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# Does vertical incomitance predict the diplopia outcome in orbital fracture patients? A prospective study of 188 patients

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ABSTRACT

*Objective:* To determine the predictive value of vertical incomitance for diplopia outcome in orbital fracture patients.

*Patients and methods:* A prospective cohort study composed of patients with orbital fractures was designed. The predictor variable was vertical incomitance, and the primary outcome variable was diplopia. Incomitance was calculated in prism diopters (Δ) as the difference of the maximum absolute deviation between the upper and lower three gaze directions. Standard statistics for patient characteristics, the Fisher exact test for categorical variables and the Wilcoxon rank sum test for continuous variables were computed.

*Results:* The sample was composed of 188 patients grouped as follows: non-operated ($n = 124$) and operated ($n = 64$). Fifty-one patients showed vertical incomitance of whom 10 (19.6%) had persistent diplopia at the 1-year follow-up. The mean incomitance was 9.6Δ in the diplopia group versus 2Δ in the non diplopia group ($OR = 1.13$; $p < 0.001$). There was a statistically significant association between vertical incomitance of >2Δ and persistent diplopia at 1 year after adjusting for the surgery variable ($OR = 1.07$; $p < 0.04$).

*Conclusion:* The present study has demonstrated that in orbital fracture patients, vertical incomitance was associated with (1) persistence of long-term diplopia, (2) the decision to perform surgery, and (3) the severity of the fracture.



## 1. Introduction

Comitance and incomitance are orthoptic terms defining the two common forms of strabismus according to the different angles of ocular deviations in space (Spiritus, 1994; Rosenbaum and Santiago, 1999; von Noorden and Campos, 2002; Yonghong et al., 2008; Archer, 2011; Cruz et al., 2011; Graeber and Hunter, 2015). Comitance refers to a constant deviation of the eyes during ocular movements typically found in patients with congenital and early-onset strabismus, which is related to supranuclear disorders and associated with normal oculo-motor muscle and nerve function. Usually, these patients do not complain of diplopia because of central suppression (Spiritus, 1994; Rosenbaum and Santiago, 1999; von Noorden and Campos, 2002; Yonghong et al., 2008; Archer, 2011; Cruz et al., 2011; Graeber and Hunter, 2015). Conversely, incomitance refers to a deviation of the visual axes whose angle changes in the different directions of the gaze increasing as the eyes move in the field of action of an underacting muscle (Rosenbaum and Santiago, 1999; von Noorden and Campos, 2002; Archer, 2011; Cruz et al., 2011). This form of strabismus is characteristically related to acquired paralytic and mechanical-restrictive factors possibly encountered after orbital trauma and is usually associated with diplopia (Rosenbaum and Santiago, 1999; von Noorden and Campos, 2002).

Different patterns of post-traumatic strabismus can be observed depending on the predominant paretic versus restrictive components that can be simultaneously exhibited. This makes the evaluation of post-traumatic strabismus especially challenging

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(Rosenbaum and Santiago, 1999; von Noorden and Campos, 2002). Moreover, the diagnosis of incomitance has typically been defined related to the primary gaze and applied to symmetrical or bilateral forms of strabismus such as intermittent exotropia. In these cases, the incomitance is characteristically elicited in lateral gazes and is only exceptionally associated with diplopia given the great capacity of central fusion of two separate horizontal images (Spiritus, 1994; Rosenbaum and Santiago, 1999; von Noorden and Campos, 2002; Yonghong et al., 2008; Archer, 2011; Cruz et al., 2011; Graeber and Hunter, 2015). Conversely, post-traumatic strabismus is typically asymmetrical and related to restrictive ocular limitation. In these cases, the incomitance would be elicited in vertical gazes inducing rapidly bothersome diplopia given the less developed capacity of the brain to fuse two separate vertical images (Rosenbaum and Santiago, 1999; von Noorden and Campos, 2002).

Moreover, the conservative and surgical management of incomitant vertical strabismus is both challenging and problematic leading to a barely predictable resolution of diplopia. Thus, the persistence of vertical incomitance can negatively affect the field of binocular single vision leading to a disabling condition that can prevent completion of common everyday tasks (Rosenbaum and Santiago, 1999; von Noorden and Campos, 2002). Therefore intuitively, it would seem important to stratify patients with diplopia following orbital fractures according to the incomitance, especially its most insidious vertical component. It is this condition that could most negatively impact the outcome of conventional orbital reconstructive procedures for the resolution of double vision. This information would become very useful for determining realistic goals when planning surgical correction of orbital fractures in patients who display severe vertical incomitance.

