A study comparing pterygomaxillary separation, with and without the use of an osteotome, during Le Fort I osteotomy

by

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ABSTRACT

Pterygomaxillary separation during Le Fort I osteotomy has been associated with life-threatening complications. Fractures of the pterygoid plates may play a role in the occurrence of these problems and may impede desired movements of the maxilla. This study compares the incidence of complications and pterygoid plate fractures during Le Fort I osteotomy with and without the use of a curved osteotome. Patients were randomly assigned to one of two groups in which pterygomaxillary separation was achieved either with or without osteotome. Measurements of lateral maxillary wall thickness, clinical assessment of the presence and location of fractures, and a subjective evaluation of the ease of downfracture were recorded. Coronal and axial CT scans were obtained between the seventh and tenth postoperative day.

There was no significant difference in incidence of pterygoid plate fracture between the two groups. A strong clinical trend was detected for males to have a greater incidence of pterygoid plate fractures than females. The incidence of palatine bone fractures was low. Low level fractures of the pterygoid plates of the sphenoid bone are a commonplace occurrence during the Le Fort I osteotomy. Further studies assessing alternative methods of pterygomaxillary separation are recommended.

RÉSUMÉ

La disjonction ptérygo-maxillaire au cours de l'ostéotomie Le Fort I a été associée à des complications graves. Les fractures des lames de l'apophyse ptérygoïde peuvent jouer un rôle dans l'apparition de ces problèmes et nuire aux mouvements désirés de la mâchoire. Cette étude compare l'incidence des complications et des fractures des lames de l'apophyse ptérygoïde au cours de l'ostéotomie Le Fort I, avec et sans l'utilisation d'un ostéotome courbé. Les patients ont été assignés au hasard à l'un de deux groupes où la disjonction ptérygo-maxillaire fut effectuée avec ou sans l'ostéotome. Les mesures de l'épaisseur de la paroi maxillaire latérale, l'évaluation clinique de la présence et du site des fractures, et l'évaluation subjective de la facilité d'effectuer la bascule inférieure ont été notées. Des tomographies coronales et axiales ont été obtenues entre le septième et le dixième jour postopératoire.

Il n'y a pas de différence significative entre les deux groupes relativement à l'incidence de fractures des lames de l'apophyse ptérygoïde. Une forte tendance clinique fut décelée chez les patients de sexe masculin, qui présentent une plus grande incidence de fractures que les patients de sexe féminin. L'incidence de fractures de l'os palatin est faible. Les fractures au niveau inférieur des lames de l'apophyse ptérygoïde de l'os sphénoïde sont fréquentes au cours de l'ostéotomie Le Fort I. Des études évaluant d'autres méthodes de disjonction ptérygo-maxillaire sont recommandées.

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INTRODUCTION

The Le Fort I osteotomy is a procedure used for the correction of dentofacial deformities. Historically, early maxillary surgery did not involve total mobilization of the maxilla. Fear of devitalization of dentoalveolar segments and damage to vascular structures prevented surgeons from freeing the maxilla from its posterior osseous attachments. Clinical experience, supported by research, has established the biological basis for mobilization of the maxilla during the Le Fort I osteotomy via the downfracturing technique.[1]

During downfracturing, pterygomaxillary (PTM) separation should ideally occur at the PTM fissure. The Le Fort I osteotomy cuts, along with the separation of the maxillary tuberosity from the point of fusion with the anterior aspect of the pterygoid plates of the sphenoid bone, achieves osseous freedom of the maxilla, allowing desired movements to be executed. A significant incidence of pterygoid plate fractures (PTPF) has been demonstrated with commonly used techniques of PTM separation.[2,3] It has been suggested that these fractures may contribute to the development of neurologic, ophthalmic[4,5,6,7,8] and life-threatening vascular complications.[9,10,11,12,13,14,15,16] There is general agreement in the literature that the incidence of these complications is very low relative to the frequency with which the Le Fort I osteotomy is performed.[10,13,17] Attention has been drawn to these rare complications because of their severe nature.

Pterygoid plate fractures are also thought to be clinically significant from a mechanical perspective as they may interfere with desired movements of the mobilized maxilla, and indirectly contribute to a greater incidence of postoperative relapse.[19,20,21] Pterygoid muscle attachment to the unseparated pterygoid plates may cause resistance to forward, superior and lateral movements of the maxilla. Retrusion may also be impeded since removal of bone in the area of the maxillary tuberosity to allow posterior displacement may be difficult.[21] It has been suggested that movements of the maxilla may also be hindered if separation of the horizontal process of the palatine bone from the palatal process of the maxilla occurs during PTM separation.[21,22] These latter complications, although not life-threatening, may be of clinical significance as they appear to occur quite commonly in the clinical setting.

Modifications of the Le Fort I osteotomy have been proposed over the past two decades in attempts to reduce the incidence of complications, and refine the technique of PTM separation.[19,21,23,24,25,26,27] These techniques share the common goal of achieving posterior bony freedom of the maxilla from the pterygoid plates, while avoiding, or minimizing damage to adjacent neural and vascular structures.

Studies describing the morphology of the PTM fissure show it to be comprised of a complex sutural system characterized by numerous bony bridges or synostoses.[19] Considerable variation in the dimensions of the PTM fissure have also been reported.[18,22,28,29] The above factors, combined with the surgical reality that access is limited, and that PTM separation is a blind procedure, may explain why non-ideal PTM separation and PTPF are a common occurrence.

Recent studies utilizing computerized tomography (CT) have demonstrated a surprisingly high incidence of PTPF after Le Fort I osteotomy.[2,3] In these studies, the reported incidence of PTPF detected via CT was much higher than that observed at the time of surgery. The reported incidence of PTPF during Le Fort I osteotomy is far greater than the incidence of life threatening complications. This has raised the question of the exact nature of the relationship between these two entities.[3] The potential role of PTPF in the occurrence of major complications is unknown at this time. It has been suggested that the underlying mechanism producing PTPF, rather than the fractures themselves, may be directly responsible for life threatening complications.[2,4] It would appear that there is a need to refine PTM separation, and to characterize fractures occurring during Le Fort I osteotomy. The reduction in incidence of PTPF, and potential avoidance of the mechanism underlying their occurrence, may result in a decrease in incidence of life threatening complications.

The objectives of this prospective, randomized study were to evaluate the relationship between two methods of pterygomaxillary separation and PTPF, and to establish if predictive factors could be identified for the occurrence of PTPF during Le Fort I osteotomies. The identification of a predictive factor for the occurrence of PTPF may permit the preferential selection of a specific technique for mobilization of the maxilla in a given individual, thus reducing the occurrence of PTPF.

LITERATURE REVIEW

HISTORY OF THE LE FORT I OSTEOTOMY

The origin of the maxillary downfracture osteotomy technique has been credited to Cheever[29,30], who reported on the use of an osteotomy technique for resection of a nasopharyngeal mass in 1864. In 1927, Wassmund[32] performed the first Le Fort I osteotomy for the correction of an anterior open bite. The procedure included osteotomies of the anterior lateral walls of the maxilla, the anterior part of the lateral nasal wall, and the base of the nasal septum. The posterior bony attachments of the maxilla were not sectioned, and no attempt was made to mobilize the maxilla at the time of surgery. Elastic traction was used postoperatively for a period of one week to close the open bite, and intermaxillary elastics were maintained for a period of 13 weeks until the maxilla was firmly united.[32]

Axhausen (1934) is credited as the first to mobilize and advance a malunited maxillary fracture via Le Fort I osteotomy. Elastic traction was used postoperatively to facilitate anterior movement and retention of the traumatically retrodisplaced maxilla.[32]

In 1942 Schuchardt described a two-stage procedure with the Le Fort I osteotomy as the first operation followed by the PTM separation as a second stage. Weights from an overhead traction device were used prior to PTM separation to pull the maxilla forward. This procedure was devised to avoid impairment of the vascular supply to the maxilla.[32]

In the early stages of maxillary surgery, fear of devitalization of bone and teeth, and fear of traumatizing vascular structures such as the descending palatine artery and internal maxillary arteries prevented surgeons from completely mobilizing the maxilla. Hence the problems of inability to move the maxilla desired distances and relapse of maxillary movements persisted.[1]

Dingman and Harding[33] were the first to include separation of the pterygoid process from the maxillary tuberosity in combination with the Le Fort I osteotomy. This method was also subsequently described by Obwegeser[32] in 1965.

