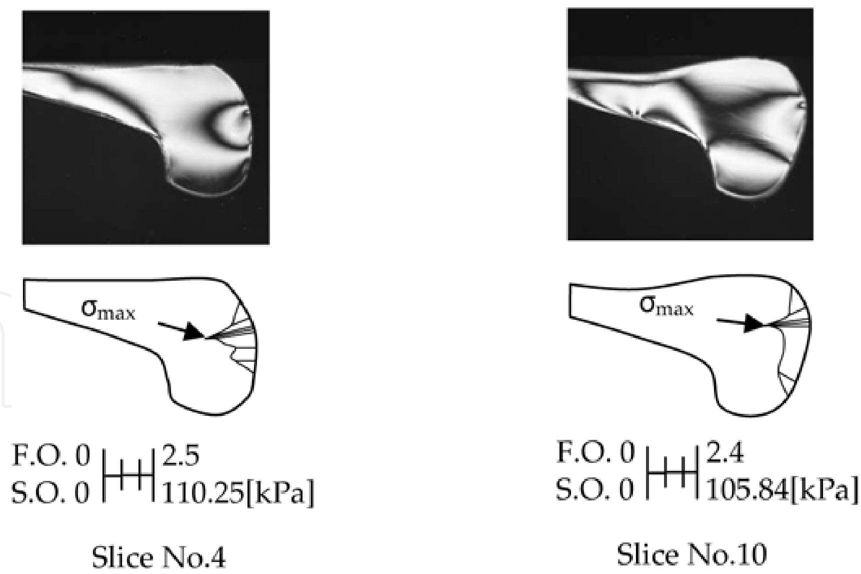


Fig. 17. Isochromatic fringe pattern of Type D (Femur)

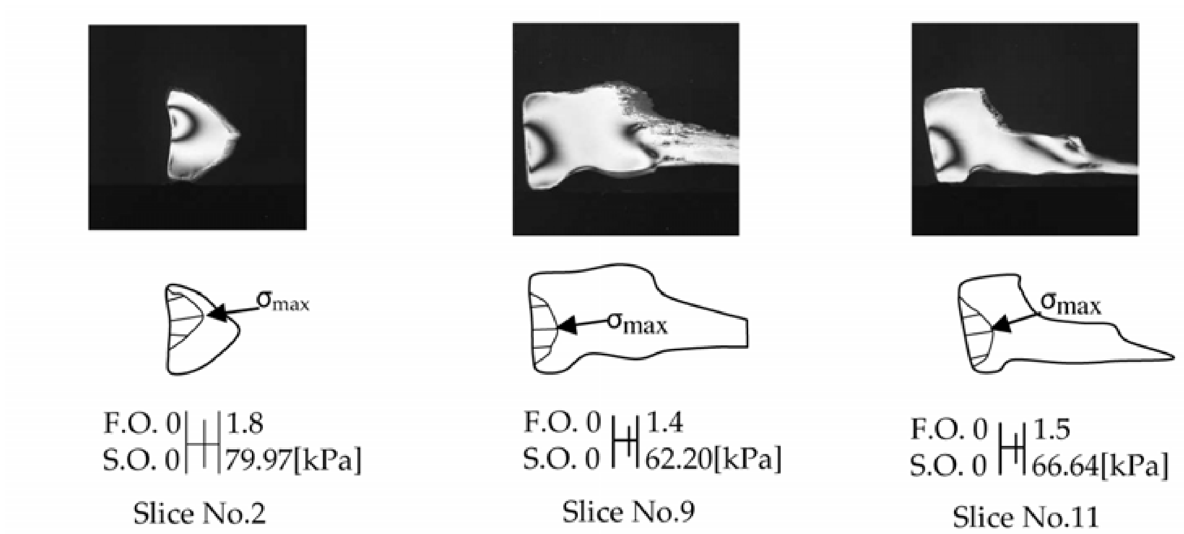


Fig. 18. Isochromatic fringe pattern of Type D (Tibia)