Additionally, ocular motility disorders and their clinical subjective manifestation (i.e., diplopia), represent the main clinical indicators used by practitioners to make decisions regarding surgical management. They are the most documented criteria used to monitor surgical outcome for orbital fractures and are the most common annoying ophthalmological sequelae. Thus far, studies on these disorders have focused mainly on the prevalence of diplopia, its possible association with development of enophthalmos and the possible beneficial effects of surgical treatment on the functional status of ocular motility (Biesman et al., 1996; Harris et al., 1998; Folkestad and Westin, 1999; Burnstine, 2002; Gosse et al., 2010; Tahiri et al., 2010; Gosau et al., 2011; Higashino et al., 2011; Alhamdani et al., 2015; Bartoli et al., 2015; Steinegger et al., 2015; Su et al., 2016; Ramphul and Hoffman, 2017; Gavin Clavero et al., 2018; Jung et al., 2018).

Conversely, only a few studies have been published reporting on the value of initial ocular motility disorders and/or diplopia to predict surgical outcome based on a comprehensive orthoptic assessment (Higashino et al., 2011; Alhamdani et al., 2015; Bartoli et al., 2015; Steinegger et al., 2015; Su et al., 2016; Ramphul and Hoffman, 2017; Gavin Clavero et al., 2018). The Hess screen test as well as its best known modified version, the Lancaster red-green test are the most commonly reported methods of assessing muscular restrictions of ocular movements in orbital traumatology. Unfortunately, these tests only provide a diagrammatic representation of ocular deviations in the nine cardinal gaze directions with no quantification of such deviations. In fact, ocular deviations are most reliably quantified by using the alternate cover test in all nine gaze directions as well as Hess-Weiss deviometry (Rosenbaum and Santiago, 1999; von Noorden and Campos, 2002).

Thus far, quantitative evaluation of ocular motility following orbital surgery has been insufficiently studied (Alhamdani et al., 2015). This has probably contributed to a certain degree of status quo situation in understanding and improving the functional management of orbital fractures in terms of single binocular vision.

To the best of our knowledge, only one study has quantitatively assessed ocular motility characteristics to determine the final outcome regarding diplopia in orbital fractures management (Alhamdani et al., 2015). However, the vertical incomitance and its potential impact on the final functional outcome in orbital trauma remains surprisingly unreported as does the association between incomitance and the type and the severity of orbital fractures.

The purposes of the present study were thus to determine (1) the predictive ability of vertical incomitance for the outcome of diplopia in patients with orbital fractures, and (2) its association with type and severity of fracture. The investigators hypothesized that vertical incomitance could predict diplopia outcome and could be associated with the fracture's severity in terms of periorbital soft tissue disruption. The specific aims of the study were to measure, compare, or estimate a set of likely variables to identify the possible risk factors of post-traumatic diplopia by analyzing the clinical charts of 188 patients with orbital fractures among whom 124 were surgically and 64 conservatively treated.

## 2. Material and methods

### 2.1. Study design

To address the research purpose, the investigators designed and implemented a prospective cohort study. This study followed the Declaration of Helsinki on medical protocol and ethics, and the regional Ethical Review Board of Geneva approved the study (Study number 12-255).

### 2.2. Study sample

All patients presenting to the Maxillofacial Surgery Division of the University Hospitals of Geneva, Switzerland between 2010 and 2016 for the evaluation and management of orbital fractures were reviewed. All patients with pure orbital fractures, defined as limited to the orbital walls, at the initial presentation who had undergone a period of at least 1 year of medical and ophthalmological follow-up were included and clinical and CT-scan data analyzed.

Patients were excluded as study subjects if they were younger than 18 years, had a previous history of orbital and/or ophthalmologic surgery, a follow-up of <1 year, impure orbital fractures and monocular vision or non-stereoscopic vision.

The criteria for surgery in all patients were based upon our following in-house criteria: 1) orbital wall defect size of greater than 2 $cm^2$ and evidence of periorbital soft tissue and/or inferior rectus muscle herniation within the maxillary sinus and/or medial rectus muscle herniation within the ethmoidal cells on CT-scan 2) immediate ocular motility restriction in at least one field of gaze or annoying diplopia at the 10-day follow-up examination 3) enophthalmos immediately obvious to the naked eye or $\geq$2 mm difference between the globe projection of the two eyes as measured by Hertel exophthalmometry at the 10-day follow-up examination of >3 mm.