In attempts to resolve the problems with maxillary positioning, Converse and Shapiro[34] proposed advancement of the maxilla via a transverse palatal osteotomy at the junction of the palatine bone and the maxilla.

The use of bone grafts at osteotomy sites to promote healing was first reported by Gillies et al in 1954.[35] The bone grafts were placed at osteotomy sites in the lateral wall of the maxilla, to promote osseous regeneration between bony segments.

In 1969 Obwegeser[36] introduced the method of inserting a bone graft between the separated maxillary tuberosity and pterygoid process. He stated that this was essential for the stability of the new maxillary position.

As clinical experience progressed, surgeons became more aggressive and complete mobilization and adequate fixation of the maxilla was accomplished. Surgeons then began to report good results with maxillary advancement.[36,37]

According to Bell[38] maxillary surgery was described in the European literature well before the North American literature. He states that maxillary surgery was not performed routinely until the work of Kole[39] was published in the English language in 1959. Prior to the development of maxillary surgery techniques, dentofacial deformities were treated by mandibular surgery alone. the development of the Le Fort I osteotomy allowed movement of the maxilla in three planes of space. This permitted the surgeon to correct deformities involving the maxilla with a predictable and stable result.[31]

Bell[38,39] can be credited with establishing the biologic basis for the Le Fort I osteotomy. In animal and human cadaver studies Bell has described how the blood supply to the maxilla is maintained during conventional maxillary surgery. This work described the collateral circulation within the maxilla and its surrounding soft tissues, as well as the many vascular anastomoses that maintain the viability of dento-osseous segments despite transection of the medullary blood supply during Le Fort I osteotomy. This work was essential to establishing a scientific and biologic basis for the Le Fort I osteotomy as we know it today. Few modifications have been proposed since Bell's original description of the procedure.[1]

More recently, the advent of rigid internal fixation has had a significant effect on orthognathic surgery. The immediate postoperative management of the patient has been facilitated due to improved respiratory function.[41] Rigid fixation although not without its disadvantages, has advanced orthognathic surgery by virtue of the absence of a prolonged (6-10 week) period of intermaxillary fixation. In many instances, this permits a more rapid and comfortable convalescence for the patient.

THE TECHNIQUE OF THE LE FORT I OSTEOTOMY

The Le Fort I osteotomy in its present form was described by Bell.[1] The basic steps of the procedure are described as follows. A horizontal mucoperiosteal incision is made above the mucogingival junction, extending from one second molar region to the other. The margins of the superior flap are raised to expose the entire lateral wall of the maxilla and zygomatic buttress, such that the infraorbital foramen and piriform apertures are exposed. The inferior mucoperiosteal tissues are minimally elevated so that they provide additional vascular supply to the maxillary bone and teeth. Horizontal supraapical osteotomies of the lateral portion of the maxilla are made from the lateral part of the piriform rim posteriorly across the canine fossa and through the zygomatic buttress to the PTM fissure, using a fissured bur in a straight handpiece, or a high-speed reciprocating saw. This cut is made 3-5 mm above the apices of the maxillary teeth, the length of which is determined by direct visualization, and correlated with measurements taken from panoramic or lateral cephalometric radiographs. The mucoperiosteum is elevated from the floor of the nose, nasal septum, and lateral walls of the nasal cavity to facilitate separation of the maxilla from these structures. Osteotomy of the nasal septum is performed via malleting of a nasal septum osteotome from a point above the anterior nasal spine, parallel with the hard palate towards the operator's finger positioned from inside the mouth, at the posterior nasal spine. The anterior lateral nasal wall is sectioned transantrally with a fissure bur in a straight handpiece. The posterior lateral nasal wall is sectioned with a sharp osteotome above the level of the nasal floor. Finally, a sharp osteotome is malleted into the PTM suture to separate the maxilla from the pterygoid plates. Digital pressure on the palatal mucosa in the region of the hamulus permits the surgeon to feel the osteotome as it transects the bone without traumatizing the underlying mucoperiosteum. The osteotome is positioned inferiorly to minimize danger to the vascular structures adjacent to the PTM fissure. The maxilla is rendered partially mobile by manipulation of the curved osteotome and manual pressure against the tuberosities. At this point, downwards pressure on the anterior maxilla produces downfracture. With a gradual increase in pressure, visualization of the superior surface of the maxilla and the nasal walls is achieved. The mucoperiosteum is elevated and retracted from the entire superior surface of the maxilla, hard palate, and lateral nasal walls. Digital pressure gradually completes fracturing of the maxilla. In this technique, disimpaction forceps are not used. The downward position of the maxilla provides access for separation of the maxilla from the pterygoid plates and the perpendicular process of the palatine bone. The maxilla is completely mobilized with careful manipulation with the osteotome and forward pressure against the tuberosities and lower part of the maxilla. The degree of mobility should be such that the maxilla can be moved passively into the desired relationship with the mandible.

Epker and Fish[29] similarly described the Le Fort I osteotomy with some variations. The pterygoid osteotome is not used to effect PTM separation at the junction of the maxilla and the pterygoid plates. They recommend that the lateral maxillary osteotomy be carried posteriorly and tapered sharply inferiorly as it passes the root apices of the terminal molar in order to facilitate downfracturing. The maxilla is then manually downfractured with force applied to the anterior maxilla. If successful, this will result in preservation of the greater palatine neurovascular bundles because the fractures occur through the sutures around their canals. Use of the curved osteotome is recommended only if the lateral wall osteotomies are verified to be completed and manual downfracture is unsuccessful.

In our institution the Le Fort I osteotomy is performed in a similar fashion. Soft tissue incisions are made in the maxillary vestibule and soft tissue dissection is performed exactly as described previously. The points for cuts in the lateral maxillary wall are identified with a fine tapered fissure burr in a straight hand-piece. These points are a minimum of 5 mm above the apices of the maxillary teeth. The planned osteotomies are made with a reciprocating saw starting at a point posterior to the zygomatic buttress, continued anteriorly through the piriform rim, and through the anterior aspect of the lateral nasal wall in the region immediately posterior to the piriform rim. A fine osteotome is then used to extend the osteotomy of the lateral wall of the maxilla to the PTM fissure, stopping anterior to the pterygoid plates. The nasal septum is then osteotomized. The lateral nasal osteotomies are performed with a guarded Silver chisel. This latter osteotomy is carried just into the vertical process of the palatine bone. Manual downfracturing is attempted without use of the curved osteotome at the PTM junction. If pressure in the anterior area of the maxilla is met with significant resistance, the osteotomy cuts are then reviewed, and downfracture is reattempted. If unsuccessful, the curved osteotome is used as described by Bell. If the foregoing is achieved without adverse PTPF or damage to vascular structures, the maxilla can be passively positioned in the desired location.

ANATOMY OF THE PTERYGOMAXILLARY REGION

This anatomical review will focus on the PTM region and structures in immediate relationship to this area. Structures of particular relevance to the step of PTM separation during the Le Fort I osteotomy will be described.