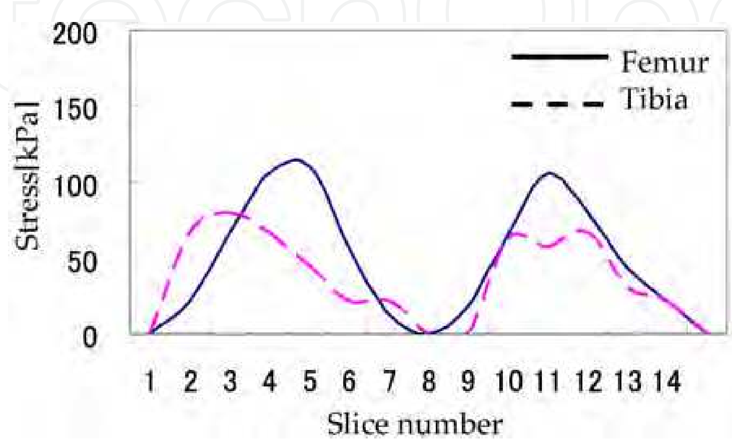


Fig. 19. Stress distribution of Type D

7.5 Type E: After the operation of the fibula excision method for severe osteoarthritis of the knee (FTA176°/ only outside meniscus remains)

The isochromatic fringe pattern and stress distribution chart of an example of Type D are shown in Fig. 20 (a), the femur, and (b), the tibia. As for the scale, the upper is the fringe order (: F.O.) and the lower is the stress value (: S.O [kPa]). On the vertical axis are the most compressed stress points, the σmax, and the slice No. are given on the horizontal axis in Fig. 21.

From Fig. 20 (a), the femur, and (b), the tibia, high order stress concentration was confirmed inside the knee for Type E. In addition, there was concentration of stress on the femur and the tibia. As for this stress distribution state was similar to Type C before the fibula excising, and there was no improvement. However, from Fig. 21, the stress regarding the contact of the condylar between bulging sections of the tibia was not verified to show improvement. From these, there is no improvement in minor Knee OA (Type D) in the contravariant shape knee arthropathy among serious illnesses. Only for the pain of the intercondylar eminence part was the effectiveness observed. However, remarkable improvement for Mild Knee OA cannot be anticipated for Severe Knee OA.

From the above, the fibula excision method is effective as a minor contravariant shape knee arthropathy remedy. In serious Knee OA, the revision of FTA was not obtained at a level of sufficient effect. In serious contravariant shape knee arthropathy, remedy by high tibial osteotomy (: HTO) and similar procedures are presumed to remedy FTA properly. In addition, in performing revision of FTA by the fibula excision method, it was found that the curative effect differs depending upon the state of the remaining meniscus.

