Analysis of Orbital Blowout Fracture Location and Hess Area Ratio

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Title

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Abstract

This study aimed to analyze the Hess area ratio in cases of blowout fracture treated in our department and clarify the outline of eye movement disorders in blowout fractures. Patients who underwent surgery for orbital blowout fractures in our department were included. Fracture locations were classified into 5 types (A, outside floor; B, C, anterior and posterior floor; D, E, anterior and posterior medial wall). The Hess area ratio was compared before and after surgery in eligible cases. The relationship between the fracture location and preoperative Hess area ratio was investigated using multiple regression analysis. The study involved 85 patients. Hess area ratio was higher postoperatively than preoperatively (70.75 ± 18.26 vs. 90.06 ± 13.99, $p < 0.01$). The postoperative Hess area ratio tended to be higher when the iliac bones were compared to other materials; however, this difference was not significant (90.73 ± 12.91 vs. 80.30 ± 17.81, $p = 0.178$). Fracture locations C and E significantly contributed to the prediction of Hess area ratio as negative regression coefficients ($p = 0.024$ and 0.013, respectively). The posterior fracture area on both the orbital floor and medial wall contributed to the decrease in preoperative Hess area ratio. This observation indicates that the reconstruction of the posterior

region is extremely crucial.

Key words: orbital blowout fracture, Hess area ratio, eye movement disorder

Introduction

The major symptoms of orbital blowout fractures include diplopia, resulting from extraocular muscle dysfunction, and enophthalmos. Ocular motility disorders are a functional problem, whereas enophthalmos is a cosmetic problem. Both conditions are indications for surgery, and their persistence after the procedure can greatly affect quality of life (QOL). Various studies have been conducted on eye movement disorder/diplopia and enophthalmos in orbital blowout fractures, in which the relationship between the type and site of fractures, extraocular muscle status, and other symptoms have been examined.[1–16] However, there are few studies using objective indicators; it is still difficult to predict the severity of symptoms following orbital blowout fractures, and residual symptoms after the surgery are often troublesome.

The Hess area ratio (HAR%) has been proposed as an evaluation method for eye movement disorders, and its usefulness has been reported in several studies.[17–19] HAR% is considered to be an excellent index because it can evaluate eye movements objectively and quantitatively. A few reports have analyzed HAR% in various types of orbital blowout fractures; however, no studies have examined the relationship with the detailed fracture location. Clarifying the relationship between the fracture location and HAR% will therefore greatly facilitate the assessment of surgical indications and contribute to the improvement of postoperative symptoms.

Thus, this study aimed to analyze HAR% in patients with blowout fractures treated in our department, evaluate the preoperative and postoperative conditions, examine the relationship between HAR% and fracture location, and unravel the pathophysiology of eye movement disorders in blowout fractures.

Materials and Methods

Ethical approval

This study was conducted in accordance with the Declaration of Helsinki. Due to the retrospective, non-interventional nature of the study, tacit consent was applied, and participants were able to opt out of the study via our website. The study protocol was reviewed and approved by the Ethics Committee at Kobe University Graduate School of Medicine (authorization number B200074).

Study subjects

Patients who underwent surgery for orbital blowout fracture in our department from March 1, 2010, to July 31, 2019, were included in the study. Patients with previous blowout fracture injuries and those injured on both sides were excluded from the HAR% measurement.

Measurements

Demographic data (age, sex, side, transplant material, fracture location, and mechanism of injury) were collected. Fracture locations were classified into the following five groups based on computed tomography images (Fig. 1): A, outside area of the infraorbital groove in the orbital floor; B, anterior inside area of the infraorbital groove in the orbital floor; C, posterior inside area of the infraorbital groove in the orbital floor; D, anterior area in the orbital medial wall; and E, posterior area in the orbital medial wall. The boundary between the anterior and posterior areas was defined by a coronal line that passes through the outermost inferior orbital fissure, with reference to studies that analyzed orbital morphology.[20]

Pre- and postoperative HAR%

HAR% is defined as the percentage of square area of the affected side compared with the healthy side on the Hess chart.[17] The following measurements were taken: length A (mm) between the upper and lower plots and length B (mm) between the left and right plots at the central field of 15 or 30 degrees of the affected eye on the Hess chart. Healthy eyes were measured in a similar manner (A' (mm) and B' (mm)). HAR% was calculated using the following equation: $(A \times B) / (A' \times B') \times 100\%$. If the plot was out of the Hess chart, the length was substituted up to the outer border of the chart (Fig. 2).