The PTM fissure is a triangular interval formed by the divergence of the maxilla from the pterygoid process of the sphenoid bone. It is oriented vertically and descends at right angles from the medial end of the inferior orbital fissure. It connects the infratemporal with the pterygopalatine fossa, and houses several important anatomical structures.[42] The osteology pertinent to this area includes the pterygoid process of the sphenoid bone, the palatine bone, and the maxilla.

Sicher and DuBrul[43] provide a description of these osseous structures. The pterygoid process of the sphenoid is described as arising at the connection between the greater wing and body of the sphenoid. The pterygoid process is split into a wider and shorter lateral, and a narrower and longer medial plate. The upper part of the two plates are fused at their anterior edges. Below, they are separated by the pterygoid notch, into which fits the pyramidal process of the palatine bone. In the posterior view the pterygoid plates are separated by the pterygoid fossa. Above this fossa, at the posterior aspect of the medial pterygoid plate, a second fossa gives origin to the tensor palati muscle. The inferior end of the lateral plate is continued by the lateral surface of the pyramidal process of the palatine bone. The inferior end of the medial pterygoid plate ends in a thin, curved, hook-like process, the pterygoid hamulus. The hamulus is separated from the medial plate itself by a deep notch through which the tendon of the tensor palati muscle passes.

The posterolateral surface of the maxillary body, the infratemporal surface, is part of the anterior wall of the infratemporal fossa. The posterior convexity of the maxillary body is called the maxillary tuberosity. A description of the union between the maxillary tuberosity and the pterygoid process of the sphenoid bone will be included in the description of the palatine bone. The posterior superior alveolar nerves enter the tuberosity through the posterior superior alveolar foramina. The palatine process of the maxilla arises as a horizontal plate from the body of the maxilla at the boundary between the body and the alveolar process. Posteriorly, the palatine process is connected to the horizontal process of the palatine bone via the transverse palatine suture.

The palatine bone supplements the maxilla and furnishes the link between the maxilla and the sphenoid bone. It grossly consists of a horizontal and a vertical plate joined at right angles. The horizontal plate as mentioned above, forms the posterior part of the hard palate. Its anterior beveled border overlaps the palatine process of the maxilla forming the transverse palatine suture. The medial border connects with the palatine bone of the contralateral side via the interpalatine suture, which is a continuation of the intermaxillary suture. The lateral border of the palatine bone, between the vertical and horizontal process, is connected to the medial side of the maxilla at the level between the body and the alveolar process. The greater palatine foramen is formed by opposing notches in the edges of these two surfaces. The pyramidal process arises from the posterolateral corner of the palatine bone, at the junction of the horizontal and vertical plates. It serves as firm anchorage of the maxillopalatine complex to the lower end of the pterygoid process of the sphenoid bone. The pyramidal process fills the pterygoid notch between the medial and lateral pterygoid plates.

In their architectural analysis of the skull, Sicher and DeBrul[43] have compared the pterygoid process of the sphenoid bone to a flying buttress extending upward to the cranial base. This buttress braces the maxillary tuberosity and absorbs the force on the posterior dentition. These structures form part of a system of vertical pillars anchored to the base of the skull, producing a stress-bearing design that meets the functional demands of the human skull.

The medial pterygoid muscle arises from the inner surface of the lateral pterygoid plate, the main origin arising in the pterygoid fossa. The muscle also originates from the lateral surface of the pyramidal process of the palatine bone and adjacent parts of the maxillary tuberosity. The fibers of the medial pterygoid run downwards, backwards, and outward to insert into the medial surface of the mandibular angle. The lateral pterygoid muscle arises from two heads. The larger inferior head originates from the outer surface of the lateral pterygoid plate. The smaller superior head originates from the infratemporal surface of the greater wing of the sphenoid. The inferior head and the majority of the superior head fibers insert into a depression in the anterior part of the neck of the condyle. The uppermost fibers of the superior head insert into the anteromedial surface of the articular capsule. Sicher and DuBrul[43] refer to the features of muscle insertions of the lateral pterygoid as being of vital clinical importance. They state that the pull of muscles must be considered in the reduction and fixation of maxillary fractures and in the surgical repositioning of the maxilla for functional and cosmetic reasons.

The description of vascular structures in the pterygomaxillary region will include the internal maxillary artery and several of its terminal branches, viz. the posterior superior alveolar, descending palatine, and sphenopalatine arteries, as well as the pterygoid venous plexus.[42]

The internal maxillary artery provides the majority of the blood supply to the maxilla via its terminal branches. Damage to this artery or one of its terminal branches is frequently responsible for incidences of hemorrhage during Le Fort I osteotomy. It arises as a terminal branch of the external carotid artery below the level of the neck of the condyle where it is embedded within the substance of the parotid gland. The artery courses behind the neck of the condyle in an anterior, upwards, and medial direction through the infratemporal fossa in close relationship to the lateral pterygoid muscle, where it crosses the lingual and inferior alveolar nerves between the lateral and medial pterygoid muscles. The artery then enters the pterygopalatine fossa where it divides into its terminal branches.

The posterior superior alveolar artery (PSA) arises from the maxillary artery just as the trunk of this artery passes into the pterygopalatine fossa. The PSA descends towards the maxillary tuberosity where it divides into branches supplying the maxillary sinus lining, alveolar bone, maxillary teeth, and gingival tissue. Vascular branches are accompanied by branches of the posterior superior alveolar nerve which are derived from the maxillary division of the trigeminal nerve.[42]

The descending palatine artery arises from the maxillary artery in the pterygopalatine fossa and descends to the palate via the greater palatine canal with the greater palatine nerve, which is derived from the maxillary nerve and pterygopalatine ganglion. The main branch of the descending palatine artery reaches the oral cavity through the greater palatine foramen.[42,43]

The posterior superior, and descending palatine artery may be severed during Le Fort I osteotomy due to their position in the posterolateral wall of the maxilla and perpendicular position of the palatine bones, respectively.[10] Bleeding from the PSA is usually not a problem unless it is an unusually large vessel.[9] The descending palatine artery is the most vulnerable source of bleeding during PTM disjunction and downfracture.[10] Hemorrhage from the artery can usually be controlled upon downfracture which permits direct visualization and placement of arterial clips if necessary.[9]

The sphenopalatine artery is the last of the terminal branches of the maxillary artery supplying a large area of the nasal cavity.[42,43] The artery passes through the sphenopalatine foramen at the uppermost part of the pterygopalatine fossa. It is in close proximity to the pterygopalatine ganglion and is accompanied by lateral nasal, septal, and nasopalatine nerve branches from the maxillary nerve and pterygopalatine ganglion. Damage to the sphenopalatine artery during Le Fort I osteotomy may manifest as delayed postoperative epistaxis.[16]

The pterygoid venous plexus represents a likely source of significant bleeding during Le Fort I osteotomy.[10] It is contained within the infratemporal fossa along with the pterygoid muscles, the internal maxillary artery, and branches of the mandibular nerve. This plexus receives tributaries corresponding to branches of the internal maxillary artery. It drains into the external jugular vein via the maxillary and retromandibular vein, and to the internal jugular vein via the deep facial, the facial, and the common facial vein. It is vulnerable to damage during instrumentation in the PTM region.

Intraoperative venous hemorrhage can usually be managed with the application of pressure packing. Arterial bleeding is usually more persistent and may present as recurrent postoperative bleeding.[10] The latter is usually characterized as high volume flow of bright red blood indicative of the blood's oxygenated status. The surgeon must be familiar with management, and be aware of the potential for immediate and delayed hemorrhage when performing the Le Fort I osteotomy.

