



## Coincidence of craniocerebral and craniofacial injuries

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### ABSTRACT

**Purpose:** To determine the incidence of craniocerebral injuries in patients who experienced upper facial or midfacial traumas associated with the disorders of consciousness. To find which types of craniofacial traumas predisposed to craniocerebral injuries. To analyze a relationship between the site of the force application and the type of resultant craniocerebral injury.

**Materials and methods:** The study included 3,481 patients with upper facial and midfacial traumas. All 425 patients with craniofacial traumas and disorders of consciousness at the time of the event or hospital admission, were qualified for computed tomography (CT) of the head.

**Results:** In 85/425 patients (20%), 70 men and 15 women (age 14–71 years), craniofacial trauma coincided with a craniocerebral injury. Upper facial dislocation and zygomatic-orbital-maxillary complex fracture significantly more often co-existed with skull, dura mater or cranial nerve injuries, and zygomatico-orbital fracture with the injuries of the brain. Application of force both centrally and laterally to the horizontal plane predisposed to skull, dura mater and cranial nerve injuries.

**Conclusion:** The recommendation to perform head CT in each patient with craniofacial trauma who experienced the disorders of consciousness is as simple as possible, yet provides high diagnostic sensitivity, facilitating proper management at initial stages post-injury.

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## 1. Introduction

Management of complex head traumas that involve both visceral and cerebral cranium requires a multidisciplinary approach with the participation of a neurosurgeon, maxillofacial surgeon, and sometimes also a laryngologist and ophthalmologist (Rajkumar et al., 2015). A plethora of classification systems of craniofacial injuries have been proposed thus far (Phillips and Turco, 2017). However, little is known about the management of complex head traumas (Phillips and Turco, 2017), and ambiguous data on clinical consequences of coinciding craniocerebral and craniofacial injuries justify further research in this matter.

The skull is a complex and difficult to analyze structure, which was reflected by a variety of proposed anatomical classification systems (Madhusudan et al., 2006; Di Ieva et al., 2014). Craniofacial skeleton constitutes the most anterior part of the head, limited superiorly by the hairline and inferiorly by the mentocervical fold.

In a classic approach, the craniofacial skeleton is divided into the upper face, midface and lower face, but Wanyura (1995) proposed a simpler topographic classification with only two units, the upper and lower face. According to Frenguelli et al. (1991), craniofacial skeleton comprises the inferior unit (mandible and maxilla up to the line of the piriform aperture), middle unit (maxillary processes, nasal bones, orbital fundus and the ethmoid), and lateral unit (zygomatic bones and zygomatic arches).

Anatomical structure and architecture of both craniocerebral and craniofacial skeleton is inhomogeneous. A number of stress-bearing zones have been identified within the skull, with weaker areas located in between. The stress-bearing zones of craniocerebral skeleton are formed by Felizet's arches, also referred to as Ratke's trabecula, which are separated by weaker zones, known as Felizet's inter-arches. In the case of craniofacial skeleton, the reinforced zones have a form of the so-called Sicher's pillars: canine, zygomatic and pterygoid ones; these are even and symmetric areas composed of a compact bone and trabecula of a spongy bone (Sicher, 1965). The Sicher's pillars determine vertical resistance of craniofacial skeleton. They arise bilaterally from the bases of alveolar processes of the mandible, communicating with the

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contralateral pillar via the hard palate. Then, they ascend, bending around the nasal cavity and the orbits; the curvature of each pillar is additionally reinforced by supraorbital and infraorbital arches. After reaching the skull base, the Sicher's pillars communicate with the Felizet's arches. These communication sites are referred to as craniofacial fulcrums: 1) the pterygoid one, formed by the orbitosphenoid arch and the pterygoid pillar, 2) the fronto-orbital one, composed of the orbitosphenoid arch and the zygomatic pillar, and 3) the glabellar one which connects the anterior Felizet's arch with the craniofacial column, two canine pillars and two supraorbital pillars.