Postoperative measurements were considered as the last available data that could be obtained (1–7 months postoperatively).

Pre- and postoperative enophthalmos

Hertel exophthalmometry was used to measure the difference between healthy and affected sides.

Postoperative evaluation of diplopia

Diplopia was checked in the top-bottom and right-left directions using the confrontation test. Diplopia at an angle less than 30 degrees in any direction was considered significant.

The HAR% calculation and fracture location determination were performed by an investigator who was not an attending surgeon.

Statistical analysis

Pre- and postoperative and implant material comparisons were performed using paired or nonpaired Student's t-test (since all these parameters showed a normal distribution or were regarded as having a normal distribution). Regarding the pre- and postoperative correlation and relationship between the location and HAR% or awareness of diplopia or Hertel exophthalmometry, simple and multiple regression analyses were used. The Microsoft Excel package (Microsoft Corp., Redmond, WA) was used to perform the statistical analyses. P <

0.05 was considered statistically significant.

Results

Demographics

Sixty-five males and 20 females with orbital fractures were included. The average age was 38.19 years; the males were significantly younger than the females (32.2 ± 16.68 vs. 57.65 ± 18.97, $p < 0.01$). There were 46 cases on the left, 37 cases on the right, and 2 cases on both eyes. The most common injuries were assault (23 cases), followed by sports injuries and falls (22 cases each), road traffic accidents (10 cases), and others (8 cases) (Supplemental Table 1). The implant material was iliac bone in 59 cases, absorbable sheet in 9 cases, titanium mesh in 6 cases, and another material in 3 cases, while none was used in 8 cases. We used cancellous bone for iliac bone transplantation.[21] Fracture types included blowout in 80 cases and orbital floor linear type in 5 cases.

Individual fracture locations were A in 10 cases, B in 29 cases, C in 60 cases, D in 23 cases, and E in 23 cases. The most frequent pattern of fracture locations was C alone in 20 cases, followed by B-C in 13 cases and D-E in 9 cases (Supplemental Table 2).

HAR%

Pre- and postoperative comparison

The analysis was performed in 26 cases in which HAR% could be measured pre- and postoperatively. HAR% increased pre- to postoperatively (70.75 ± 18.26 vs. 90.06 ± 13.99, $p < 0.01$) (Supplemental Table 3).

Single regression analysis was performed using postoperative HAR% as a criterion variable and preoperative HAR% as an explanatory variable. The regression equation obtained was $Y = (0.34 * X) + 66.39$, with a regression coefficient p value of 0.026; thus, preoperative HAR% was considered to be a useful predictor of postoperative HAR% (Fig. 3).

Comparison between transplant materials

In cases in which postoperative HAR% could be measured, differences between materials were examined for 24 cases that underwent transplantation. The iliac bone was transplanted in 20 cases, and other transplant materials were used in 4 cases.

Preoperative HAR% was not different between the iliac bone and other materials (68.94 ± 18.98 vs. 70.81 ± 15.63, $p = 0.856$). Postoperative HAR% tended to be greater for the iliac bone than other materials; however, this difference was not significant (90.73 ± 12.91 vs. 80.30 ± 17.81, $p = 0.178$) (Supplemental Table 4).

Relationship between fracture location and preoperative HAR%

The analysis was performed in the 66 cases in which preoperative HAR% could be measured.

Multiple regression analysis was performed using preoperative HAR% as a criterion variable and age/location (A, B, C, D, E) as an explanatory variable. Fracture locations C and E contributed significantly to the prediction of HAR% as negative regression coefficients ($p = 0.024$ and 0.013, respectively) (Supplemental Table 5).

