Analysis of the strain Strength of the hydraulic cast materials
— using a 3 dimension pressure sensor —

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Abstract

The purpose of this study was to evaluate the strain strength of hydraulic casts (hard type casts) against loads using a 3 dimension pressure sensor. When joint fixation is performed in clinical practice, various fixation materials are used. In recent years, hard type casts have more often been used than conventional plaster casts. Hard type casts provide adequate fixation force when placed in 3-4 layers as circles, and present no clinical inconvenience. Therefore, little attention has been paid to the appropriate number of layers as fixation strength. In addition, there have been no studies on the thickness of casts (number of cast layers) and the strain strength of casts against loads. To obtain basic data on these items, we 3-dimensionally calculated and analyzed strain strength of cast plates using 6 types of load and 4 types of thickness (number of cast layers). As a result, the optimal cast thickness for fixation was 3 layers or more on the x- and z- axes, and 4 layers or more on the y- axis.

Ⅰ. Introduction

There are various joint immobilization methods in clinical practice. In recent years, hydraulic cast materials (hard type casts) have been used more often than conventional plaster casts. When applied as rings in 3-4 layers, hard type casts provide adequate immobilization strength and cause no clinical inconvenience, presenting few problems. Therefore, it was not necessary to consider the number of layers in terms of immobilization strength. On the other hand, when these cases are not applied to the entire circumference but used as half-cut casts (Schale) or splints for joint immobilization, the understanding of the relationship between the number of layers and immobilization strength is important. However, there have been no studies on this relationship.

In this study, we evaluated differences in immobilization strength among the numbers of layers of the Scotch cast (3M) as a hard type cast. Cast plates that differ in the number of layers (2, 3, 4, and 5 layers) were produced, and 6 different weights were applied to each plate, and force components generated in the plates were detected using 3-dimension pressure sensors and analyzed.

Ⅱ. Materials and Methods

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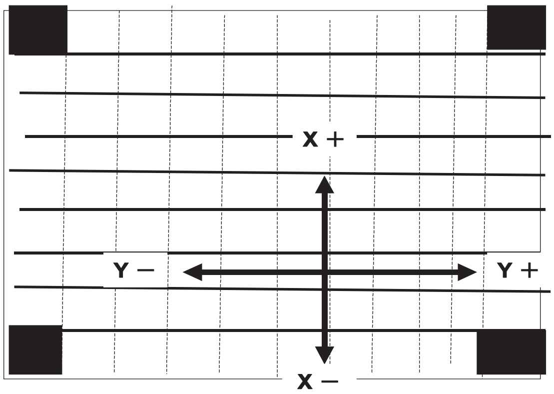

Fig. 1. Weaving directions of the Scotch cast and the establishment of the x- and y-axes

The Scotch cast was cut into a 10.5cm square, and the areas at its four angles (black areas) were placed on the sensors. The axis perpendicular to the plate was designated as the z-axis.

A. Materials and determination of 3 dimension force

Hard type casts have high immobilization strength and are composed of polyurethane resin immersed in glass fibers. Hard type casts were bent into 2, 3, 4, and 5 layers, hardened, and cut into 10.5cm square plates. Six plates were prepared for each number of layers. The glass fiber cloth of hard type casts is woven in a certain regular pattern. In our preliminary experiment, dimension force resulting from loading differed among the weaving directions. Therefore, we measured components on the x- and y- axes as shearing stress (horizontal components) and that on the z-axis as perpendicular stress (perpendicular component), considering the weaving direction (Fig. 1).

B. Measurement and analysis

For measurement, 3-dimension pressure sensors (USL10-H3, Tekku Gihan) were used. An 11.0cm square was formed on a table, and 3-component pressure sensors were placed on 20mm square areas at four angles of the 11.0cm square. The sensor part of the 3-dimension pressure sensor was a dome-type natural rubber (diameter, 8.5 mm). On these rubbers, each 10.5 cm hard type cast plate was placed. This experiments were performed, after con firming adequate friction due to adherence between the sensor parts and the cast plate.

