Correlation Between Volume of Herniated Orbital Contents and the Amount of Enophthalmos in Orbital Floor and Wall Fractures

Zhiyong Zhang, DDS, MD, Yi Zhang, DDS, MD,† Yang He, DDS, MD,‡ Jinggang An, DDS, MD,§ and Roger Arthur Zwahlen, MD, DMD, Priv.-Doz., FEBOMFS‖*

Purpose: To analyze the correlation between the volume of herniated orbital contents and the amount of enophthalmos in orbital floor and wall fractures.

Materials and Methods: Patients with secondary enophthalmos due to unilateral orbital floor and wall fractures were recruited. Computed tomography–assisted measurements of both orbits as well as of the amount of enophthalmos were performed. The following volumes were calculated: *1*) the overall volume of both the healthy and fractured orbit, *2*) the volume of herniated orbital contents at the orbital walls, *3*) the volume of herniated orbital contents anterior and posterior to the vertical eyeball equator. The amount of enophthalmos was also measured by computed tomography. Multifactor linear regression analysis was performed to obtain correlations between the amount of enophthalmos and the measured volumes.

Results: Twenty-three patients were included. The average enophthalmos was 4.0 mm (SD = 1.49). Although correlation between volume differences of healthy and fractured sides was not statistically significant, the overall volume of the herniated orbital contents was significantly correlated ($P < .05$) with the amount of enophthalmos. Regarding the specific orbital sites of herniation, the orbital floor was detected to be most significantly correlated to the amount of enophthalmos ($P < .05$), although only the herniation posterior to the vertical eyeball equator.

Conclusion: The overall volume of herniated orbital contents correlated significantly with the amount of enophthalmos. The orbital floor was detected to be the site most significantly correlated with the amount of enophthalmos (although only if herniation occurred posterior to the vertical eyeball equator). Only the volume of herniated soft tissues posterior to the eyeball equator showed correlation with the amount of enophthalmos.

J Oral Maxillofac Surg 70:68-73, 2012

Orbital fractures are common in midfacial trauma, often in combination with zygomatic fractures.[1] All 4 orbital walls (medial, lateral, roof, and floor) may be involved, causing complications such as diplopia due to impaired eyeball motility and enophthalmos.[2] Indications for open reduction in orbital fractures have been established.[3] To date, surgical management of an enophthalmos exceeding 3 mm represents the gold standard.[4,5]

*Attending Doctor, Outpatient Dental Center, Peking University School of Stomatology, Beijing, Peoples' Republic of China.

†Professor, Department Oral and Maxillofacial Surgery, Peking University School of Stomatology, Beijing, Peoples' Republic of China.

‡Attending Doctor, Department Oral and Maxillofacial Surgery, Peking University School of Stomatology, Beijing, Peoples' Republic of China.

§Clinical Associate Doctor, Department Oral and Maxillofacial Surgery, Peking University School of Stomatology, Beijing, Peoples' Republic of China.

‖Oral and Maxillofacial Surgery, Prince Philip Dental Hospital, University of Hong Kong, Hong Kong SAR, Peoples' Republic of China.

Address correspondence and reprint requests to Dr Zhang: Department of Oral and Maxillofacial Surgery, Peking University School of Stomatology, 22 South Avenue Zhongguancun, Beijing, People's Republic of China; e-mail: zhangyi2000@263.net

0278-2391/12/7001-0$36.00/0
doi:10.1016/j.joms.2011.02.036

To determine the extent of enophthalmos, however, remains difficult because of variable decongestion patterns of the postinjury edema.[6] Catone et al[7] detected that 7% to 10% of patients undergoing conservative treatment of blowout fractures suffered from persistent enophthalmos. Research of enophthalmos sites and extent might help both to facilitate the decision-making process of whether to operate and to predict the best possible outcome. Unnecessary surgical comorbidities could be avoided. Enophthalmos occurs because of increased orbital volume, atrophy of the orbital fat, and soft tissue contracture. The volumetric change of the orbital socket, however, is considered the most important factor.[8-11] Because significant difference exists regarding the size of both orbital sockets, measurement of enophthalmos based on comparison of the 2 sides is not reasonable.[12] Subsequently, some researchers began to measure the volume of herniated soft tissue, but the reliability was limited because of inadequate techniques.[13,14] In addition to these limitations, the effect of different fracture sites in the orbital socket on enophthalmos remains unknown. The orbital floor is the most common fracture site in the orbital socket, often causing significant soft tissue herniation into the inferiorly located maxillary sinus.[15] On the contrary, the orbital roof remains mostly intact and plays a limited role in the subject of enophthalmos.[16] Therefore, special emphasis was paid to the correlation between the extent of enophthalmos and the herniated soft tissue volume in medial and lateral wall and orbital floor fractures. Clinical experience suggests that soft tissue herniation into the retrobulbar area seems to be important in the development of enophthalmos. Therefore, analysis of herniated soft tissue anterior and posterior to the vertical eyeball equator was additionally performed.