Enophthalmos

Pre- and postoperative comparison and relationship with fracture location

The cases measured by the Hertel exophthalmometry were 59 before and 37 after surgery. The between-eye difference significantly decreased pre- to postoperatively (1.65 ± 1.36 vs. 0.39 ± 0.68, $p < 0.01$) (Supplemental Table 6). No association was found between the postoperative results and fracture location on multiple regression analysis.

Diplopia

Relationship between fracture location and postoperative awareness of diplopia

At the last follow-up (more than 6 months after surgery), 6 cases remained aware of significant diplopia (7%). No significant relationship was found between residual diplopia and fracture location on multiple regression analysis.

Discussion

The major sequelae of the orbital blowout fracture are diplopia from extraocular muscle dysfunction, enophthalmos, and infraorbital nerve hypoesthesia.[22] In particular, diplopia and enophthalmos greatly influence the QOL of patients, and there are various studies to date regarding factors associated with these symptoms.

There are multiple reports proposing that enophthalmos is caused by the expansion of orbital volume.[1-6] Sung et al.[4] reported that there is a significant linear positive correlation between the area of the medial orbital wall fracture and the degree of enophthalmos. Zhang et al.[3] revealed that the overall volume of herniated orbital contents significantly correlates with the amount of enophthalmos. Moreover, several studies have focused on the relationship between fracture location and enophthalmos. Ahmad Nasir et al.[5] described that the involvement of the posterior ledge and inferior orbital fissure is significantly associated with enophthalmos. A report by Alinasab et al.[6] on patients with hernia suggested that a visible deformity is related to the distance from the inferior orbital rim to the posterior edge of the fracture. Regarding enophthalmos, it is considered that both the size and the location of the fracture area are related.

Considerable research has further been done on factors associated with diplopia.[7–16] Tahiri et al.[10] reported that the presence of preoperative diplopia and radiologic evidence of extraocular muscle swelling was strongly associated with diplopia at 6 months after repair. Matsunaga et al.[12] showed that in patients with inferior rectus muscle swelling on the injured side ≥1.6 times greater than on the non-injured side on preoperative coronal computed tomography (CT) images, double vision and slight impairment of eye movements may remain after surgery. Moreover, Jin et al.[9] described that patients who experience swelling of the extraocular muscles on CT scan are more likely to have residual postoperative diplopia. Rectus muscle swelling is considered to be one of the significant factors associated with diplopia. There are various studies on fracture range, location, and diplopia. Higashino et al.[11] reported that all cases of punched-out orbital floor fractures were associated with diplopia when the fracture width was less than half the diameter of the globe, and Shah et al.[14] showed that small- and medium-sized fractures with soft tissue herniation are more likely to cause diplopia than large-sized fractures. Due to the problem of orbital content tissue herniation, a narrow fracture range may be associated with a higher risk of eye movement limitation. Regarding the location, Burm et al.[7] reported that diplopia was associated with 25% of medial wall fractures, 80% of orbital floor fractures, and 80.9% of combined medial and floor fractures. Schönegg et al.[16] reported a statistically significant correlation between fractures of the anterior and medial thirds of the orbital floor and double vision. Contrarily, Park et al.[13] revealed that orbital floor fractures tend to cause diplopia more commonly than medial wall fractures. However, extraocular movement limitation was not found to be dependent on the location of the orbital wall fracture. Although diplopia is likely to occur in floor fractures, there are only a few studies regarding its detailed location.

Regarding diplopia, the timing before the surgery appears to be crucial. Several specialists recommend early surgery (<14 days),[23,24] while others state that early surgery is not necessary,[25–27] and a valid conclusion has not been reached so far.

HAR% is considered to be a useful index of eye movement.[17–19] Furuta et al.[17] reported no postoperative diplopia in cases of preoperative HAR% >85%, and Grenga et al.[18] showed that all patients with preoperative HAR% >85% had no postoperative diplopia and that the majority of patients (57%) with preoperative HAR% <65% experience postoperative diplopia. In addition, Yamanaka et al.[19] reported that the mean postoperative HAR% was significantly improved compared with preoperative HAR%. Furthermore, our study demonstrated that postoperative HAR% was significantly higher than preoperative HAR% and that preoperative HAR% was significantly associated with postoperative HAR%.