Voltage signals occurring in the 3-dimension pressure sensors following weight loading were recorded on a personal computer via an amplifier, AD converter, and a 16CH PC memory recorder (DLR2000, Tekku Gihan:Fig. 2). The sampling frequency was 100 Hz, and measurement values were expressed in terms of kgf. As loads, 6 different weights (400, 800, 1,200, 1,600, 2,000, and 2,400 g) were placed at the center (a circle with a diameter of 30 mm) of the

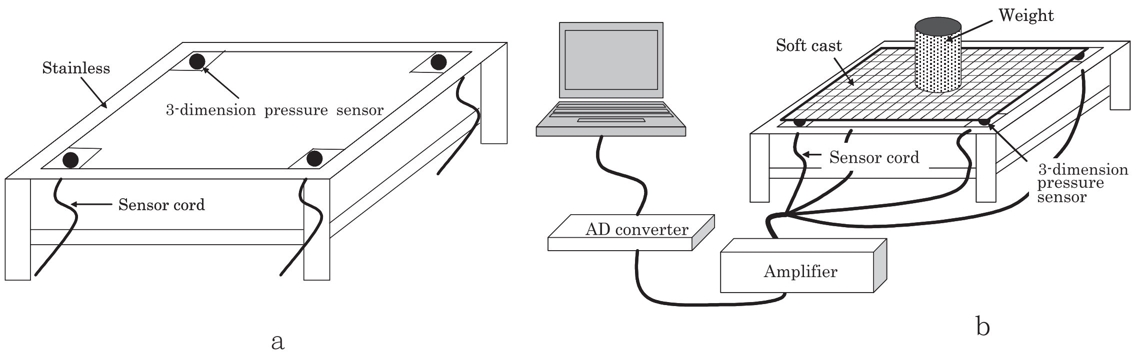

Fig. 2 Schemes of the experimental apparatus

a: Three-dimension pressure microsensors were placed at the 4 angles of a stainless table with props. The size of the sensors was 20 mm (length) - 20 mm (width) - 4 mm (height).

b: A 10.5cm square cast plate was placed on the 3-dimension pressure sensors, and a weight load was applied to the center of the plate. Signals generated on the sensors were recorded on a personal computer via an amplifier and AD converter.

cast plate, and continuous recording was performed for 10 seconds after weight application. During the 10 second measurement, the value 5 seconds after weight application when plate displacement was stabilized was regarded as the representative value. When a weight was placed at the center of the plate, the center was depressed, resulting in the occurrence of dimension force. As shown in Fig. 1, the dimension force could be measured on the x- and y-axes as values in the plus or minus direction. On the x- and y-axes, the total of absolute values of data was considered to be the dimension force on each axis. In our preliminary experiment, 2 layer plates allowed measurement using weights only to 2,000 g due to low strength, and plates with the other layers allowed measurement using weights to 2,400 g. Data analysis was performed by multiple comparison (Tukey Kramer test) with significant levels of both 1% and 5%.

Ⅲ. Results

A. 3 dimension force according to the number of layers and loads

With an increase in the load, the 3 dimension force increased (Table 1). The strength against strain on the x-axis was high, and the cast plate deformation was stable. However, the strength against strain on the y-axis was low and varied among the number of layers. The strength on the x-axis was about 2-2.5 times that on the y-axis irrespective of the load or number of layers. The component on the z-axis did not differ among the amounts of load or the numbers of layers.

B. X-axis

Strength did with a 400 g load not differ among the number of layers. Strength significantly with a load of 800 g or more, decreased for 2 layers alone ($p < 0.01$). Strength did not with a 2,400 g load, differ among the number of layers except in 2 layers (Fig. 3-a).

C. Y-axis

Since the strength of the y-axis was lower than that of the x-axis due to the direction of weaving, dimension force differed among the loads and the numbers of layers. With a 400 g load, strength was significantly low for 2 layers alone ($p < 0.01$) but was the same among the other numbers of layers. With an 800 g load, significant differences were observed between 2 layers and 3 layers ($p < 0.001$) and between 3 layers and 4/5 layers ($p < 0.01$), but no difference was observed between 4 layers and 5 layers. Similar results were obtained using weights to 2,000 g. With a 2,400 g load, measurement was impossible

Table 1 Numbers of layers of the scotch cast and dimension force values and standard deviations on each axis

(Unit: kgf)

	Number of layers	400 g	800 g	1,200 g	1,600 g	2,000 g	2,400 g
X-axis	2	0.034±0.006	0.060±0.006	0.093±0.011	0.134±0.011	0.167±0.013	
	3	0.029±0.003	0.050±0.002	0.070±0.008	0.087±0.005	0.111±0.008	0.126±0.006
	4	0.034±0.006	0.054±0.006	0.079±0.012	0.093±0.012	0.111±0.014	0.123±0.018
	5	0.032±0.005	0.051±0.004	0.070±0.006	0.086±0.007	0.102±0.012	0.116±0.014
Y-axis	2	0.021±0.002	0.063±0.004	0.095±0.006	0.139±0.006	0.166±0.009	
	3	0.019±0.007	0.040±0.012	0.051±0.012	0.067±0.005	0.090±0.012	0.122±0.011
	4	0.014±0.003	0.024±0.006	0.026±0.005	0.041±0.010	0.051±0.008	0.071±0.008
	5	0.014±0.001	0.022±0.006	0.026±0.007	0.030±0.010	0.042±0.012	0.047±0.013
Z-axis	2	0.046±0.003	0.084±0.004	0.122±0.006	0.167±0.005	0.206±0.006	
	3	0.046±0.001	0.082±0.003	0.129±0.003	0.170±0.005	0.214±0.005	0.240±0.005
	4	0.044±0.003	0.083±0.004	0.129±0.004	0.170±0.004	0.204±0.006	0.242±0.009
	5	0.040±0.004	0.076±0.004	0.121±0.005	0.166±0.006	0.194±0.007	0.233±0.005