In this study, computer-assisted measurements were used to analyze the various volumes of the orbital socket and the herniated soft tissues. Subsequently these measurements were correlated with varying amounts of enophthalmos to detect eventual significant relationships. Because the Hertel exophthalmometer is not reliable,[17-19] enophthalmos was also measured with computed tomography (CT)–based electronic data and software packages.

This study may facilitate surgeons' decision-making processes regarding the choice of conservative or operative treatment in orbital wall and floor fractures.

Materials and Methods

The Maxillofacial Trauma Center of the Peking University School of Stomatology serves as a regional referral center for facial trauma patients. In this retrospective study, the data of 23 patients who underwent conservative treatment of unilateral orbital fractures, referred to the unit between September 2004 and March 2007, were included in accordance with the principles outlined in the Declaration of Helsinki. For each patient, a preoperative CT scan of the head was performed with a Siemens 16-slice CT machine (Siemens, Berlin, Germany) with 2-mm pitch and a reconstruction thickness of 0.625 mm. Before and during scanning, it was ensured that the logo line of the CT machine was perpendicular to the patient's orbitomeatal line. The scanning range extended from the skull to the chin.

MEASUREMENT OF ENOPHTHALMOS

The CT data in DICOM format were imported into the Mimics 8.11 software package (Materialize, Leuven, Belgium). The largest diameter of the eyeball was selected on axial CT scans. A perpendicular line from the most prominent point of the lateral edge of healthy orbital side to the head midline was laid,

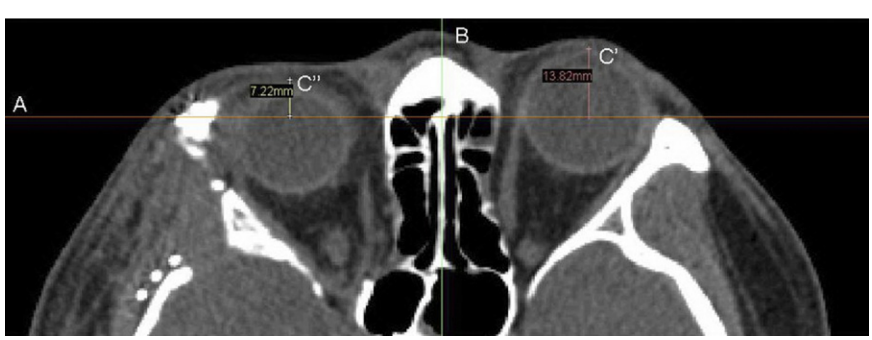

FIGURE 1. Computed tomography (CT) showing the enophthalmos of the right orbit. CT data were imported into the software package Mimics 8.11. On an axial CT scan, a line (*A*) perpendicular to the nasal septum (*B*) was drawn from the most prominent point of the zygomatic bone of healthy side extending through the fractured orbit. From this line, perpendicular lines to the most prominent point of the cornea on each side were laid (C′ healthy side; C″ fractured side). The difference between the length of C′ and C″ represents the amount of exophthalmos.

Zhang et al. Herniated Orbital Content Volume and Amount of Enophthalmos. J Oral Maxillofac Surg 2012.

which served as measurement baseline. The vertical distance from the most prominent of the cornea point to the baseline was then measured as the exophthalmos value. The difference of measurement value between the healthy side and the affected side was taken as the enophthalmos value (Fig 1).

MEASUREMENT OF THE OVERALL ORBITAL VOLUME

CT raw data in DICOM format were imported into the Mimics 8.11 software package. The bony border of the orbit was lined out on all axial scans containing the orbital socket. The orbital rim and the optical foramen were chosen as the anterior and posterior borders. After lining out all slices from the orbital roof to the floor, the software automatically generated an image in stereolithography format, which was imported into Geomagic Studio 4.0 (Raindrop Geomagic, Research Triangle Park, NC) to calculate the orbital volume (Fig 2).