The retaining trabeculae, first described by Ombredann, are the true sites of skeletal reinforcement, composed of a compact, trauma-resistant bone, arranged in three clusters located symmetrically on both sides of the upper face. The retaining trabeculae can be found within the zygomatic bone, frontal processes of the maxilla and at the point where the alveolar processes of the maxilla communicate with the hard palate. The Ombredann's trabeculae are separated by three stress-prone linear zones that cross the Sicher's pillars. These zones have been identified during a cadaveric study conducted by a French military surgeon René Le Fort; the Results of this study constituted the basis for the most widespread classification system of craniofacial fractures (Phillips and Turco, 2017).

The classic classification system of craniofacial fractures proposed by Le Fort, although used to this date, primarily due to its simplicity and clarity for physicians with various specialties, unfortunately does not accurately reflect the real clinical condition. As emphasized by many authors, massive craniofacial injuries differ considerably in terms of their pathological anatomy and clinical presentation from classic *en bloc* fractures included in the Le Fort's classification, and their treatment requires different management strategies (Merville, 1974; Merville et al., 1974; Manson, 1986; Scherer et al., 1989; Donat et al., 1998; O'Sullivan et al., 1999; Aksoy et al., 2002; Buitrago-Tellez et al., 2002; Katzen et al., 2003; Samolczyk-Wanyura, 2007). Moreover, it needs to be stressed that the properties of living tissues differ from those analyzed in cadaveric studies. Thus, the data about craniofacial fractures obtained by Le Fort during his cadaveric study should not be generalized onto living persons with this type of trauma (Merville, 1974; Merville et al., 1974; Manson, 1986; Samolczyk-Wanyura, 1989, 2007; Scherer et al., 1989; Donat et al., 1998; O'Sullivan et al., 1999; Aksoy et al., 2002; Buitrago-Tellez et al., 2002; Katzen et al., 2003).

A more comprehensive classification of craniofacial fractures, used in our present study, has been proposed by Samolczyk-Wanyura (1989). This author identified seven main groups of craniofacial fractures. The Samolczyk-Wanyura (1989) classification is based on the point of force application, the extent of the skeletal injury, clinical presentation and potential complications, and as such, can be helpful in the determination of a management strategy. In this system, craniofacial injuries of the upper face are classified into two types: 1) fronto-orbito-nasal fractures associated with a damage of the glabellar fulcrum and both fronto-orbital fulcrums, and distribution of the injury's force between the three Felizet's arches and whole surface of the craniofacial column, from where it is transmitted to the sphenoid corpus and further down between the Sicher's pillars, and 2) cranio-orbital fractures with damage of the fronto-orbital fulcrum and distribution of the injury's force along the ethmoid plates, and then, between the Felizet's arches onto the calvarium and skull base, and between the Sicher's pillars onto the craniofacial skeleton.

According to Samolczyk-Wanyura (1989), the type of midfacial trauma depends on the point where the injury's force had been applied. When the force is applied centrally, it may cause a

midfacial injury in the form of 1) unilateral or bilateral orbitonasal dislocation (Tessier et al., 1971; Morax and Bernard, 1983; Samolczyk-Wanyura, 1989, 2007; Wanyura, 1990) with the fracture of nasal bones, walls and inferomedial rims of the orbit and the ethmoid, or 2) upper facial dislocation, according to Merville et al. (1974), referred to as comminuted facial dislocation, with the detachment of the upper facial unit from the skull along the classical line of high Le Fort III craniofacial dissociation, and the detachment of palatal plate from the rest of the skull along the line of Le Fort I fracture. In turn, the midfacial fractures caused by force applied laterally, can be classified into three types: 1) isolated fractures of orbital fundus, frequently with a concomitant fracture of medial orbital wall, b) zygomatico-orbital fractures, usually caused by force applied perpendicularly to the zygomatic Sicher's pillars, and involving its largest curvature, i.e. lateral and inferior orbital rim, zygomatico-alveolar crest and zygomatic arch, and 3) zygomatic-orbital-maxillary complex fracture caused by force applied laterally onto the zygomatic bone and spreading onto the maxilla along the zygomatic pillar and infraorbital Sicher's arch, which Results in the fracture of zygomatic bone, anterior, lateral and medial surfaces of the mandible and two or three orbital walls (lateral, inferior and medial) (Merville, 1974; Samolczyk-Wanyura, 1989, 2007).