In the management of patients with dentofacial deformities, the surgeon must also be aware of the possible existence of variations of normal vascular and osseous anatomic relationships. This is particularly true of patients with syndromal deformities as these may predispose to a greater risk of complications with the

Le Fort I osteotomy.[44]

COMPLICATIONS ASSOCIATED WITH THE LE FORT I OSTEOTOMY

A review of the literature indicates that life threatening complications associated with the Le Fort I osteotomy are relatively infrequent. However, there is little indication of the true frequency of such complications. Debilitating or life threatening complications that have been documented in relation to maxillary osteotomies can be broadly categorized as vascular (immediate or delayed), neurologic, and ophthalmic. Vascular complications specifically include severe intraoperative and delayed postoperative hemorrage,[9,10] arteriovenous fistulas,[11,13] false aneurysms,[11] and internal carotid artery thrombosis.[47] This review will not cover local complications of tooth and osseous segment devitalization. However relapse of the maxilla as it relates to the effects of the musculature in the PTM region will be discussed.

Turvey and Fonseca[14] studied the anatomy of the internal maxillary artery in the pterygopalatine fossa and its relationship to the Le Fort I osteotomy. Dissection of 16 adult cadaver specimens (32 sides), was done in order to establish the relationship of the internal maxillary artery in the PTM fossa to the PTM suture. The height of the PTM junction and the external diameter of the internal maxillary artery were also examined.

The mean distance between the most inferior junction of the maxilla and pterygoid process to the most inferior position of the internal maxillary artery as it entered the pterygopalatine fossa was 25 mm, with a range of 23-28 mm and a standard deviation of 1.49 mm. These latter measurements were based on the dissection of 29 internal maxillary artery specimens. Three of the 32 specimens were not used, as they had been previously partially dissected. The mean height of the PTM suture in 8 specimens was 14.6 mm, with a range from 11 to 18 mm and a standard deviation of 3.11 mm. The internal maxillary artery was measured in nine specimens as it entered the pterygopalatine fossa prior to giving off any terminal branches. The mean external diameter was 2.63 mm, ranging from 2.5 to 3.0 mm with a standard deviation of 0.377 mm. No explanation is offered as to why the measurements of internal maxillary artery diameter, and PTM suture height were limited to 9 and 8 specimens respectively, when presumably 29 specimens were available for dissection. The sample size in this dissection was very small such that the relevance of the mean values is questionable.

The authors concluded that PTM disjunction may be carried out safely, without fear of severing the internal maxillary artery. Based on the data collected in this study, they established guidelines for safely conducting PTM separation. The osteotome should be placed under the periosteum inferiorly in the PTM junction with the inferior tip palpable from the palatal aspect assuring its proper inferior placement. The osteotome should be directed medially and anteriorly while separating the middle third of the face from its posterior attachments. Directing the osteotome superiorly should be avoided. The authors recommended that with appropriate inferior positioning of curved osteotome, the margin of safety from the superior cutting edge of the osteotome with a 15 mm cutting edge to the internal maxillary artery is approximately 10 mm in the adult patient.

The authors appropriately mention that the specimens used in this study were apparently normal. Patients with dentofacial and craniofacial deformities may have vascular anomalies that may only be appreciated at the time of surgery.

In earlier publications on midface surgery, Tessier has commented that one of his concerns with mobilization of the middle third of the face was hemorrhage from the internal maxillary artery. He later indicated that this complication had not occurred.[45]

In 1975 Converse[46] reported on a case of severe hemorrhage arising during PTM separation in a patient with Crouzon's syndrome undergoing midface osteotomies. The patient was inadvertently extubated and died as a result of these complications.

Newhouse et al[13] reported a case of severe intraoperative hemorrhage arising in a 32 year old female with a diagnosis of vertical maxillary excess and mandibular retrognathia immediately after downfracturing of the maxilla. Maxillary impaction was planned with 8 mm posterior, and 6 mm anterior ostectomies. The Le Fort I osteotomy had been accomplished in the usual method, with use of a curved osteotome to effect PTM separation bilaterally. No significant bleeding was encountered until the maxilla was downfractured. Downfracture manipulation of the maxilla resulted in profuse bleeding from the right posterior region. Multiple arterial and venous cutdowns, aggressive transfusion of blood products, and ligation of the right external carotid artery were the initial steps taken to stabilize the patient with limited success. The hemorrhage was finally controlled via local packing and wire stabilization of the maxilla. Angiography was performed in order to determine the source of hemorrhage prior to removal of the packing material. A traumatic arterio-venous communication involving the right internal carotid artery and internal jugular vein was detected at the base of the skull. The patient underwent a neck exploration in order to ligate the right internal carotid, and to obliterate the jugular foramen with a muscle graft. Surgical exploration of the region revealed that the right pterygoid plates were completely separated from the base of the skull as well as the maxilla. The authors speculated that with PTM disjunction the right pterygoid complex was detached, and a sharp bony edge was forced posteriorly, lacerating the vessels during downfracture manipulation. Because of the loss of a posterior point of stability for the maxilla (with fracture of the pterygoids from the skull base), the entire PTM complex was possibly forced posteriorly. The tenth and twelfth cranial nerves were also found to be damaged. It is speculated that this may have occurred at the time of the original surgery, during the insertion of the pressure packs, or during surgical exposure for treatment of the arteriovenous fistula.

The authors concluded that although most hemorrhagic episodes during mid-face surgery are due to trauma to the internal maxillary artery, internal carotid artery hemorrhage is also possible. The authors recommended that the posterior lateral maxillary osteotomy be directed low into the PTM fissure, and that, if possible, the posterior osteotomy be performed through the tuberosity precluding manipulation further posteriorly.

Brady et al[47] published what they believe to be the first reported case of carotid artery thrombosis after elective maxillary or mandibular osteotomy. This case involved a Le Fort I osteotomy and bilateral sagittal sliding osteotomy of the mandible in a patient with right hemifacial microsomia. The patient had a right internal carotid artery thrombosis which manifested as a neurologic deficit 18 hours post surgery. Carotid angiogram demonstrated the defect, and CT of the brain showed the corresponding changes in blood supply to the brain. The authors speculated that the injury occurred due to a sudden sharp blow to the right carotid artery region when the mandibular osteotomy was performed, or when the maxillary tuberosity was separated. No details of the exact sequence or technique used for the Le Fort I osteotomy were given, but the tuberosities were separated from the pterygoid plates using a curved osteotome and mallet.

A review of the syndrome of carotid artery thrombosis by Flemming and Petrie[48] provides an explanation for the mechanism of this injury. Blunt trauma to the head and neck, including surgery may cause contusion or stretching of a major artery, specifically to the layers of the arterial wall. This may result in an intimal flap or a subintimal hematoma producing occlusion by thrombosis. Spasm secondary to injury, compounded by hypotension which creates sluggish flow, may predispose to thrombus formation. The above patient had a craniofacial anomaly of hemifacial microsomia which may have altered relationships of the maxilla and mandible to the great vessels of the neck. Nevertheless, it is important to note that blunt trauma to the head and neck has been known to produce internal carotid artery thrombosis.

Other case reports of major vascular complications have subsequently been published. In 1986 Habal[49] reported a case of carotid-cavernous sinus fistula following midface advancement in a patient with Charcot-Marie-Tooth syndrome. This patient had a craniofacial anomaly necessitating mid-face advancement and mandibular osteotomy to correct an open bite. Minimal operative details were provided, the authors stating that the operative procedure went smoothly and without complications. A carotid cavernous sinus fistula was diagnosed one year post-operatively via carotid angiography when the patient was investigated for proptosis, dilated orbital vessels, unilateral chemosis, and complaints of buzzing in her head. A bruit was heard on auscultation over the right side of the neck and right side of the orbit. The lesion was treated via balloon embolization without further complication, and the proptosis gradually resolved over the following six months.