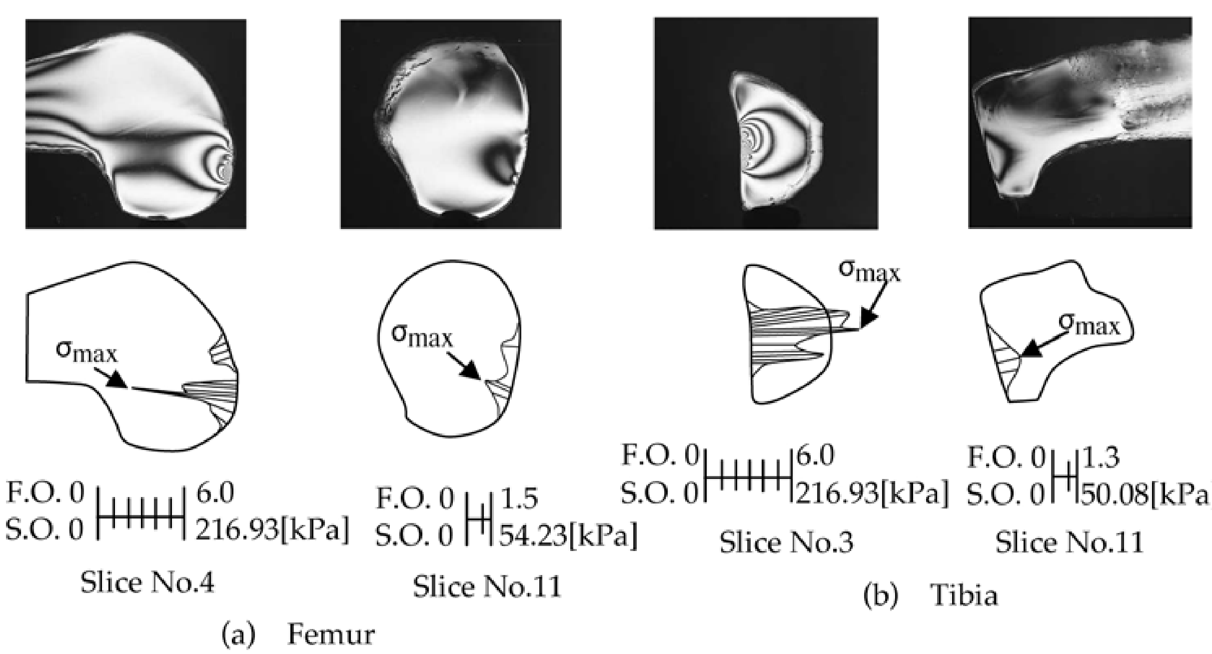


Fig. 20. Isochromatic fringe pattern of Type E

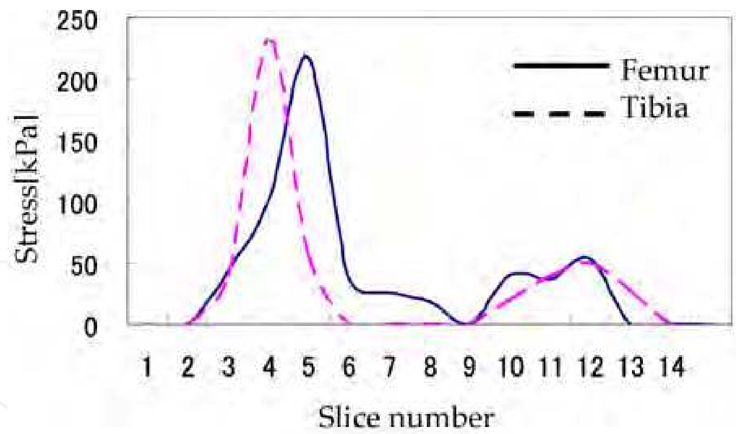


Fig. 21. Stress distribution of Type E

8. Examination about the adaptation condition of the fibula excision method

In this research, other than the photoelastic stress freezing method, pressure of the knee joint was measured by a small-sized pressure sensor. The advantage of using a pressure gauge is that it can obtain results continually. (Segmented type small-sized pressure sensor with a thickness of 2mm and a diameter of 6mm :Kyouwa dengyou * PSM) In this experiment, FTA was changed gradually, and the influence on the knee joint was observed. As for the test-piece, a similar epoxy resin model to that used for stress freezing method was used. Similarly, the amount of remaining meniscus was considered. Similar load equipment and loads 9.8N, which is 1/11 at the time of the stress freezing method from the special quality of the pressure sensor, was used. The pressure sensor was installed in the occurrence position of the principal stress max from the result of the stress freezing method. In Fig. 22 the pressure sensor position and pressure gauge are shown.

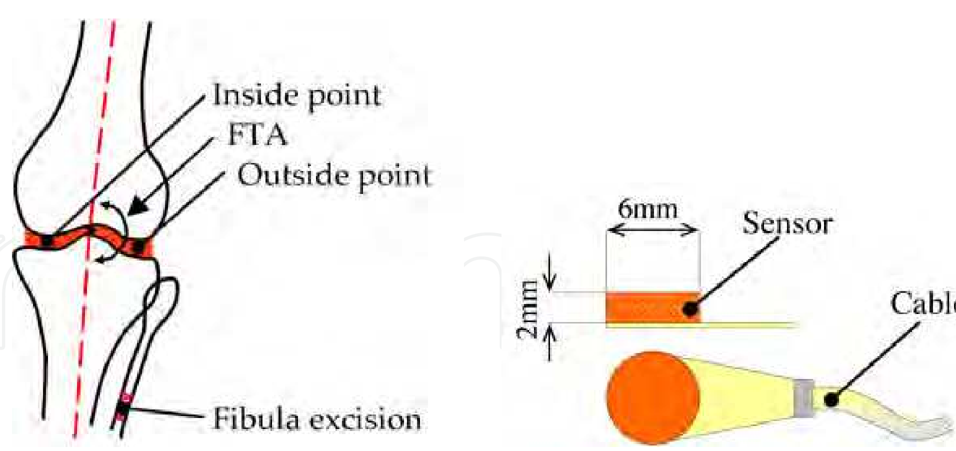


Fig. 22. Pressure sensor position and pressure gauge

8.1 Examination of normal knee joint

Fig. 23 shows the results of the experiment on a normal knee joint. Fig. 26 shows the results after the fibula excision method. In the graph, the vertical axis represents the pressure value, and on the horizontal axis FTA is shown. The solid line indicates inside the knee joint, and the broken line shows the pressure outside.