Post-traumatic pathologies of the craniocerebral skeleton and intracranial structures include fractures of the skull vault with translocation of bone fragments or without, rupture of the dura mater with post-traumatic liquorrhea and pneumocephalia, cranial nerve injuries, epidural or subdural hemorrhage, post-traumatic subarachnoid hemorrhage, cerebral hemorrhagic contusion, post-traumatic cerebral hematoma and brain edema. To simplify the analyses, all the pathologies mentioned above were classified into three groups, as described below.

The aims of the study were: 1) to determine the incidence of craniocerebral injuries in patients who experienced upper facial or midfacial traumas associated with the disorders of consciousness, 2) to find which types of craniofacial traumas according to the Samolczyk-Wanyura (1989) classification system predisposed to craniocerebral injuries, and 3) to analyze a relationship between the site of the force application and the type of resultant craniocerebral injury.

## 2. Material and methods

The analysis included patients with upper facial and midfacial traumas, treated at the St. Barbara Regional Specialist Hospital No. 5 in Sosnowiec in 2000–2015. The hospital is a tertiary trauma center, which explains the relatively large number of patients referred due to head traumas.

Craniofacial injuries were diagnosed based on clinical presentation and head radiograms. Patients with lower facial traumas were excluded from the analysis due to their relatively small number. Eventually, the study included medical histories of 3,481 patients.

The concomitant craniocerebral injury was suspected whenever the patient presented with disorders of consciousness at the time of admission, as confirmed by other than the maximum value of the Glasgow Coma Scale (GCS). Another criterion of suspected craniocerebral injury was the loss of consciousness at the time of the trauma. Based on these criteria, 425 patients were qualified for computed tomography (CT) of the head. In 85 of those patients, upper facial or midfacial trauma turned out to coincide with a craniocerebral injury. This group included 70 men and 15 women aged between 14 and 71 years (mean 36 years).

Shortly after the admission, the patients were evaluated and treated by various specialists, most often general surgeons,

orthopedists and maxillofacial surgeons. The neurosurgeon was called if features of fresh bleeding within the cranial cavity were found in the CT scan of the head. The qualification criteria for head CT that had been used at our center seem to be simple, reproducible and highly sensitive. This is vitally important as the physician who first evaluates a patient with a head trauma needs to assess the situation promptly and to make appropriate diagnostic and therapeutic decisions.

To simplify the analysis, craniocerebral injuries diagnosed based on head CT were classified into the following three groups: 1) group I – injuries of the skull, dura mater and cranial nerves; this group included patients diagnosed with linear craniocerebral fractures (n = 48), craniocerebral inclination (n = 17), acute epidural hemorrhage (n = 18), pneumocephalia (n = 25), rhinorrhea (n = 11), and olfactory nerve injury (n = 19), 2) group II – cerebral injuries; this group included patients diagnosed with cerebral hematoma (n = 15), cerebral wound (n = 1), and cerebral edema (n = 43), and 3) group III – post-traumatic lesions in subdural and subarachnoid space; this group included patients diagnosed with acute subdural hematoma (n = 9), posttraumatic subarachnoid hemorrhage (n = 3), and subdural hygroma (n = 1).

Craniofacial injuries were classified with the previously mentioned system proposed by Samolczyk-Wanyura (1989). To demonstrate that application of the force at a given site predisposed to some specific type of craniofacial injuries, the latter were classified as follows: 1) depending on the relation of the injury's force to horizontal plane: as central (n = 4), lateral (n = 21) or mixed (n = 60), and 2) depending on the relation of the injury's force to vertical plane: as high (n = 4), low (n = 24) or global (n = 57).

In 39 cases, conservative management was recommended by both a neurosurgeon and maxillofacial surgeon. Other patients required maxillofacial surgery with conservative neurosurgical management (n = 32), both maxillofacial surgery and neurosurgery (n = 8), or neurosurgery with the conservative maxillofacial approach (n = 6).

The data were subjected to statistical analysis with Dell Statistica v.13 package (Dell Inc. 2016; [software.dell.com](http://software.dell.com)). The Results were considered significant at  $p < 0.05$ . The analysis was based on the non-parametric maximum likelihood chi-square test of independence.