A direct causal relationship between the surgery performed and the vascular lesion was not established. The authors stated that carotid-cavernous sinus fistula is not an anomaly associated with Charcot-Marie-Tooth syndrome, but there may be some different characteristics at the base of the skull that precipitate this problem. Acquired carotid-cavernous sinus fistulae of unknown origin have been described in the literature but posttraumatic ones are the most common. Blunt trauma is reported as the major cause of such fistulas.[50] The authors describe this sequela as a rare complication of craniofacial surgery, the diagnosis usually being made by symptomatology, including headaches, buzzing, proptosis, and chemosis on the affected side, and confirmed by arteriography. The most common finding on physical examination is a bruit on the affected side. They recommend that the craniofacial surgeon who operates on the upper part of the face and cranial base either for congenital or acquired deformities, be prepared to diagnose this clinical entity.

Lanigan and Tubman[12] reported on carotid cavernous sinus fistula following a maxillary osteotomy. In this case a Le Fort I osteotomy, bilateral sagittal split osteotomy and advancement genioplasty were performed on a 23 year old male with a diagnosis of vertical maxillary excess and mandibular retrognathia. Extreme difficulty was encountered during the down fracturing of the maxilla. Thick posterior walls of the maxilla and heavy buttresses of bone postero-medially were sectioned with a chisel bilaterally before the maxilla could be mobilized. Both descending palatine arteries which were transected by the chisel, were identified upon downfracture and clipped. The remainder of the surgery and immediate post-operative course were uneventful. The patient presented 10 weeks postoperatively with the complaint of a pulsing sensation in his left ear. This progressed to diplopia. A left carotid arteriogram revealed an arteriovenous fistula between the intracavernous portion of the left internal carotid artery, and the cavernous sinus. Neuroophthalmologic consultation also revealed partial loss of function of the left oculomotor nerve, left abducens nerve, and one cm. of exophthalmus. The patient underwent balloon embolization of the lesion with near complete resolution of his symptoms, and no further recurrence of any problems was noted. Radiographic evidence from the arteriogram indicated that the origin of the fistula was from the base of the skull near the foramen lacerum. This, combined with the extreme difficulty encountered in achieving downfracture led the authors to conclude that the damage to the internal carotid artery was most likely secondary to a basal skull fracture.

The authors recommended that sectioning through the posterior aspect of the maxillary tuberosity itself, rather than at the PTM junction should be carried out to achieve posterior separation of the maxilla. Such an approach would avoid involving areas of the PTP and the dense posterior medial walls of the maxilla.

In 1984 Lanigan and West[9] published the results of a survey of oral and maxillofacial surgeons regarding their experiences with cases of postoperative bleeding after Le Fort I osteotomy. The survey attempted to contact surgeons in medical centers which dealt with a large volume of orthognathic cases, and surgeons that were known to have encountered hemorrhagic complications post Le Fort I osteotomy. Findings in 15 reported cases were tabulated, the following generalizations were made:

1. Postoperative hemorrhage following Le Fort I osteotomy is an infrequent complication.

2. The vessels most frequently involved are the greater palatine artery, the internal maxillary artery, or the pterygoid venous plexus.

3. Hypotensive anesthesia does not appear to be a significant factor in masking the surgeon's ability to detect hemorrhage at the time of surgery.

4. The most common treatment selected for this complication is anterior and posterior

nasal packs.

5. Arterial hemorrhage tends to be more persistent (than venous hemorrhage), and occasionally is recurrent in nature, making it difficult to manage.

This paper reviewed the local vascular anatomy relating to the Le Fort I osteotomy and the most likely sources of bleeding. Treatment methods were reviewed and included nasal packing, transantral ligation of the internal maxillary artery, ligation of the external carotid artery, and angiography with embolization. On the basis of the information retrieved from the survey a protocol was then proposed for the management of postoperative hemorrhage with the Le Fort I osteotomy.

The method of surgeon selection in the above survey appeared to be very biased. A valid estimation of the incidence of hemorrhagic complications cannot be derived from the information retrieved in this survey. Unfortunately, the method of PTM separation does not appear to have been investigated as part of this survey.

In 1986, Lanigan[10] repeated a survey on major vascular complications following orthognathic surgery among oral and maxillofacial surgeons in North America. Of the 5000 questionnaires mailed, approximately 800 were returned. Thirty-three surgeons reported 39 cases of major postoperative hemorrhage following maxillary surgery, and 27 surgeons reported 30 cases of major intraoperative hemorrhage. The term "major" was not qualified, but the authors stated that this point was open to interpretation by the surgeons.

The authors stated that no inferences can be made regarding the incidence of hemorrhagic complications from the cases reported in this survey. They speculated that this may have represented an underestimation of the true incidence of these events, as some surgeons may have elected to withhold information regarding complications they have encountered. They do however agree with Freihofer's[17] experience that significant postoperative hemorrhage after Le Fort I osteotomy is a rare complication that occurs in less than one percent of cases.

Well documented cases were discussed as case histories, and the management of intraoperative and postoperative hemorrhage was reviewed extensively on the basis of the information collected from this survey. The authors concluded that hemorrhage post Le Fort I osteotomy continues to be a rare but significant complication.

These last two studies focus on the incidence and management of hemorrhagic complications with the Le Fort I osteotomy. Unfortunately no attempt was made to correlate the occurrence of these complications with the method of PTM separation used in the case reports. It does not appear that this information was requested of the surveyed surgeons. Given the small response rate, one must question the reliability of the responses to such a questionnaire, and hence the conclusions derived from the information retrieved.

A rare neurologic complication of lacrimal dysfunction has been reported by Tomasseti et al[8] in a case of Le Fort I osteotomy performed on a 23 year old female for advancement of a retrodisplaced maxilla. PTM separation was performed bilaterally with use of an osteotome. Difficulty with mobilization of the maxilla was encountered necessitating reexploration of the lateral nasal osteotomies and PTM region. Upon downfracture it was noticed that the left pterygoid plate was fractured, the level of the fracture was not specified. The remainder of the procedure was performed uneventfully. Her immediate postoperative course was unremarkable with the exception of a broken right circumzygomatic wire that was replaced under local anesthesia with intravenous sedation.

Three weeks later, the patient presented with the complaint of inability to produce tears from the left eye. There was no visual or motor dysfunction. Normal function of the lacrimal gland had returned by the eighth postoperative month. The authors hypothesized that the injury was most likely related to the fracture of the pterygoid plate on the affected side. The explanation proposed was injury to the postganglionic parasympathetic nerves supplied to the lacrimal gland via the zygomatic nerve. The nerve fibers may have been entrapped in a crack in the maxilla, or injury from a bone splinter from the fractured PTP may have occurred. This represents an unusual complication related to the Le Fort I osteotomy.

Watts[5] reported on a unilateral abducens nerve palsy following a Le Fort I osteotomy. Although post-traumatic abducens nerve palsy has been reported by Goubran[51] in 1978, the authors indicated that no other cases of abducens nerve palsy were found in the literature of that time period.

The case history involved a Le Fort I osteotomy performed in the standard fashion with PTM separation achieved with the pterygoid osteotome. On the first postoperative day, the patient complained of diplopia in right lateral direction, and the right eye failed to demonstrate right lateral movement. Ophthalmologic consultation confirmed the diagnosis of right abducens nerve palsy. The patient completely recovered after a period of 7 weeks.

The authors discussed that the abducens nerve is the most inferolateral of all the nerves in the superior orbital fissure and because of its position is probably the most likely one to be damaged should there be any involvement of the superior orbital fissure at a low level. The authors proposed the following mechanisms of injury:

1. A continuation of the PTP upwards to the inferolateral margin of the SOF, causing injury to the nerve by bleeding or displaced bone spicules.