Regarding the graft materials, iliac bone grafts tended to have a higher HAR% than other materials; however, no significant difference was noted. This difference between transplant materials may be due to selection bias. Mesh-type materials can more easily create anatomical shapes even in large areas; therefore, materials other than the iliac bone may be used in cases of extensive and severe damage. Therefore, iliac bone grafts may be better.

Moreover, we investigated the relationship between preoperative HAR% and the precise location of fractures and found that the posterior orbital floor (C area) and medial wall (E area) influence preoperative HAR%. To our knowledge, no such correlation has been reported to date. This finding may indicate that the reconstruction of the posterior region is extremely crucial during surgery.

In this study, enophthalmos was significantly improved postoperatively; however, no association was found between the postoperative results and fracture location. Since postoperative enophthalmos depends on the accuracy of surgical reduction, it is presumed that no direct correlation was found with the fracture location. Additionally, the relationship between postoperative awareness of diplopia and the fracture location was not significant. It is possible that the results were not statistically significant due to the small number of people with residual diplopia.

The limitations of this study include the fact that postoperative results could not be examined for the fracture location because the number of cases in which postoperative HAR% could be measured was scarce, and other factors such as inferior rectus muscle swelling were not considered. In the future, it is desirable to accumulate more cases, analyze factors other than the preoperative location, and investigate the relationship between postoperative reconstruction accuracy (whether reconstruction of the posterior region is possible) and HAR%.

In conclusion, we examined orbital blowout fractures treated in our department regarding HAR%. The posterior fracture area on both the orbital floor and medial wall contributed to the decrease in preoperative HAR%. This finding indicates that the reconstruction of the posterior region is important during surgical treatment.

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Figure Legends

Fig. 1

Fracture location.

Fig. 2

The chart on the left (left eye) shows the affected side, and the chart on the right (right eye) shows the healthy side. HAR% is calculated using the following equation: $(A \times B) / (A' \times B') \times 100\%$. HAR%, Hess area ratio.

Fig. 3

Regression line of preoperative HAR% and postoperative HAR%. HAR%, Hess area ratio.

Supplemental Digital Content

Supplemental Table 1. Demographics

Supplemental Table 2. Fracture location

Supplemental Table 3. Comparison of pre- and postoperative differences in HAR%

Supplemental Table 4. Characteristics of graft materials

Supplemental Table 5. Relationship between fracture location and preoperative HAR%

Supplemental Table 6. Comparison of pre- and postoperative differences in enophthalmos

Figure 1

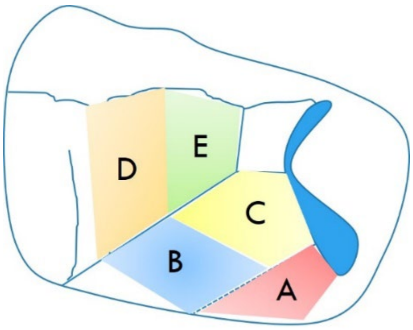


Figure 2

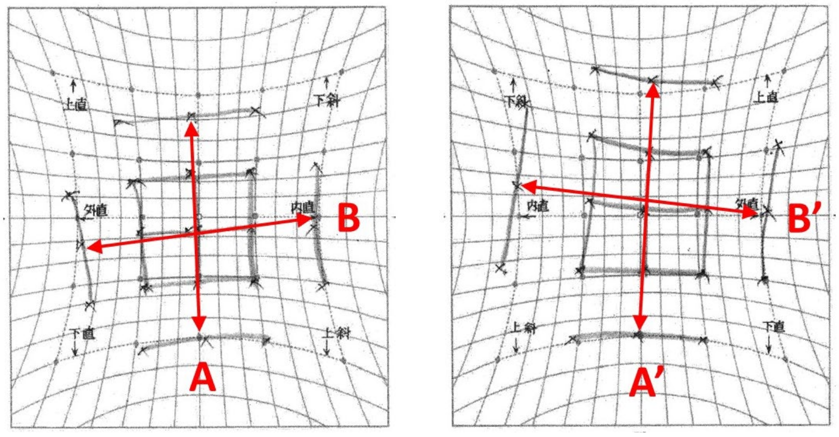
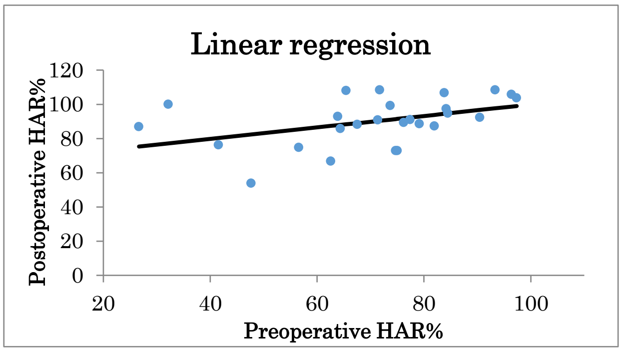