### 3. Results

#### 3.1. The coincidence of craniofacial traumas with craniocerebral injuries in patients with the disorders of consciousness

In line with the criteria specified above, 425 patients with craniofacial traumas who presented with the disorders of consciousness at the time of the event or admission to our center, were qualified for CT of the head. In 85 of these patients, head CT confirmed the presence of a craniocerebral injury. Hence, one per every five patients who experienced an upper face or midface trauma associated with the disorders of consciousness presented with a concomitant craniocerebral injury.

#### 3.2. The relationship between the type of craniofacial trauma according to the Samolczyk-Wanyura (1989) classification system and the occurrence of craniocerebral injury and type thereof

Three out of seven types of craniofacial traumas included in the Samolczyk-Wanyura (1989) classification system significantly more often co-existed with craniocerebral injuries in our patients. Specifically, upper facial dislocation and zygomatic-orbital-maxillary complex fracture turned out to co-exist with the group I

craniocerebral injuries, namely cranial, dura mater or cranial nerve injuries. Furthermore, zygomatico-orbital fracture was shown to be significantly more common in patients with group II craniocerebral injuries (injuries of the brain) (Tables 1–3, Figs. 1–3).

#### 3.3. The relationship between the site of the force application to the horizontal or vertical plane and the type of resultant craniocerebral injury

Statistical analysis demonstrated a significant relationship between the application of extensive mixed force both centrally and laterally to the horizontal plane and the occurrence of group I craniocerebral injuries, i.e. those involving the skull, dura mater and cranial nerves (Table 4, Fig. 4).

### 4. Discussion

A plethora of classification systems for craniofacial injuries have been proposed thus far. The classification used in our study, developed by Samolczyk-Wanyura (1989), accurately reflects the type of the injury and the site of force application, and as such, facilitates the diagnostic and therapeutic process. The classic, most widespread classification of craniofacial injuries proposed by Le Fort is not as comprehensive as the system mentioned above, which makes it less useful from a physician's perspective (Merville, 1974; Merville et al., 1974; Donat et al., 1998; Aksoy et al., 2002; Samolczyk-Wanyura, 2007; Phillips and Turco, 2017). Our present study demonstrated that some specific types of craniofacial traumas identified using the Samolczyk-Wanyura (1989) system might predispose to craniocerebral injuries whenever they are associated with the disorders of consciousness. Our group of 85 patients was too small to formulate any ultimate conclusions in this matter, but the hereby presented Results justify further research on the problem in question.

The established algorithm for craniofacial trauma management, according to which each patient who did not score maximally (15 pts) on the GCS or had a history of loss of consciousness immediately after trauma, should undergo CT of the head, seems to be too general. However, using such an approach, a physician, even one without adequate experience in neurological examination, is less likely to overlook a severe craniocerebral injury. Thus, this diagnostic strategy has been used by many authors (Lim et al., 1993; Alvi et al., 2003; Czerwinski et al., 2008) and is a routine practice at our center. In our present study, one out of five patients who experienced a craniofacial trauma and satisfied the above-mentioned qualification criteria for head CT indeed presented with a craniocerebral injury. This seems to be the key finding of this study, implying that the abovementioned diagnostic algorithm provides high sensitivity in the identification of individuals with

**Table 1**  
Coincidence of upper facial dislocation with group I craniocerebral injuries.

|   | Upper facial dislocation |         | Total % total |
|---|--------------------------|---------|---------------|
|   | No                       | Yes     |               |
| Skull, dura mater or cranial nerve injury |                          |         |               |
| No  | 8                        | 0       | 8             |
| % column:                                 | 15.69%                   | 0.00%   | 9.41%         |
| % line:                                   | 100%                     | 0.00%   |               |
| Yes                                       | 43                       | 34      | 77            |
| % column:                                 | 84.31%                   | 100.00% | 90.59%        |
| % line:                                   | 55.84%                   | 44.16%  |               |
| Total                                     | 51                       | 34      | 85            |
| % total:                                  | 60.00%                   | 40.00%  |               |

Chi-squared test,  $p = 0.003$ .