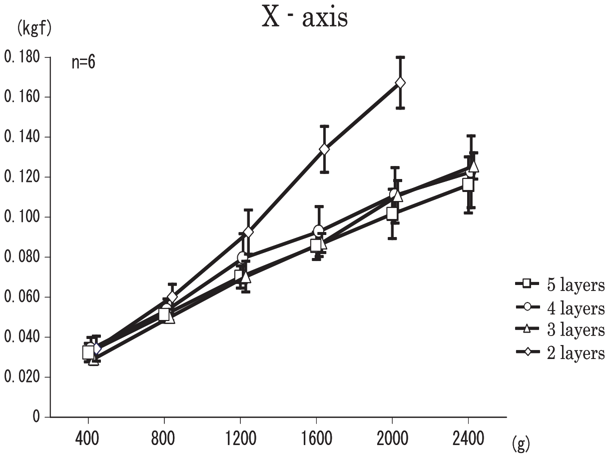

Fig.3 a

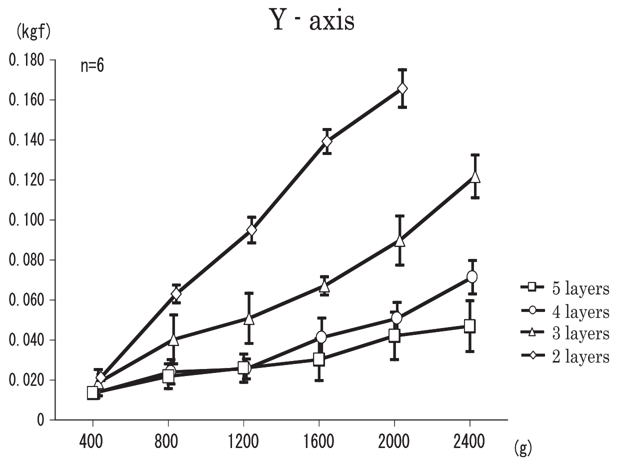

Fig.3 b

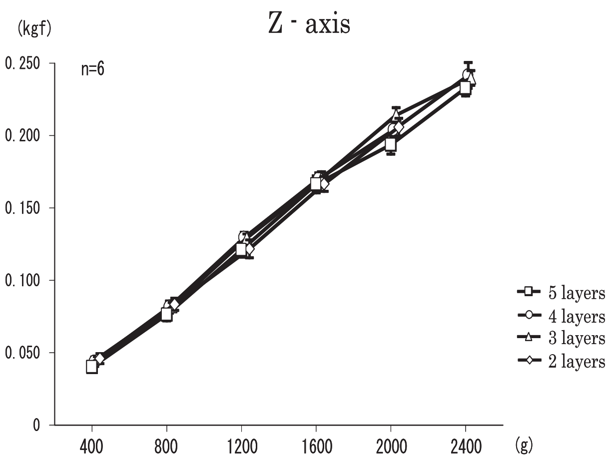

Fig.3 c

Fig. 3 Results of measurement

Dimension force (kgf) on the a. x-, b. y-, and c. z-axes
Symbols in the graph: -□- (5 layers), -○- (4 layers), -△- (3 layers), -◇- (2 layers)

for 2 layers, and significant differences ($p < 0.01$) were observed among the other numbers of layers (Fig.3-b).

D. Z-axis

The z-axis represents force that vertically presses the plate. With an increase in the load, the dimension force on the z-axis increased. However, no significant difference was observed among the numbers of layers using weights to 1,600 g. With a 2,000 g load, a significant difference ($p < 0.01$) was observed between 2/3 layers and 5 layers (Fig. 3-c).