2. Transmitted force to the nerve from use of the osteotome.

In light of negative tomographic findings and a rapid recovery, the latter possibility of transmitted force producing a neuropraxia was favored by the authors.

In 1986 Carr and Gilbert[7] reported a case of isolated partial third nerve palsy following maxillary osteotomy on a patient with unilateral cleft lip and palate. On the first postoperative day the patient was noted to have a right sided ptosis, and divergent strabismus with diplopia. The right pupil was larger than the left, but both were reactive to light and the consensual response was intact. The patient underwent urgent CT scanning to rule out a possible retro-bulbar hemorrhage and it was negative. The patient's symptoms completely resolved by the eighth postoperative week. The authors suspected a neuropraxia to have been caused either by direct transmitted force to the nerve during separation of the PTP or delayed ascending edema and hematoma formation. The partial isolated nature of this third nerve palsy led the authors to suspect abnormal anatomical features contributing to the pathogenesis of the nerve lesion.

In 1988 Reiner and Willoughby[6] reported on another case of transient abducens nerve palsy following Le Fort I osteotomy, with CT findings to suggest the possible cause. A 27 year old female underwent Le Fort I osteotomy and bilateral vertical ramus osteotomies without intraoperative complications. No intraoperative details were offered, and the surgery was described as uneventful, with minimal blood loss. On the first postoperative day the patient complained of "double vision" on looking to the right. Immediate ophthalmologic and neurologic consultation confirmed the diagnosis of right abducens nerve palsy. CT scans of the course of the right sixth cranial nerve demonstrated a comminuted fracture through the body of the sphenoid bone passing through the sella turcica, with lateral displacement of a fragment onto the medial surface of the right cavernous sinus. The patient recovered completely five months following surgery without further intervention.

The authors stated that although the cause of the abducens nerve palsy was a fracture of the sphenoid bone, the reason the fracture itself occurred was not clear. They suspected that it may have occurred because of increased force, or inappropriate direction of force from the osteotome, or placement of the osteotome too high on the pterygoid plates. It is stressed that the direction of the osteotome in its application to the PTM fissure is important in preventing unwanted fractures.

In 1993 Lanigan et al[4] reviewed the literature pertaining to ophthalmic complications associated with orthognathic surgery. They also presented case reports of ophthalmic complications obtained from a previous survey of North American oral and maxillofacial surgeons.[10] In this review, Lanigan et al[4] stated that potential ophthalmic complications can include a decrease in visual acuity, extraocular muscle dysfunction, neuroparalytic keratitis, and nasolacrimal problems involving both an increase or a decrease in tearing. The authors hypothesized that these injuries could result from traction, compression, or contrecoup injuries to neurovascular structures in the PTM region. These adverse events are thought to be produced from forces transmitted during the PTM separation with use of an osteotome or from damage sustained by fractures extending to the base of the skull or the orbit. It is stated that evidence to support these proposed mechanisms of injury in association with PTM dysjunction (separation) or maxillary downfracture is limited.

The authors addressed case reports in the literature as well as one of the reported cases from their survey to provide evidence for the role of PTM separation or maxillary downfracture in this problem. The first case report has already been reviewed in the literature review of this paper on the preceding page.(Reiner and Willoughby[6]) The reader is directed to this review in the immediately preceding text.

A study by Hiranuma et al[54] is cited as indirect evidence of the above mechanisms of injury. The reader is directed to the review of this study on page 36. This study provides indirect evidence in dry skulls that large tensile and compressive strains are generated at the medial pterygoid plate on the side of osteotome application. This strain increased with incorrect angulation of the osteotome. Lanigan et al[4] theorize that when this strain is distributed to the adjacent skull structures, it may result in compression, traction, or contrecoup injuries to neurovascular stuctures.

The case report presented in the paper by Lanigan et al[4] describes delayed postoperative blindness of the right eye occurring in a patient who had undergone Le Fort I and bilateral sagittal split osteotomies for the correction of apertognathia. The patient had previously undergone (two years prior) Le Fort I and mandibular osteotomies with iliac crest bone graft for the treatment of this open bite, but further surgery was unfortunately necessary due to relapse of the malocclusion. The intraoperative description of the procedure was unremarkable. The visual problem consisted of an absence of light perception in the right eye and a fixed, dilated right pupil occurring the morning after surgery. A consensual pupillary response was noted in the right eye , but was diminished in amplitude. The clinical impression presented was of a complete right optic nerve dysfunction and a partial right oculomotor nerve palsy.

CT examination revealed multiple facial and basilar skull fractures including the roof and posterior wall of the maxillary sinus, and the pterygoid plates. There appeared to be a fracture through the medial wall of the orbit posteriorly, fracture of the sphenoid bone extending through the floor of the middle cranial fossa, and a fracture through the lesser wing of the right sphenoid bone extending just lateral to the optic foramen. A small bony fragment was found to be in close proximity to, or in contact with the right optic nerve in the region of the optic foramen near the superior orbital fissure. The CT report indicated that the optic nerve was diffusely enlarged distal to the optic foramen, but that it was unaffected proximally. The patient did not regain any vision in the right eye.

The surgeon involved in this case indicated that anatomic differences in the pterygomaxillary region, as compared with the first surgery, necessitated use of the curved osteotome to achieve PTM separation at a point closer to the base of the skull. The previous surgery included a posterior maxillary impaction and bone grafting which was believed to have resulted in partial obliteration of the normal PTM fissure and more robust bone in this region. These factors were thought to have contributed to the fractures extending to the base of the skull and orbital regions despite the atraumatic and routine PTM dysjunction and downfracture noted at the time of surgery.

The authors indicated that the exact nature of the optic nerve injury, whether indirect or direct, is unclear. They suspected that the delayed onset of the blindness, was suggestive of an indirect cause of injury. The optic nerve was most likely damaged as it crossed the superior orbital fissure.

Lanigan et al[4] have stated that there is no doubt that fractures extending towards the base of the skull in the middle cranial fossa, or towards the orbit, have the potential to lead to the complication of blindness. They referred to posttraumatic cases of blindness that have been reported where no obvious fractures were detected on CT scan. On this basis, they suggested that excessive energy delivered to the region of the optic canal, or hairline fractures which are radiographically undetectable, may result from the process of PTM separation. It was recommended that ophthalmic complications be borne in mind, and that patients should be monitored for any signs or symptoms related to such problems in the postoperative period.

The preceding review of vascular, neurologic, and ophthalmic complications represents what appears to be a collection of isolated and rare case reports. One can speculate that the number of severe complications actually reported may be representative of a larger number that are not reported in the literature. The exact cause of these complications remains unknown. Some appear to be associated with anatomic variations, other complications have been attributed to unfavorable fractures in the pterygomaxillary region or transmission of excessive forces to adjacent neurovascular structures. These reports indicate the potential for severe complications arising with the Le Fort I osteotomy.

ALTERNATIVE TECHNIQUES OF PTERYGOMAXILLARY SEPARATION

Numerous papers have been published regarding techniques for improving and modifying the Le Fort I osteotomy. Many deal specifically with separation of the maxilla from its posterior attachments, i.e., pterygomaxillary separation (PTMS). The early papers were the result of difficulties of inadequate maxillary mobilization and postoperative relapse following Le Fort I osteotomy with maxillary advancement for the correction of pseudo Class 3 malocclusions with midface retrusion. More recent articles have proposed modifications of pterygomaxillary separation in order to minimize the occurrence of potential complications and to diminish the incidence of PTPF rendering PTMS more predictable.