Figure 3



Linear regression
120
100
80
60
40
20
0
Postoperative HAR%
20
40
60
80
100
Preoperative HAR%

Supplemental Digital Content

Supplemental Table 1. Demographics

Number	male	65
	female	20
Age, years Mean (SD)	male	32.2 (16.68)
	female	57.65 (18.97)
Laterality	left	46
	right	37
	both	2
Mechanism	assault	23
	sports	22
	falls	22
	traffic accidents	10
	others	8

SD, standard deviation

Supplemental Table 2. Fracture location

Individual		Pattern	
A	10	C	20
B	29	BC	13
C	60	DE	9
D	23	CE	5
E	23	ABC	5
		CD	4
		BCDE	4

A, outside area of the infraorbital groove in the orbital floor; B, anterior inside area of the infraorbital groove in the orbital floor; C, posterior inside area of the infraorbital groove in the orbital floor; D, anterior area in the orbital medial wall; E, posterior area in the orbital medial wall.

Supplemental Table 3. Comparison of pre- and postoperative differences in HAR%

	Preoperative	Postoperative	Comparison
	Mean (SD)	Mean (SD)	p-value
HAR%	70.75 (18.26)	90.06 (13.99)	<0.01

HAR%, Hess area ratio; SD, standard deviation

Supplemental Table 4. Characteristics of graft materials

	Iliac bone	Others	Comparison
	Mean (SD)	Mean (SD)	p-value
Number	20	4	
Preoperative HAR%	68.94(18.98)	70.81(15.63)	0.856
Postoperative HAR%	90.73(12.91)	80.30(17.81)	0.178

HAR%, Hess area ratio; SD, standard deviation

Supplemental Table 5. Relationship between fracture location and preoperative HAR%

Summary output	
Regression statistics	
Multiple R	0.420
R square	0.177
Adjusted R-square	0.093
Std. error of the estimate	22.225
Observations	66

ANOVA

	Sum of squares	df	Mean square	F	F(0.95)
Regression	6246.77	6	1041.128	2.108	2.257
Residual	29142.038	59	493.933		
Total	35388.808	65			

	Coefficients	Standard error	t	P	Lower 95%	Upper 95%
Intercept	103.967	11.442	9.086	<0.001	81.072	126.863
Age	-0.211	0.141	-1.495	0.140	-0.493	0.071
A	-11.011	8.943	-1.231	0.223	-28.906	6.883
B	6.339	6.721	0.943	0.349	-7.11	19.788
C	-21.307	9.163	-2.325	0.024	-39.643	-2.971
D	-8.746	6.898	-1.268	0.21	-22.549	5.057
E	-17.612	6.874	-2.562	0.013	-31.367	-3.856

ANOVA, analysis of variance; A, outside area of the infraorbital groove in the orbital floor; B, anterior inside area of the infraorbital groove in the orbital floor; C, posterior inside area of the infraorbital groove in the orbital floor; D, anterior area in the orbital medial wall; E, posterior area in the orbital medial wall; HAR%, Hess area ratio; df, degrees of freedom.

Supplemental Table 6. Comparison of pre- and postoperative differences in enophthalmos

	Preoperative	Postoperative	Comparison
	Mean (SD)	Mean (SD)	p-value
Between-eye difference in exophthalmometry (mm)	1.65 (1.36)	0.39 (0.68)	<0.01

SD, standard deviation