The severity of the fracture was evaluated by CT scan examination and classified as follows:

Type 1: Linear fractures with the fracture line running along the infraorbital nerve canal to the retrobulbar area with bone displacement less than the orbital floor thickness; Type 2: Displaced fractures with periorbital soft tissue herniation and with the inferior rectus and/or medial rectus muscle within the orbit; Type 3: Displaced fractures with periorbital soft tissue herniation with the inferior rectus muscle within the maxillary sinus and/or the medial rectus within the ethmoidal cells.

All patients were assessed initially after the trauma and 3–12 months post-trauma by an experienced orthoptist supervised by an ophthalmologist using the following examinations: 1) distance and near visual acuities, 2) Hertel exophthalmometry for enophthalmos evaluation, 3) corneal light reflex (Hirschberg test), 4) measurements of binocular misalignment using an alternate prisms cover test in all nine cardinal gaze directions at 6 m distance and Hess-Weiss coordimetry, 5) horizontal/vertical and incyclo/excyclotorsion deviation with Harms wall deviometry, 6) torsional deviations of the visual axis with Maddox rod screen testing, 7) vertical deviation with the Bielschowsky head-tilt test.

Additionally, diplopia was evaluated by assessment of ductions and versions in the six cardinal fields of gaze by asking the patient to follow the examiner's finger without moving the head. Incomitance was calculated in prism diopters (Δ) as the difference of the maximum absolute deviation between the upper and lower three gaze directions. To note, we decided to focus on vertical incomitance which, given the limited ability of the brain to fuse two separate vertical images, can generate disabling forms of diplopia that are difficult to manage either conservatively or surgically. The cut-off value for the diagnosis of vertical incomitance was set to >2Δ, which represents the limit of cerebral vertical fusional capacity to overcome vertical deviations (von Noorden and Campos, 2002).

### 2.3. Study variables

The predictor variable was vertical incomitance and primary outcome variable was diplopia. Other study variables included age, gender, mechanism of injury, fracture location and severity, time between trauma and examination, pre- and post-operative symptoms and type of treatment (surgical versus conservative).

### 2.4. Data analysis

Analyses were done using R 3.4.1 statistical software (R Development Core Team, Vienna, Austria). Patient characteristics were described using standard statistics (mean, standard deviation, frequency and percentages) and were compared using the Fisher exact test for categorical variables and the Wilcoxon rank sum test for continuous variables. We examined the ability of vertical incomitance to predict diplopia at 1 year using receiver operating curves (ROC), area under the curve (AUC), sensitivity, specificity, and predictive values. Finally, the association between diplopia at 1 year and vertical incomitance was estimated using logistic regression, adjusting for surgical treatment.

## 3. Results

Among the 188 patients who fulfilled the inclusion criteria, mean age at the time of trauma was 44.5 years (standard deviation 20.9 years) with a male predominance (138 patients; 73.4%).

64 out of the 188 patients (34%) were operated. Compared to non-operated patients, operated patients were similar in their age and gender distribution, as well as in the mechanism and side of fracture (Table 1).

However, they differed in terms of type and site of fracture, with operated patients having more floor or combined floor and medial wall and Type 3 fractures. Of the 15 patients with diplopia at 1 year, 2 had not undergone surgery and 13 had been operated. Vertical incomitance, either measured as a continuous deviation or with a cutoff at 2Δ, strongly differed between operated and non-operated patients (Table 1). Indeed, only 11.3% of non-operated patients had vertical incomitance, while 57.8% of operated patients presented vertical incomitance ($p < 0.001$). The maximum deviation of the vertical incomitance at baseline was highly variable among operated and non-operated patients (Fig. 1).