From Fig. 23, in the healthy knee joint, when FTA was small, (X leg tendency), a small high pressure occurred outside. As FTA (O leg tendency) became larger, it decreased the pressure outside and pressure inside increased. As for pressure inside and outside becoming equal, it was verified that it is at approximately FTA 178°. Optimum FTA, at which the knee joint is stabilized, is therefore approximately 178°. Also, this result was similar to the result in the above photoelastic stress freezing method.

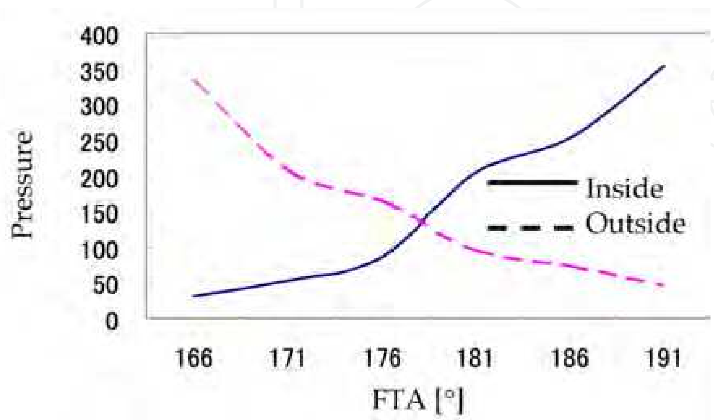


Fig. 23. Pressure distribution of no excision

8.2 Examination after the fibula excision method

From Fig. 24, after the fibula excision method, it can be seen that when FTA was small, (X leg tendency) pressure was increased outside, and when FTA was large, (O leg tendency) pressure increased inside. Pressure inside and outside became equal near the FTA 173°~183°, a wide range compared to before the fibula excision method. As for this, FTA was revised by the fibula excision method, and it is thought that the range of FTA at which the knee joint was stabilized became wide.

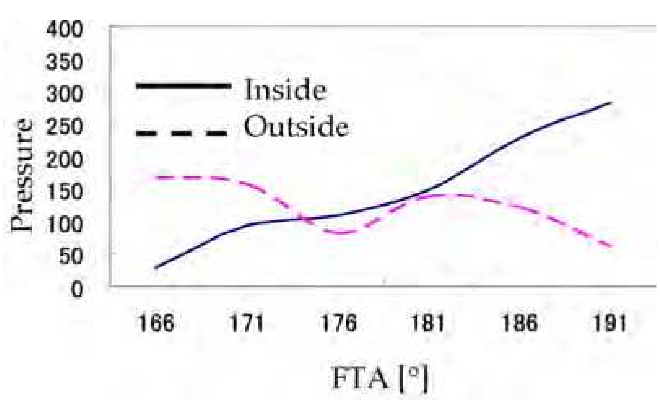


Fig. 24. Pressure distribution of fibula excision

8.3 Examination of FTA and the adaptation condition

The pressures inside and outside the knee were added, and the overall pressure was calculated. The percentage pressure on the inside and the outside were calculated. A result for a normal knee joint is indicated in Fig 25, and that after the fibula excision method is indicated in Fig 26. The vertical axis ratio is the pressure (%), and on the horizontal axis FTA is shown. The percentage on the pressure inside the knee joint is given by a solid line, and the percentage of the pressure on the outside is shown as a broken line.

From Fig. 25, it can be seen that in the normal knee joint, the ratio of pressure inside and outside almost became equal at approximately FTA 178°, but, when FTA changed, that ratio changed suddenly. Especially, the FTA change in ratio was large within the range of 171°~181°. It is thought that 1° or 2° of change in FTA produces a great effect on the knee joint.

However, after the fibula excising, results in Fig. 26, the FTA ratio of pressure was almost 174°~183°, and remarkable reduction in pressure both inside and outside the knee could be seen. The knee joint was mechanically stabilized. In addition, it was found that the pressure which is loaded outside was lightened mechanically. Depending on this, it can be effective concerning the outside contravariant shape knee arthropathy (X leg).

Therefore, as for the fibula excision method, it is thought to be especially effective for adaptation concerning minor OA patients of FTA 174° ~ FTA 183°.