Ⅳ. Discussion

In recent years, It has become rare that the treatment by external immobilization alone for limb fracture is continued, and invasive treatment (internal fixation) such as external fixation and pinning has actively been performed. Various criteria are applied to the selection of such methods. Sasaki [2] classified radial distal end fractures into the stable and instable types, and considered the stable type to be an indication of external immobilization and the unstable type to be an indication of external fixation. He described that morphology as similar as possible to the anatomical morphology should be attained because of the close relationship between morphology after healing and prognosis. At present, invasive treatment may be selected based on this consideration. However, it has also been reported[3, 4] that morphology after healing (i.e., malunion on X-ray films) is not always consistent with outcomes in aged patients with osteoporosis, suggesting no necessity for attaining morphology as similar as possible to the anatomical morphology. There was also a study on the use of an improved Chinesestyle external immobilization method as a functional prosthesis in limited cases of radial distal end fracture[1], which is a typical treatment method by external immo-

bilization alone. We have developed basic principles,
based on the latter, that the indications for conservative treatment should be expanded using devices for external immobilization, and have evaluated the relationship between immobilization materials and immobilization strength. When immobilization involving the entire limb circumference is performed, the purpose of immobilization can be achieved by using an appropriate number of layers of the cast. However, when casts are used as splints, their strength considerably changes with the number of layers, though also associated with the immobilization area and extent, and therefore basic data on the relationship between the number of layers and immobilization strength have been required. However, since the expression of immobilization strength using objective parameters has been impossible to present, there have been no studies on this relationship. We developed a 3-dimension pressure sensor (USL10-H3: Tekku Gihan) that allows measurement of the strength of materials as force components in 3 directions, and analyzed the immobilization strength of cast plates in terms of the number of layers and dimension force occurring after loading.

Our preliminary experiment showed a higher strength against strain on the x-axis than that on the y-axis. Therefore, this difference was considered to be a characteristic of the material. Force components on all the x-, y-, and z-axis significantly differed between 2 layers and 3 layers ($p < 0.01$) but not among 3, 4, and 5 layers. On the y-axis, a significant difference was observed between 2 layers and 3 layers with a load of 800 g or more ($p < 0.01$) and between 3 layers and 4 layers with a load of 1,200 g or more ($p < 0.01$). With a load of 2,400 g or more, a significant difference was also observed between 4 layers and 5 layers ($p < 0.01$), but such strong external force can not occur during joint immobilization. Therefore, 3 layers was regarded as the necessary number of layers for the maintenance of immobilization strength. In this study, the difference in strength between the x- and y- axes due to weaving directions was considered to be a characteristic of the material. However, since the x- and y-axes represent the longitudinal and transverse directions of the cast, the difference in strength between the two axes causes strain during immobilization. Therefore, this property may cause strain in the immobilization material due to isometric movements when the cast is used as a splint, which is a clinical problem requiring consideration.

The component on the z-axis is perpendicular force acting on the plate and is negligibly associated with the development of strain due to external force. Therefore, casts used in 3 layers or more may cause no problems in immobilization strength.

V. Conclusion

A. We evaluated the immobilization strength of a hard type cast using our new 3-dimension pressure sensors.

B. Using the 3-dimension pressure sensors, the strain of the material following loading can be measured as dimension force in 3 directions. In hard type cast plates, the strength on the x-axis was about 2.0-2.5 times that on the y-axis.

C. On the x- and y-axes, 3 layers or more may provide necessary immobilization strength.

D. On the y-axis, immobilization strength significantly differed between 3 layers and 4/5 layers. Therefore, when casts are used as splints, and higher strength is necessary, 4 layers or more may be desirable.

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水硬化性キャスト材の強度解析
－３分力検出器を用いて－

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要旨：

（目的）本研究は，水硬化性キャスト材（以後，ハードタイプ　キャスト）に対して，負荷に対する歪み強度を3分力検出器を用いて検証することにある．

（方法）臨床で関節固定をおこなう場合，様々な固定材料が用いられるが，近年は従来のギプス包帯よりハードタイプ　キャストを用いることが多い．ハードタイプ　キャストは環状に3～4層重ねると十分な固定力が得られ，臨床上も不都合はないことから固定強度としての層数を敢えて考慮することはなかった．また，厚み(キャスト層数)と負荷間に生じるキャスト材の歪み強度を調査した報告も見られない．今回，これらに関した基礎的データを明らかにするため，6種類の負荷と4種類の厚み(キャスト層数)を用いてキャスト板の歪み強度を3次元で算出して解析した．

（結果）固定を行う場合，キャストの厚みはx軸，z軸で少なくとも3層以上，y軸で4層以上が望ましい．

（結語）本結果は，ハードタイプ　キャストの固定強度を決定する上での指針になると考えられる．

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