**Table 1**
Sample characteristics at baseline.

| | Not operated N = 124 | Operated N = 64 | *p* |
|---|---|---|---|
| Gender | | | 0.86 |
| Male | 90 (72.6%) | 48 (75.0%) | |
| Female | 34 (27.4%) | 18 (25.0%) | |
| Age in years, median (IQR) | 43.5 [26.0; 63.0] | 31.0 [25.0; 48.0] | 0.03 |
| Mechanism of trauma | | | 0.07 |
| Aggression | 39 (31.5%) | 31 (48.4%) | |
| Fall | 38 (30.6%) | 11 (17.2%) | |
| Car accident | 24 (19.4%) | 7 (10.9%) | |
| Sport | 15 (12.1%) | 11 (17.2%) | |
| Other | 8 (6.5%) | 4 (6.2%) | |
| Site of fracture | | | 0.01 |
| Floor | 71 (57.3%) | 46 (71.9%) | |
| Medial wall | 32 (25.8%) | 7 (10.9%) | |
| Floor and medial wall | 9 (7.3%) | 10 (15.6%) | |
| Roof | 8 (6.5%) | 1 (1.6%) | |
| Lateral wall | 4 (3.2%) | 0 (0.0%) | |
| Type of fracture | | | <0.001 |
| Type 1 | 57 (46.0%) | 7 (10.9%) | |
| Type 2 | 52 (41.9%) | 19 (29.7%) | |
| Type 3 | 15 (12.1%) | 38 (59.4%) | |
| Incomitance | | | |
| Mean (SD) | 0.81 (2.12) | 6.23 (8.43) | <0.001 |
| N (%) | 14 (11.3%) | 37 (57.8%) | <0.001 |
| Diplopia | 2 (1.6%) | 13 (20.0%) | <0.001 |

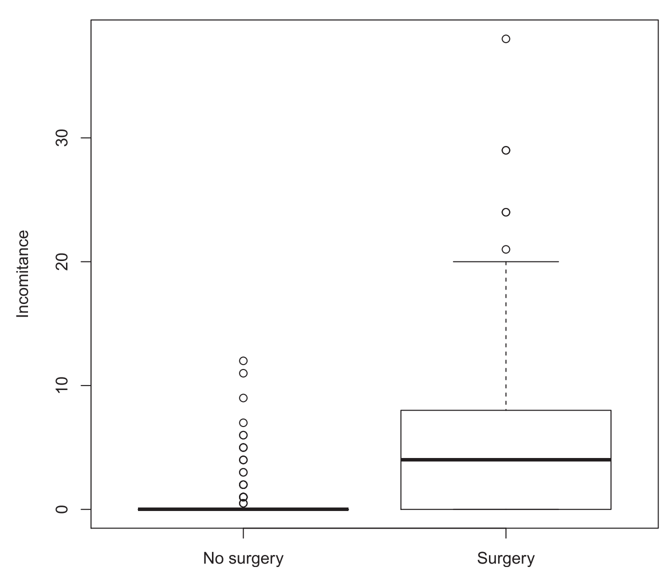


**Fig. 1.** Boxplots of incomitance at baseline for operated and non operated patients.

Fifty-one patients showed vertical incomitance of whom 10 (19.6%) had persistent diplopia at the 1-year follow-up. Patients with vertical incomitance were similar in terms of gender, age, mechanism, site and side of the fracture. However, they differed strongly on the type of fracture, with only 7.8% of Type 1 fractures among patients with vertical incomitance, compared to 43.8% among patients with no vertical incomitance ($p < 0.001$) (Table 2).

The mean vertical incomitance was 9Δ in the diplopia group versus 2Δ in the non diplopia group (Fig. 2) showing a strong association between vertical incomitance and diplopia (OR = 1.13; $p < 0.001$). This association remained significant even after adjusting for surgical treatment (OR = 1.07; $p < 0.04$).

Of the 15 patients with diplopia at 1 year, 10 had vertical incomitance, yielding a sensitivity of 66.7%. The specificity was 76.3%. The positive and negative predictive values (PPV and NPV)