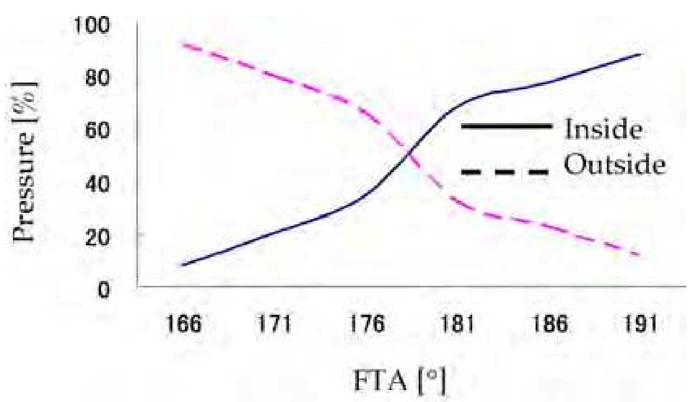


Fig. 25. Percentage of pressure in no excision

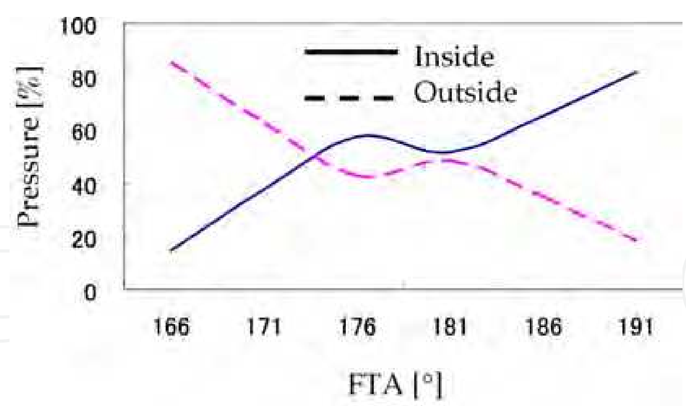


Fig. 26. Percentage of fibula excision

9. Conclusion

In this research, the fibula excision method was examined. The experiment dealt with the knee joint of a normal state, Osteoarthritis of the Knee before and after operation and supposed one foot standing and was concerned with stress state. The state of FTA and remaining meniscus, which are a diagnostic guide of the Osteoarthritis of the knee, clearly influenced the result of the operation.

Experimental conditions of 5 types of experimental hybrids, A-E, used the 3-dimensional stress freezing method and pressure gauge to examine the effectiveness and application conditions of the fibula excision method.

As a result, the knowledge below was obtained:

1. The fibula excision method showed validity for Mild inside type Osteoarthritis of the knee and is suitable for cases of FTA 186 ° and much remaining meniscus.
2. Doing the revision of FTA, the curative effect of the fibula excision method differs depending upon disease condition. The effect is related in the remaining state of the meniscus.
3. As for the fibula excision method, it is suggested to be suited for the remedy of outside contravariant shape knee arthropathy (X leg).

10. Future direction

The photoelastic experiment the analysis of principal stress and singular point is possible too. This analysis is the major feature which only photoelastic experiment is possible. This research utilizes this feature and would like to use in remedy and development of the bone and the artificial joint.

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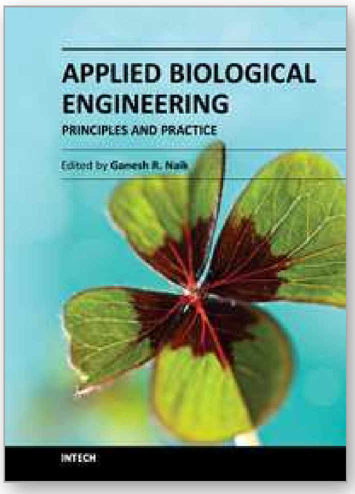

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Biological engineering is a field of engineering in which the emphasis is on life and life-sustaining systems. Biological engineering is an emerging discipline that encompasses engineering theory and practice connected to and derived from the science of biology. The most important trend in biological engineering is the dynamic range of scales at which biotechnology is now able to integrate with biological processes. An explosion in micro/nanoscale technology is allowing the manufacture of nanoparticles for drug delivery into cells, miniaturized implantable microsensors for medical diagnostics, and micro-engineered robots for on-board tissue repairs. This book aims to provide an updated overview of the recent developments in biological engineering from diverse aspects and various applications in clinical and experimental research.

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