MEASUREMENT OF THE HERNIATED SOFT TISSUE VOLUME

Using the Mimics 8.11 software package, the herniated tissue borders of the medial and lateral wall were outlined on axial CT scans level by level, and sagittal CT scans were used to outline the borders of herniated tissue in orbital floor fractures. The borders of the herniated soft tissues were corrected by coronal position. Completing the outlining at all relevant slices, the 3-dimensional reconstruction of herniated soft tissue was calculated and imported into Geomagic Studio 4.0 in stereolithography format to calculate the volumes (Fig 2).

MEASUREMENT OF THE HERNIATED TISSUE VOLUME ANTERIOR AND POSTERIOR TO THE EYEBALL EQUATOR

The vertical eyeball equator was defined as the maximum diameter of the eyeball in the coronal view.

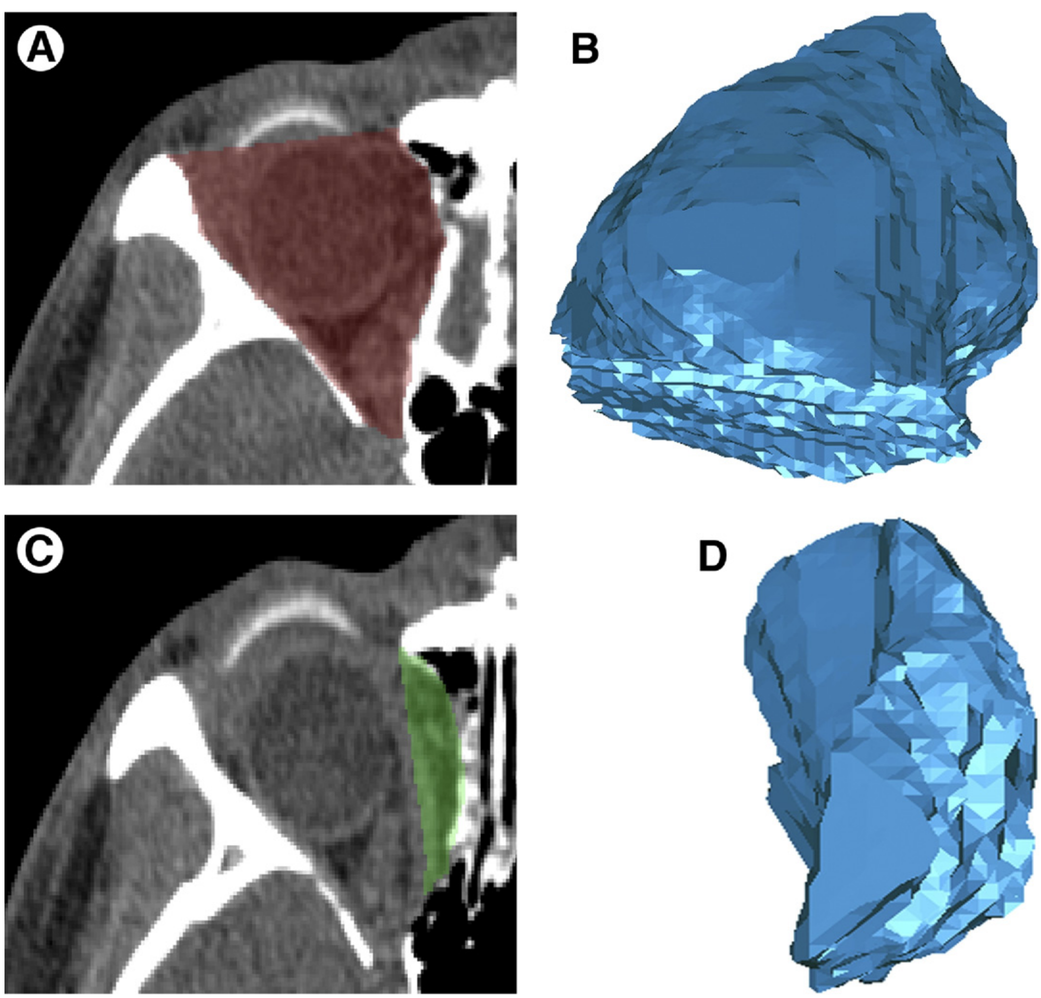

FIGURE 2. Measurement of the orbital socket. *A*, Outlining the border of the orbital socket in the axial computed tomography scan. The zygomatic bone represents the lateral and the lateral nasal wall the medial border. *B*, Reconstructed 3-dimensional images of the orbital socket are delivered by the Mimics software package. *C*, Outlining the herniated content in the medial border of the orbital socket. *D*, Reconstructed 3-D image of the herniated tissue.