**Table 2**
Sample characteristics at baseline by vertical incomitance.

| | Vertical incomitance | | *p* |
|---|---|---|---|
| | No | Yes | |
| | N = 137 | N = 51 | |
| Male gender | 101 (73.7%) | 37 (72.5%) | 1.00 |
| Age in years, median (IQR) | 42.0 [25.0, 59.0] | 33.0 [27.5, 59.0] | 0.89 |
| Mechanism | | | 0.92 |
| Aggression | 50 (36.5%) | 20 (39.2%) | |
| Fall | 35 (25.5%) | 14 (27.5%) | |
| Car accident | 24 (17.5%) | 7 (13.7%) | |
| Sport | 20 (14.6%) | 6 (11.8%) | |
| Other | 8 (5.8%) | 4 (7.8%) | |
| Fracture site | | | 0.20 |
| Floor | 83 (60.6%) | 34 (66.7%) | |
| Medial wall | 29 (21.2%) | 10 (19.6%) | |
| Floor and medial wall | 12 (8.8%) | 7 (13.7%) | |
| Roof | 9 (6.6%) | 0 (0%) | |
| Lateral wall | 4 (2.9%) | 0 (0.0%) | |
| Fracture type | | | <0.001 |
| Type 1 | 60 (43.8%) | 4 (7.8%) | |
| Type 2 | 54 (39.4%) | 17 (33.3%) | |
| Type 3 | 23 (16.8%) | 30 (58.8%) | |
| Diplopia | 5 (96.4%) | 10 (19.6%) | <0.001 |

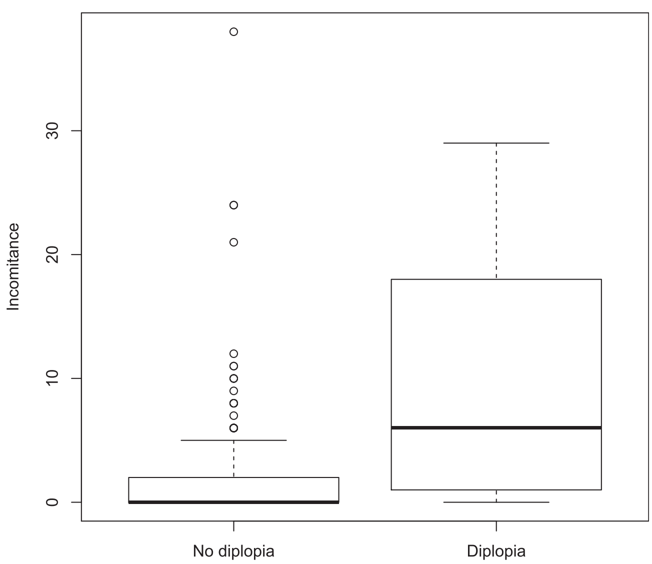


**Fig. 2.** Boxplots of incomitance at baseline for patients with and without diplopia at 1 year. The mean vertical incomitance was 9Δ in the diplopia group versus 2Δ in the non diplopia group.

were 19.6% and 96.4%, respectively. Note that PPV was low due to the low prevalence of diplopia at 1 year. Based on this sample, a more sensitive cutoff, which would reduce the risk of false negative results (i.e., missing patients who will develop diplopia), could be fixed at 0.8Δ. This second cutoff yielded a sensitivity of 80.0% and a specificity of 68.2%. Fig. 3 displays the ROC curve of vertical incomitance and diplopia (AUC: 0.78), with the two cutoffs (0.8Δ and 2Δ) indicated by the two round circles.

## 4. Discussion

The purpose of the present study was to evaluate the predictive value of vertical incomitance for diplopia outcome in patients with orbital fractures and its possible association with the fracture's severity.

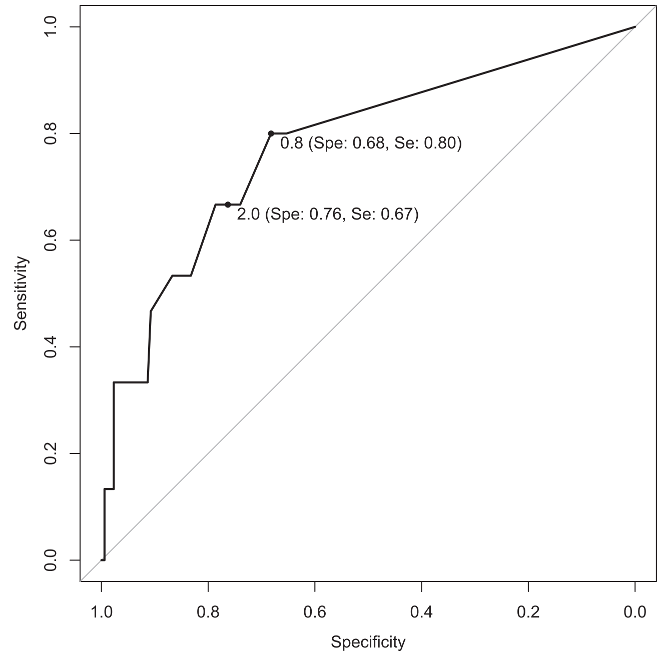


**Fig. 3.** ROC curve of vertical incomitance and diplopia (AUC: 0.78), with the two cutoffs (0.8Δ and 2Δ) indicated by the two round circles.