**Table 2**  
Coincidence of zygomatico-maxillary-orbital fracture with group I craniocerebral injuries.

| Skull, dura mater or cranial nerve injury | Zygomatico-maxillary-orbital fracture |        | Total % total |
|---|---------------------------------------|--------|---------------|
|   | No                                    | Yes    |               |
| No  | 4                                     | 4      | 8             |
| % column:                                 | 5.80%                                 | 25.00% | 9.41%         |
| % line:                                   | 50.00%                                | 50.00% |               |
| Yes                                       | 65                                    | 12     | 77            |
| % column:                                 | 94.20%                                | 75.00% | 90.59%        |
| % line:                                   | 84.42%                                | 15.58% |               |
| Total                                     | 69                                    | 16     | 85            |
| % total:                                  | 81.18%                                | 18.82% |               |

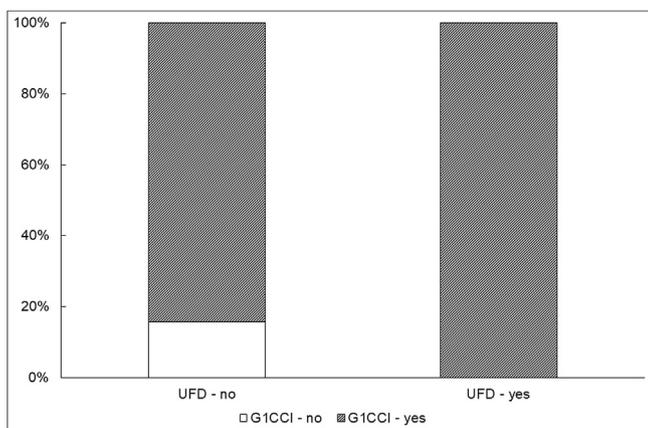
Chi-squared test,  $p = 0.034$ .

**Table 3**  
Coincidence of zygomatico-orbital fracture with group II craniocerebral injuries.

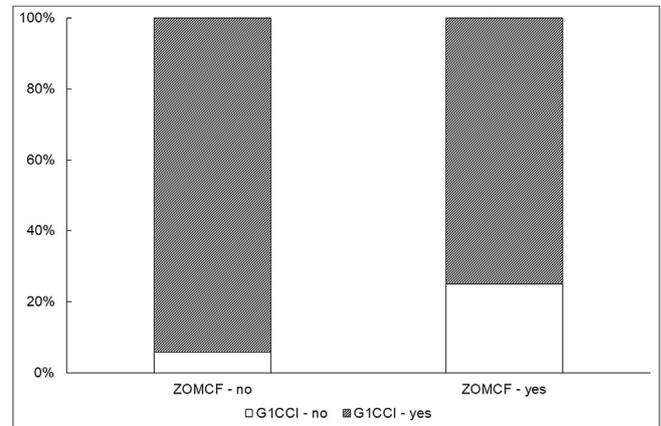
| Brain damage | Zygomatico-orbital fracture |        | Total % total |
|--------------|-----------------------------|--------|---------------|
|              | No                          | Yes    |               |
| No           | 22                          | 6      | 28            |
| % column:    | 28.95%                      | 66.67% | 32.94%        |
| % line:      | 78.57%                      | 21.43% |               |
| Yes          | 54                          | 3      | 57            |
| % column:    | 71.05%                      | 33.33% | 67.06%        |
| % line:      | 94.74%                      | 5.26%  |               |
| Total        | 76                          | 9      | 85            |
| % total:     | 89.41%                      | 10.59% |               |

Chi-squared test,  $p = 0.028$ .