Zhang et al. Herniated Orbital Content Volume and Amount of Enophthalmos. J Oral Maxillofac Surg 2012.

FIGURE 3. Computer-assisted definition of the eyeball equator. The largest diameter was found in the coronal computed tomography (CT) scan and was taken as the eyeball equator. The position of the equator was also showed in the axial and sagittal CT scan. According to the eyeball equator, the measurement of the herniated content in the orbital floor was divided into herniation anterior and posterior.

Zhang et al. Herniated Orbital Content Volume and Amount of Enophthalmos. J Oral Maxillofac Surg 2012.

With similar technique as described earlier, both the anterior and posterior herniated soft tissues volumes were calculated (Fig 3).

STATISTICAL ANALYSIS

Using SPSS13.0 software (SPSS, Chicago, IL), backward screening of multiple linear regression was performed to analyze the correlation between the amount of enophthalmos and the earlier-mentioned volumetric variables. After the overall orbital volume differences, the overall herniated soft tissue volumes, and the extent of enophthalmos were correlated, correlations between the amount of enophthalmos and the herniated soft tissue volume of each wall as well as between the extent of enophthalmos and herniated soft tissue volumes anterior or posterior to the eyeball equator were calculated.

Results

Twenty-three patients (14 men, 9 women) were included in this study. Age ranged between 19 and 59 years (mean, 34 years). In 16 cases, the fractures were due to traffic accidents, in 3 due to assault, in 2 due to sports accidents, and in 1 each due to an accident at work and an explosion. The patients were first seen in the outpatient clinic of the Department of Oral and Maxillofacial Surgery at Peking University after a mean period of 11.8 weeks after conservative treatment of the trauma (range, 3–84 weeks). Sixteen cases showed combined orbital floor and medial wall fractures; isolated floor fracture was seen in 4 cases; and isolated medial wall fractures occurred in 3 cases. The orbital roof as well as the lateral wall was intact in all cases.

An average of 4-mm enophthalmos was calculated (SD = 1.49 mm).

Although volume differences between the healthy and fractured sides was not statistically significantly correlated, overall volume of the herniated orbital contents did correlate significantly with the extent of enophthalmos ($P < .05$; Table 1).

Regarding the specific orbital sites of herniation, the orbital floor was most significantly correlated to amount of enophthalmos ($P < .05$; Table 2), although only to the herniation posterior to the vertical eyeball equator (Table 3).

Discussion

Enophthalmos is a major complication of orbital fractures, possibly leading to functional eye impairment and disturbed facial appearance.[3] Generally, enophthalmos greater than 3 mm is considered surgically corrected, the surgery should be finished 2 weeks after injury.[3-5] A reliable prediction of the extent of enophthalmos could facilitate the decision-making process regarding whether to pursue conservative or operative treatment. Moreover, a better understanding with respect to involved orbital locations and their influence on the consecutive developing enophthalmos could lead to improved treatment outcomes.

Several studies have considered *1*) the increase of orbital volume in blowout fractures, *2*) the atrophy of herniated orbital fat, and *3*) scarring processes of intraor-

Table 1. CORRELATIONS BETWEEN THE DIFFERENCE OF THE HEALTHY AND FRACTURED ORBITAL SOCKET VOLUME, THE HERNIATED ORBITAL CONTENTS AND THE AMOUNT OF ENOPHTHALMOS

	Unstandardized Coefficients		Standardized Coefficients		
Model	B	Standard Error	Beta	*t*	*P* Value
1 (Constant)	1.158	1.023	0.320		1.132
Overall orbital volume difference	−0.023	0.112	−0.045	−0.206	.839
Overall volume of herniated contents	0.674	0.229	0.634	2.939	.009
2 (Constant)	2.094	0.612	3.423		.003
Overall volume of herniated contents	0.641	0.185	0.603	3.464	.002

Zhang et al. Herniated Orbital Content Volume and Amount of Enophthalmos. J Oral Maxillofac Surg 2012.

bital soft tissue to be important mechanisms related to the development of enophthalmos.[8-11]