We hypothesized that vertical incomitance could predict diplopia outcome and could be associated with the fracture's severity. The specific aims of the study were to measure, compare, or estimate a set of likely variables to identify the possible risk factors of post-traumatic diplopia by analyzing the clinical charts of 188 patients with orbital fractures among whom 124 were surgically and 64 conservatively treated.

The results of this study supported our hypothesis revealing a significantly predictive value of vertical incomitance for diplopia persistence in patients with orbital fractures. A significant association between the severity of vertical incomitance and the decision to perform surgery rather than opt for conservative treatment and with the severity of the fracture was also determined.

Unfortunately, these results could not be compared with other data in the literature, given the absence of similar studies describing incomitance as a possible parameter that could influence the functional outcome of orbital fractures. Although the literature is replete with clinical studies describing management of orbital fractures, only few studies have specifically focused on the quantitative evaluation of ocular motility (Biesman et al., 1996; Harris et al., 1998; Folkestad and Westin, 1999; Burnstine, 2002; Gosse et al., 2010; Tahiri et al., 2010; Gosau et al., 2011; Higashino et al., 2011; Alhamdani et al., 2015; Bartoli et al., 2015; Steinegger et al., 2015; Su et al., 2016; Ramphul and Hoffman, 2017; Gavin Clavero et al., 2018; Jung et al., 2018). To date, only Alhamdani et al. (2015) have investigated the association between clinical measurement of ocular motility disturbances and the final diplopia outcome in patients with orbital fractures. They retrospectively analyzed data from 87 patients either managed surgically or conservatively who were assessed by using the Goldmann perimeter. They showed an association between their own in-house binocular single vision score and the diplopia outcome, the follow-up time and the number of follow-up visits.

In contrast to our method, the assessment of ocular motility was based on the muscular excursions in 6 cardinal directions of gaze using a modified Goldmann perimeter chart technique. The main weakness associated with this method is that the Goldmann perimeter is a semi-quantitative test that only evaluates the capacity of the oculomotor and neuro-sensorial system to suppress or fuse images and thus the ability to function without double vision. Moreover, this ability is highly variable between individuals. The authors did not assess horizontal, vertical and torsional angular deviations in the conventional nine diagnostic positions of gaze in prism diopters.

Interestingly, our results also revealed that patients with a severe periorbital tissue entrapment were those with the highest degree of vertical incomitance and with persistent diplopia over the long term.

This finding seems to suggest the hypothesis that vertical incomitance could reflect the clinical severity of the anatomical disruption of the orbital musculo-connective motility apparatus on the fracture's side. The importance of the role played by this apparatus in ocular movements has been highlighted by Koorneef (Koornneef, 1982). It is now well known that the scar between the muscles and the damaged connective septa system rather than a true entrapment of the muscles within the maxillary sinus and/or ethmoidal cells is responsible for the traction effects that explain the restrictive condition typically found after orbital fractures muscle. This particular restrictive pattern has been advocated as the main cause of the vertical strabismus that produces severe motility disturbances in upward and downward gaze in abduction and adduction. The vertical ocular deviations secondary to this restriction can generate different degrees of incomitance, which is enhanced as the eye movement is directed in the fields of gaze of the fracture site (Rosenbaum and Santiago, 1999; von Noorden and Campos, 2002; Archer, 2011; Cruz et al., 2011; Koornneef, 1982; Iliff et al., 1999).