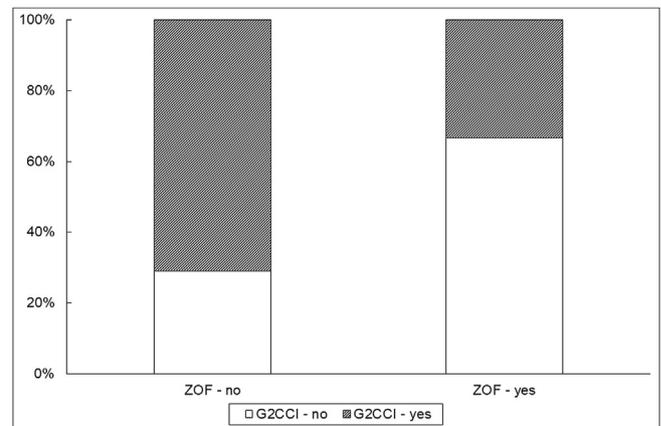
craniofacial trauma who are at increased risk of concomitant craniocerebral injury. Theoretically, at the time of admission to a hospital, the patient subjected to a brief neurological assessment might score 15 pts on the GCS, did not report a loss of consciousness, or there were no witnesses to confirm that he/she was unconscious at the time of the trauma. Under such circumstances, also other risk factors of craniocerebral injury reported in literature should be considered (Stiell et al., 2001), among them open skull fracture or radiographic evidence of a calvarial fracture fissure, manifestations of basilar skull fracture (raccoon eyes, Battle's sign), at least two episodes of vomiting, and age of 65 years or older. It is also worth adding antiaggregant and anticoagulant drugs to the above list, the use of which increases the risk of significant, large intracranial bleeding after a head injury.



**Fig. 1.** Coincidence of upper facial dislocation (UFD) with group I craniocerebral injuries (G1CCI).



**Fig. 2.** Coincidence of zygomatico-maxillary-orbital fracture (ZOMCF) with group I craniocerebral injuries (G1CCI).



**Fig. 3.** Coincidence of zygomatico-orbital fracture (ZOF) with group II craniocerebral injuries (G2CCI).

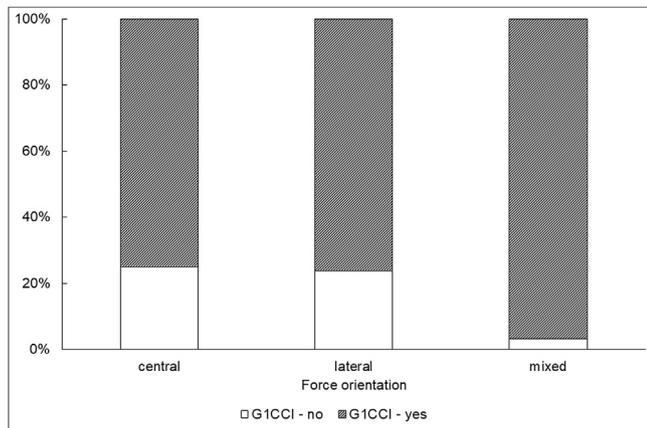
Markedly more often, CT of the head performed shortly after the trauma does not show fresh haemorrhagic lesions in the brain, and the presence of complete loss or at least disorders of consciousness at the time of the trauma, or post-traumatic retrograde amnesia, provide enough evidence to diagnose brain commotion coinciding with a craniofacial trauma. According to Keenan et al. (1999), the coincidence of craniofacial trauma with brain commotion is associated with a nearly two-fold increase in the likelihood of concomitant intracranial injury. It needs to be stressed that brain commotion itself does not cause organic intracranial lesions that can be visualized by neuroimaging. Hence, a force applied either solely onto the craniofacial skeleton or onto craniofacial and craniocerebral skeleton needs to be large enough to cause both signs of brain commotion and structural intracranial injury that can be seen on head CT.

No study of coinciding craniofacial and craniocerebral traumas would be complete without addressing the issue of the so-called "boxing injury", i.e. a punch to the chin resulting in mandibular fracture. During such trauma, the head is rapidly tilted backwards, which may cause an injury to the poles of frontal and temporal lobes. This injury is frequently associated with the rupture of the so-called bridging veins, which results in formation of subdural hematomas. Moreover, the rapid movement of the head and dislocation of the brain cause strain to the neurovascular scaffolding of the brainstem which may lead to massive damage. In

**Table 4**

Relationship between the site of force application to the horizontal plane and the occurrence of group I craniocerebral injuries.