Early attempts to characterize the nature of fractures in the PTM area during

Le Fort I osteotomy were based on cadaver studies. In their study, Wikkeling and Koppendraaier[20] postulated that it was unlikely for ideal PTMS to occur during Le Fort I osteotomy. Ideally the osteotome should severe the junction between the maxilla, the pyramidal process of the palatine bone and the pterygoid process such that the latter remains intact. Information regarding the location of the osteotomy lines in the PTM-tuberosity area, as well as identification of adjacent structures that could be potentially damaged, was obtained via careful dissection of the cadaver specimens. Le Fort I osteotomy was performed on eleven hemisectioned human subjects fixed in formalin. The curved osteotome was used at the PTM fissure to effect separation of the maxilla from its attachment to the pterygoid plates. The findings indicated three fracture types: 1."Ideal" fracture,

2. An "oblique" fracture through the dorsal part of the maxillary sinus, and

3. a high "nearly horizontal" pterygoid process fracture.

This study included an anatomical study of the PTM region in a series of twenty macerated human Indian skulls ranging in age from new born, to specimens in which synostosis of the sphenobasilar synchondrosis had occurred. The aim of this portion of the study was to suggest an optimal age for patients to undergo Le Fort I osteotomy based on development of the PTM region.

The conclusions of this paper were as follows:

1.The fracture in the PTM region is not always ideal. Muscle traction in combination with non-ideal separation may contribute to relapse of maxillary position as described by Perko.[37]

2. Severe bleeding during surgery and postoperative palatal anesthesia are explained by injury to the greater palatine artery and nerve. This was detected in the dissection specimens.

3. In the anatomical study of the PTM area, the younger skulls demonstrated an absence of direct bony connection between the PT process and the maxillary tuberosity, the palatine bone being intercalated between the two. Eventually, full bony union develops between the palatine bone, the pterygoid process, and the maxillary tuberosity. This union occurs by the time that synostosis of the sphenobasilar synchondrosis has occurred. In light of the results of the anatomical study, it was speculated that performing Le Fort I osteotomy in adolescents may reduce the number of non-ideal fracture lines. However, no definite recommendation with respect to optimal age of operation was made. The results of this study led to the development of the swan's neck osteotome designed to facilitate attainment of the desired fracture line.

The premise for this swan's neck osteotome was that separation of the PTM junction could be rendered more predictable if the fracture produced would coincide with the plane of fusion of the dorsal part of the maxillary sinus with the anterolateral part of the pyramidal process of the palatine bone. If the osteotome could be aimed in this direction, ie., from a posterolateral to anteromedial direction, this would avoid fracturing the pterygoid process since the applied force would be directed well away from it. Also, the plane of the osteotomy would leave the pterygopalatine canal and its contents safely embedded in the anterolateral plane of the pyramidal process.[26]

The swan's neck osteotome was designed such that the cutting edge of the instrument could reach the PTM junction easily while allowing the cutting force to be directed from a postero-lateral direction. Wikkeling and Tacoma repeated a cadaver specimen study on eleven specimens with the use of the swan's neck osteotome to effect PTM separation. In contrast to the previous study, all but one of the eleven separations were ideal. These more favorable results led the authors to propose a clinical trial with the use of this instrument. The stated disadvantage of this osteotome is that the mucous membrane incision must be extended further distally.

The critics of cadaver studies on fixed specimens state that these studies are not indicative of clinical conditions. Robinson and Hendy[52] carried out a study examining PTPF caused by Le Fort I osteotomy in unfixed cadavers. PTMS was accomplished with the use of the curved pterygoid osteotome in eight unfixed cadaver specimens in which the standard Le Fort I osteotomy technique was utilized. A higher incidence of PTPF was reported than in the two previous studies performed on fixed hemisectioned specimens. The PTP remained attached to the base of the skull in only four of sixteen sides. PTPF were divided into two groups, those which occurred above the level of the osteotomy cut (low level), and those which occurred at, or near the base of the skull (high level). Of the twelve PTPF, five were high level fractures. There was no apparent correlation between the presence, position, and extent of the PTPF, and whether that side of the osteotomy had been performed first or second. The conclusion drawn is that PTMS may result in unpredictable fractures, and that alternative approaches to PTMS may be preferable to the standard technique.

Use of the swan's neck osteotome in intact, unfixed cadavers rather than fixed, hemisected heads as used by Wikkeling and Tacoma[26] was evaluated by Cheng and Robinson[57] in 1993. Le Fort I level osteotomy was performed on twelve whole cadavers. Pterygoid plates were fractured in nine of twenty-four sides. In contrast to previous cadaver studies the pterygoid chisel was used. All of the PTPF were at the level of the osteotomy cut, and none was found at higher levels. The authors concluded that the likelihood of complications may be lower using this instrument, and alternative techniques should be investigated.

In an attempt to establish the best type of osteotome and methodology for PTMS, Hiranuma et al[54] measured strain distribution over surrounding bone structures during Le Fort I osteotomy on dry skulls. The Obwegeser osteotome was compared to the swan's neck osteotome. Larger tensile and compressive strains were detected at the medial pterygoid plate on the side of osteotome application with both osteotomes. Hence, the medial pterygoid plate can easily be fractured during PTM disjunction with either osteotome. However, the intensity of strain was higher in the Obwegeser osteotome group than in the swan's neck group. Therefore it is suggested that there is less risk of accidental fracture of the pterygoid process separated with the swan's neck osteotome. Proper positioning of the Obwegeser osteotome is important such as to avoid posterosuperior compression of the pterygoid process, and to minimize the probability of causing PTPF. The disadvantage of the swan's neck osteotome is its sinuous configuration that renders its application to the PTM junction unexpectedly difficult.

The lack of predictability of lines of fracture in the PTM area during Le Fort I osteotomy and documentation of intra and postoperative complications thought to be related to these unfavorable fractures, led to proposals of alternative methods of PTM separation.

In 1974 Dupont[27] proposed the use of a posterior vertical maxillary osteotomy through the maxillary tuberosity. It was postulated that placement of the osteotomy as usually described, between the PT process and the maxilla may be a problem because of the lateral convexity of the maxilla, and medial location of the pterygoid process. The use of a 2 mm osteotome through a transbuccal approach after sharp and blunt dissection through the cheek was described, the rationale being that the anterior site of the osteotomy would facilitate mobilization of the maxilla, as well as bone grafting and bone block advancement. The procedure also affords greater visibility. This technique is reported as advantageous in posttraumatic cases where the pterygoid plate process may be recessed or mobile, and where the normal path of the internal maxillary artery may be modified and may be subject to injury by the usual blind posterior osteotomy. The area of osteotomy also produces a wider bony area in which to set a posterior blocking bone graft. The authors considered that autogenous bone grafting was mandatory in cases of Le Fort I osteotomy advancement in order to prevent late postoperative recession and recurrence of deformity.

This was a technical article. No scientific attempt was made to confirm the hypothetical benefit of this technique. The authors simply reported use of this method with satisfactory results.

Posterior vertical maxillary osteotomy through the tuberosity has also been proposed by Trimble et al[21] via an intraoral approach. The description of the technique involves use of a straight osteotome placed distal to the second molar approximately 0.5 cm above the crest of the tuberosity, and pressed firmly against the mucosa, no incision being made. The osteotome is held at a 45 degree angle to the sagittal plane of the maxilla so as to be directed posteriorly, medially, and slightly upwards. A finger is placed on the palatal mucosa, at the junction of the hard and soft palate. The osteotome is struck until no osseous resistance is felt, and the tip of the osteotome can be palpated as it penetrates the tuberosity just medial to the inferior aspect of the PTMF. If a third molar is present, it is removed first. If it is impacted, access is attained through an incision extending posterior and superiorly from the distobuccal aspect of the second molar. After removal of the tooth, the osteotome is passed through the same incision. If no third molar is present, a sharp incision is made with the tip of the osteotome in the location described above. The usual extension of the horizontal mucosal incision is limited in extension to the mesial aspect of the second premolar because it is not necessary to place the osteotome within the subperiosteal tunnel towards the PTM junction as in the classic PTM separation technique.