The measurement of vertical incomitance as the maximum ocular deviation between upward and downward gaze in all directions will provide information of paramount importance as it would help in quantifying the contribution of the periorbital tissue damage to ocular motility disorders and thus to the development of diplopia (Rosenbaum and Santiago, 1999; von Noorden and Campos, 2002; Archer, 2011; Cruz et al., 2011). This information could help in solving the eternal dilemma of determining which patients will benefit from surgical repair of orbital fractures, knowing that it might be impossible to achieve complete resolution of diplopia induced by restrictive conditions. Thus, in light of our results, it would seem appropriate to propose surgical management of patients with fractures associated with a vertical incomitance of more than 2Δ given their propensity to induce long term diplopia. In fact, vertical incomitance has been recognized as one of the most challenging strabismus problems to treat and also as the most important risk factor for developing bothersome diplopia. Some authors have advocated combining orbital fracture repair, which is determinant in relieving the motility apparatus restriction, with a weakening procedure of the overacting synergist in the contralateral eye (Archer, 2011; Cruz et al., 2011). Nevertheless, it should be pointed out that although it is often possible to obtain a satisfactory ocular alignment in the primary position, the field of single binocular vision could be insufficient to accomplish common daily tasks (Rosenbaum and Santiago, 1999; von Noorden and Campos, 2002; Archer, 2011; Cruz et al., 2011; Koornneef, 1982; Iliff et al., 1999). Thus, the treatment of vertical incomitance must be well discussed with the patient in order to establish realistic goals. The patient should also be aware of the risk of residual bothersome and intractable diplopia after the surgery.

Regarding the management of the orbital fractures, although the literature is replete with reports describing conservative versus surgical treatment, thus far there are no consensual international guidelines to resolve this highly sensitive issue. Thus, given the absence of well standardized guidelines for determining the need, timing and best choice of treatment for OFs, surgeons rely on empirical in-house decision-making algorithms mainly based on the association of different clinic-radiological findings (Biesman et al., 1996; Harris et al., 1998; Levine et al., 1998; Folkestad and Westin, 1999; Burnstine, 2002; Gosse et al., 2010; Tahiri et al., 2010; Gosau et al., 2011; Higashino et al., 2011; Matsunaga et al., 2011; Schouman et al., 2012; Kang et al., 2013; Kunz et al., 2013; Alhamdani et al., 2015; Bartoli et al., 2015; Steinegger et al., 2015; Bruneau et al., 2016; Su et al., 2016; Ramphul and Hoffman, 2017; Gavin Clavero et al., 2018; Jung et al., 2018). This means that the decision varies substantially from surgeon to surgeon, although the generally accepted attitude is to wait 1–2 weeks for observation before deciding the management strategy.

Regarding the prediction of persistent sequelae of ocular motility, severe diplopia immediately after the trauma and young age have thus far been the only risk factors that have emerged from the literature (Tahiri et al., 2010; Higashino et al., 2011; Alhamdani et al., 2015; Su et al., 2016; Ramphul and Hoffman, 2017; Gavin Clavero et al., 2018). Lesions of the inferior rectus muscle as indicated by an augmentation of muscular volume on CT scan have been associated with the persistence of binocular diplopia and ocular motility abnormalities as well as the occurrence of enophthalmos (Levine et al., 1998; Matsunaga et al., 2011; Schouman et al., 2012; Kang et al., 2013). In a previous study, we demonstrated a correlation between the maximum height of periorbital tissue herniation within the maxillary sinus, inferior rectus muscle displacement relative to the level of the orbital floor as measured on coronal CT scan images and the persistence of binocular diplopia as well as the severity of the ocular motility restriction and the development of enophthalmos (Schouman et al., 2012). Similar results have also been confirmed by other studies.

The main strength of the present study is that it is the only large case series to date to assess prospectively the relationship between incomitance and diplopia outcome in orbital fracture patients. Moreover, the orthoptical evaluation was standardized, and the clinical-radiological follow-up visits were with fully compliant patients. Data were collected during well structured routine clinical examinations, and the physicians at that time were blinded to the goal of the study. The main limitation of our study is that the orbital repairs were performed by various surgeons using different techniques.

## 5. Conclusion

The present study has demonstrated that in orbital fracture patients, vertical incomitance was associated with (1) persistence of long-term diplopia irrespective of surgical versus conservative management, (2) the decision to perform surgery, and (3) the severity of the fracture.

Therefore, vertical incomitance could be seen as the missing link between damage to the orbital musculo-connective motility apparatus and restrictive residual diplopia and could be used as a useful clinical parameter for assessing the severity of the orbital fracture and for predicting the risk of an unfavorable diplopia outcome.

## Ethical approval

To address the research purpose, the investigators designed and implemented a prospective cohort study. This study followed the Declaration of Helsinki on medical protocol and ethics, and the regional Ethical Review Board of Geneva approved the study (Study number 12-255).


## Financial disclosure statement

This research did not receive any specific grant.

## Conflicts of interest

All the authors declare that they have no conflict of interest.

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