At the beginning, most studies focused on the volumetric difference between the fractured and healthy orbital socket, which was correlated with the extent of enophthalmos. Under the premise that both orbital sockets were symmetrical in volume, in 1994, Whitehouse et al[9] detected an increase in enophthalmos of 0.8 mm per each 1 mL of increased orbital volume. Dolynchuk et al[10] argued that if the overall volume difference between healthy and fractured orbit was more than 4% to 5%, enophthalmos would be greater than 3 mm. However, in 1988 Parsons and Mathog[12] had already detected a 7% to 8% difference related to the overall volume between the fractured and nonfractured orbit. Similar findings to the latter study were found in the current study: the average volume difference of the overall orbital cavity between the healthy and fractured side was 5.7 mL (range, 1.1–12.3 mL); correlation of this difference with the extent of enophthalmos did not show any statistical significance.

Several authors performed correlations between herniated soft tissue volumes and the amount of enophthalmos.[13,14] Jin et al[13] calculated an enophthalmos greater than 2 mm when the herniated soft tissue exceeded a volume of 0.9 mL and greater than 3 mm when exceeding 2.1 mL. In orbital fractures with an enophthalmos of 2 mm and more, Ploder[14] detected average volumes of herniated soft tissues of about 1.89 ± 1.19 mL. Unfortunately, insufficient accuracy inheres in studies that correlate herniated tissue volumes and enophthalmos. Assumptions, as elliptical fracture defects and semielliptical herniated tissue volume, are biased. Both defects as well as herniated soft tissue volumes may vary, rendering difficult any mathematical approximation to the reality. Others measured the enophthalmos with a Hertel exophthalmometer, an instrument with an enormous inherent measurement error as has been confirmed elsewhere.[17-19] Enophthalmos measurement represents the cornerstone for the reliability of enophthalmos-related studies; to date, only a few studies have tried to confirm the measurement accuracy of the Hertel exophthalmometer that is usually used in clinical examination.[17-19]

To improve measurement accuracy in this study, CT scans with a slice thickness of 0.625 mm were used with professional graphic software packages. Later, computer-aided data were used to measure enophthalmos, a method yielding better reliability compared with the Hertel exophthalmometer method.[20]

It was shown that the amount of herniated soft tissue volume was correlated with the amount of enophthalmos. In statistical analysis of correlations between the difference of the healthy and fractured orbital socket volumes and between the herniated orbital contents and the amount of enophthalmos, only the overall volume of herniated orbital contents showed significant correlation with the amount of

Table 2. CORRELATION BETWEEN THE VOLUMES OF HERNIATED CONTENTS OF THE MEDIAL AND LATERAL WALLS AND THE ORBITAL FLOOR AND THE AMOUNT OF ENOPHTHALMOS

	Unstandardized Coefficients			Standardized Coefficients		
	B	Standard Error		Beta	*t*	*P* Value
(Constant)	1.883	0.659	2.856	0.010		
Medial	0.575	0.223	0.512	2.586		.018
Floor	0.782	0.230	0.688	3.403		.003
Lateral	1.322	0.732	0.353	1.807		.087

Zhang et al. Herniated Orbital Content Volume and Amount of Enophthalmos. J Oral Maxillofac Surg 2012.

Table 3. CORRELATION BETWEEN THE VOLUME OF HERNIATED CONTENTS POSTERIOR AND ANTERIOR TO THE EYEBALL EQUATOR AND AMOUNT OF ENOPHTHALMOS

Model	Unstandardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	*t*	*P* Value
1. (Constant)	1.697	0.609	2.788		0.011
Posterior to eyeball equator	0.989	0.249	0.650	3.979	.001
Anterior to eyeball equator	0.324	0.237	0.224	1.368	.18
2. (Constant)	2.026	0.571	3.548		0.002
Posterior to eyeball equator	0.981	0.254	645	3.868	.001

Zhang et al. Herniated Orbital Content Volume and Amount of Enophthalmos. J Oral Maxillofac Surg 2012.

enophthalmos, with a standardized coefficient of 0.603. This indicates that secondary enophthalmos results not only from an orbital wall fracture but also from combined orbital wall fractures. Significant correlation between enophthalmos and each orbital wall (medial, lateral wall, and floor) was found, with the orbital floor posterior to the eyeball equator most significantly correlated. In orbital floor fractures, the ratio of herniated tissue volume of the floor and the overall herniated tissue volume was 56.43%. Possible reasons include the vicinity of the adjacent maxillary sinus and the gravitation effect.