| Skull, dura mater or cranial nerve injury | Site of force application |         |        | Total % total |
|---|---------------------------|---------|--------|---------------|
|   | central                   | lateral | mixed  |               |
| No  | 1                         | 5       | 2      | 8             |
| % column:                                 | 25.00%                    | 23.81%  | 3.33%  | 9.41%         |
| % line:                                   | 12.50%                    | 62.50%  | 25.00% |               |
| Yes                                       | 3                         | 16      | 58     | 77            |
| % column:                                 | 75.00%                    | 76.19%  | 96.67% | 90.59%        |
| % line:                                   | 3.90%                     | 20.78%  | 75.32% |               |
| Total                                     | 4                         | 21      | 60     | 85            |
| % total:                                  | 4.71%                     | 24.71%  | 70.59% |               |

Chi-squared test,  $p = 0.019$ .**Fig. 4.** Relationship between the site of force application to the horizontal plane and the occurrence of group I craniocerebral injuries (G1CCI).

turn, the strain to the perforating vessels supplying skull base nuclei may contribute to their injury and formation of intracerebral hematomas in deep structures of the brain (Ząbek, 1994). According to Czerwinski et al. (2008), the “boxing injury” may be also associated with subarachnoid hemorrhage and epidural hematomas. Those authors postulated that massive brain damage associated with this kind of trauma is a consequence of rotational acceleration which may result from direct transmission of the injury’s force by the condyloid processes of the mandible onto the skull base and brain (Czerwinski et al., 2008). As only one patient with lower face trauma and concomitant craniocerebral injury has been treated at our center in 2000–2015, we did not address the issue of “boxing injury” in this study. Published data about the incidence of “boxing injuries” are inconclusive. According to some authors, among them Haug et al. (1994) and Hung et al. (2004), this type of trauma occurs rarely, which remains in opposition to the findings published by the others, for example, Pawłowska (1966) and Carlin et al. (1998).

Our observations regarding the relationship between sex and the incidence of craniofacial traumas are consistent with previously published Results, confirming that upper facial fractures are markedly more common among men than in women (Wanyura, 1990; Samolczyk-Wanyura, 2004, 2005; 2006, 2007; Drugacz et al., 2005; Tomaszewski et al., 2006; Scheyerer et al., 2015; Oliveira-Campos et al., 2016).

Our study identified road accidents as the most common cause of craniofacial traumas. This observation is consistent with the Results published by many authors (Manson et al., 1985; Haug et al., 1990, 1992; 1994; Samolczyk-Wanyura and Wanyura, 1991; Hus-sain et al., 1994; Gaboriau and McDonald, 1996; Sargent and Rogers, 1999; Hohlrieder et al., 2004; Pappachan and Alexander, 2006; Rajkumar et al., 2015; Oliveira-Campos et al., 2016). According to

some researchers (van Beek and Merckx, 1999), road accidents result in craniofacial trauma nearly twice as often as physical abuse; however, some studies documented a growing trend in the number of craniofacial traumas resulting from physical abuse and sports activities (Gaboriau and McDonald, 1996), especially among children and adolescents (Exadaktylos et al., 2004).

## 5. Conclusion

Due to their complex etiology, skull fractures constitute a challenge for surgeons, and selection of the most appropriate treatment strategy still raises controversies (Kessler and Hardt, 1998; Samii and Tatagiba, 2002; Gabrielli et al., 2004; Sander et al., 2006; Scheyerer et al., 2015). Our presented findings suggest that adherence to an established diagnostic algorithm seems to be optimal, the safest option in the early management of patients with craniofacial traumas, especially those at increased risk of concomitant craniocerebral injuries.

It is recommended to perform a head CT scan (without contrast) for each patient with craniofacial injury who did not score maximally (15 pts) on the GCS or had a history of loss of consciousness immediately after trauma. Such an algorithm is characterized by high sensitivity. It is also worth emphasizing that the coincidence of craniofacial trauma with craniocerebral injury occurs most often in the case of upper facial dislocation and extensive injuries located laterally, in the area of the zygomatic bone.

## Conflicts of interest

B. Biaszczyk: none declared. M. Studziński: none declared. P. Ładziński: none declared.

## Contribution to the study

B. Biaszczyk: Collecting and assembly of data, data analysis and interpretation, manuscript writing, final approval of manuscript. M. Studziński: Conception and design, collecting and assembly of data, data analysis and interpretation, final approval of manuscript. P. Ładziński: Conception and design, final approval of manuscript.

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