Further evaluations showed that only the volume of herniated soft tissues posterior to the eyeball equator correlated with the amount of enophthalmos. This finding is consistent with the study of Manson et al.[21] Two possible explanations for this finding might be, first, that the support system of the eyeball is located posterior to the eyeball equator, and fractures within this area may deteriorate the support system. A second possibility is that in old orbital fractures, scarring processes posterior to the eyeball could further aggravate an enophthalmos; this assertion might be supported in the case series presented here, because orbital fractures older than 8 weeks accounted for 65.2% of all cases (15/23).

In conclusion, the results of this study suggest that orbital walls (floor, medial, and lateral) behind the eyeball equator are key locations in enophthalmos.

References

1. Ellis E, el-Attar A, Moos KF: An analysis of 2,067 cases of zygomatico-orbital fracture. J Oral Maxillofac Surg 43:417, 1985
2. Hwang SH, Bae YC, Jeon JY, et al: Clinical analysis in reconstruction of orbital blow-out fracture using the hydroxyapatite. J Korean Soc Plast Reconstr Surg 25:1067, 1998
3. Nam SB, Bae YC, Moon JS, et al: Analysis of the postoperative outcome in 405 cases of orbital fracture using 2 synthetic orbital implants. Ann Plast Surg 56:263, 2006
4. Koo L, Hatton MP, Rubin PA: When is enophthalmos significant. Ophthal Plast Reconstr Surg 22:274, 2006
5. Dulley B, Fells P: Long-term follow-up of orbital blow-out fractures with and without surgery. Mod Probl Ophthalmol 14:467, 1975
6. Converse JM, Smith B: Editorial on the treatment of blowout fractures of the orbit. Plast Reconstr Surg 62:100, 1978
7. Catone GA, Morrissette MP, Carlson ER: A retrospective study of untreated orbital blow-out fractures. J Oral Maxillofac Surg 46:1033, 1988
8. Lee JW, Chiu HY: Quantitative computed tomography for evaluation of orbital volume change in blow-out fractures. J Formos Med Assoc 92:349, 1993
9. Whitehouse RW, Batterbury M, Jackson A, et al: Prediction of enophthalmos by computed tomography after “blow out” orbital fracture. Br J Ophthalmol 78:618, 1994
10. Dolynchuk KN, Tadjalli HE, Manson PN: Orbital volumetric analysis: Clinical application in orbitozygomatic complex injuries. J Cranio Maxillofac Trauma 2:56, 1996
11. Fan X, Shen Q, Li H: etc. Orbital volume measurement of enophthalmos of orbital blowout fractures. Zhonghua Yan Ke Zhi. 38:39, 2002
12. Parsons GS, Mathog RH: Orbital wall and volume relationships. Arch Otolaryngol Head Neck Surg 114:743, 1988
13. Jin HR, Shin SO, Choo MJ, et al: Relationship between the extent of fracture and the degree of enophthalmos in isolated blowout fractures of the medial orbital wall. J Oral Maxillofac Surg 58:617, 2000
14. Ploder O, Klug C: Evaluation of computer-based area and volume measurement from coronal computed tomography scans in isolated blowout fractures of the orbital floor. J Oral Maxillofac Surg 60:1267, 2002
15. Hosal BM, Beatty RL: Diplopia and enophthalmos after surgical repair of blowout fracture. Orbit 21:27, 2002
16. Sullivan WG: Displaced orbital roof fractures: Presentation and treatment. Plast Reconstr Surg 87:657, 1991
17. Matic DB, Tse R, Banerjee A, et al: Rounding of the inferior rectus muscle as a predictor of enophthalmos in orbital floor fractures. J Craniofac Surg 18:127, 2007
18. Frueh WT, Frueh BR: Errors of single-mirror or prism Hertel exophthalmometers and recommendations for minimizing the errors. Ophthal Plast Reconstr Surg 23:197, 2007
19. Ameri H, Fenton S: Comparison of unilateral and simultaneous bilateral measurement of the globe position, using the Hertel exophthalmometer. Ophthal Plast Reconstr Surg 20:448, 2004
20. Zhang ZY, Zhang Y, An JG, et al: Measurement of the globe proptosis by CT and its accuracy in patients with unilateral orbital fracture [Chinese]. J Plast Surg 25:169, 2009
21. Manson PN, Clifford CM, Su CT, et al: Mechanism of global support and posttraumatic enophthalmos: The anatomy of the ligament sling and its relation to intramuscular cone orbital fat. Plast Reconsr. Surg 77:193, 1986