The authors consider this approach anatomically less hazardous. It facilitates mobilization of the maxilla and it permits a larger vascular pedicle to be maintained. The claimed increased mobility of the maxilla is questionable, as the positioning of the posterior osteotomy as described, places it in an area of firmly attached mucosal tissues. One might speculate that significant subperiosteal dissection of these tissues may be necessary to achieve desired maxillary movements.

Precious and Ricard[19],and Precious et al[23], have advocated not using an osteotome to achieve PTM separation. The technique involves Le Fort I osteotomy cuts being made in the standard fashion with the exception that a saw is used instead of an osteotome to divide the lateral nasal wall. No osteotomy or separation in the PTM region is attempted. Downward pressure is applied symmetrically, first in the piriform rim area, with the Tessier forceps. This pressure is transmitted as a vertical force exerted in the long axis of the vertical line of reinforcement in the anterior maxilla, which in turn initiates an opening influence in a vertical direction in the region of the PTM fissure. As separation progresses, a point of rotation is established at the posteroinferior aspect of the maxilla. Subsequently, the Tessier spreaders are placed in the osteotomy one side at a time, in the region of the posterior zygomatico-maxillary reinforcement (zygomatic buttress), again exerting a predominantly vertical direction of force such that complete separation occurs between the tuberosity and the PTP of the sphenoid bone.

This technique was used in 500 cases with clinically satisfactory results. Two types of separation were recorded. Type 1 separation was a complete clean separation of the maxilla from the PTP in which the tuberosity was intact and in which the horizontal process of the palatine bone remained with the maxilla. Type 2 separation was described as clean separation similar to type 1, but in which a small cuff of the horizontal process of the palatine bone adjacent to the neurovascular bundle remained attached to the pterygoid process of the sphenoid bone . Type 1 separation occurred in 83% of the 500 cases, and type 2 separation in 17% of cases. The author states that use of this technique avoids fracture comminution of the PTP and the maxillary tuberosity, hence minimizing the risk of damage to adjacent neurovascular structures.

No difficulties were encountered with either type of separation in achieving passive repositioning of the mobilized maxilla. With type 2 fractures, removal of the small cuff of the horizontal process of the palatine bone was easily accomplished with a fine rongeur forceps. The rational for this downfracturing technique appears to be based on the authors' clinical impression that successful separation of the PTM junction is achieved while maintaining the integrity of structures in the PTM region hence minimizing the occurrence of potential complications associated with fractures of the PTP.

Unfortunately, the use of clinical examination to assess the integrity of structures in the PTM area has been shown to be inadequate. CT imaging studies have demonstrated that the actual incidence of PTPF is much higher than that detected by surgeons via tactile and visual intraoperative inspection. This technique has appropriately been evaluated via postoperative computerized tomography in a paper to be reviewed later.

Vargas-Garcia[25] has recommended an altered-sequence osteotomy to effect separation of the PTM junction. With this technique, the pterygoid osteotome is used to produce PTM disjunction prior to osteotomy of the postero-medial wall of the maxilla. This stabilizes the maxilla and hypothetically avoids improper fractures of the PTP that may be caused by radiating vibrations transmitted to the PTM region with malleting of the osteotome positioned at the PTM junction.

This technique was compared to the standard technique in a small retrospective study group of fourteen patients. Of the seven patients treated with the standard sequence of osteotomy, six patients demonstrated unilateral or bilateral PTPF, and mobilization of the maxilla was difficult in these cases. Only one of seven patients treated by the proposed technique demonstrated a unilateral PTPF. In the remaining six patients, the PTP were found to be completely intact, attached to the base of the skull, and separated from the maxillary tuberosity. These results are based on tactile and visual inspection at the time of surgery. Although the results seem promising in this small sample of patients, conclusions with regards to actual status of the PTP cannot be derived for reasons previously stated.(ie absence of CT imaging).

Juniper and Stajcic[24] have recommended use of a right angled oscillating saw to cut through the PTM junction. After Le Fort I osteotomy cuts are made in the standard fashion, the blade of the saw is placed into the PTM junction, and is aimed downwards and medially towards the arch of the palate adjacent to the last molar tooth. Completion of the osteotomy is confirmed by palpation of the vibrating saw through intact mucosa. The authors reported on the clinical use of this technique in six patients undergoing Le Fort I osteotomy with good clinical results and no complications. The advantage proposed is that the thin oscillating saw is unlikely to impart any compressive stress on the PTP hence avoiding PTPF and potential complications.

Evidence from experimental studies on cadaver specimens and dry skulls indicated that improperly directed forces at the PTM junction caused deviation of the fracture line from the desired plane.[20,52,54] On this basis and on the basis of work by Wikkeling and Tacoma[26] with the swan's neck osteotome, Stajcic[22] attempted to demonstrate in a series of twelve cadaver specimens, that increasing the angulation of the curved osteotome (relative to the sagittal plane) in its application to the PTM fissure would decrease the incidence of PTPF. The twelve fresh cadaver specimens were divided into two groups. In group 1, PTM separation was achieved with use of the curved osteotome in the standard fashion, the angulation of the osteotome to the sagittal plane being approximately 50 degrees. In group 2, the osteotome was applied through a separate vertical incision in the PTM region. The angulation of the osteotome in these cases was approximately 80 degrees to the sagittal plane. The results of this study indicated that increased angulation of the osteotome relative to the sagittal plane appeared to reduce the incidence of PTPF. However this approach is not recommended as it can produce an undesirable separation of the palatine bone from the maxilla, and posterior dislocation of fracture fragments.

It is difficult to derive clinically applicable information from this study since, as in other cadaver studies, there is little to indicate that the findings in this study are reproducible in vivo. Measuring the exact angulation of the osteotome relative to the sagittal plane of the maxilla would seem to be impractical and difficult in a clinical setting.

There appears to be justification and validity in proposing alternative techniques or alternatives to PTMS in the standard fashion. However, the previously cited studies are technical descriptions or cadaver specimen studies, some with anecdotal reports of satisfactory use of the proposed method. In 1993, Lanigan[28] reviewed the literature pertaining to alternative approaches to PTMS. The conclusion from the review of these studies was that these cadaver studies provided little experimental evidence to confirm that the proposed modifications are safer than the standard approach to PTMS with the curved osteotome. Despite this statement, Lanigan attempted to evaluate the effectiveness of alternative methods of PTMS in 50 fresh cadaver specimens. The specimens were divided into 5 study samples:

1. Conventional PTM separation.
2. PTM separation through the maxillary tuberosity as described by Trimble et al[21].
3. Osteotomy through the tuberosity with an 8 mm straight, sharp osteotome as the first cut of the Le Fort I osteotomy.
4. Manual downfracture of the maxilla without prior PTM separation.
5. Use of the Stryker micro-oscillating saw with a 9 mm blade to separate the maxillary tuberosity and the PT plates.

Several generalizations regarding PTMS were made:

1. None of the techniques consistently produced PTMS.
2. PTPF occurred in groups where the pterygoid osteotome was not used.
3. The use of the pterygoid osteotome in groups 1 and 2 produced the lowest number

of ideal separations and the highest number of high level PTPF.

4. The use of a small, straight, thin osteotome through the tuberosity as the initial bone cut, and the use of the oscillating saw proved better than the simple manual downfracture technique.

5. No fractures were found to extend to the base of the skull. This could not be positively concluded due to limited access of the dissections.

6. In cases where an osteotome was utilized, the incidence of PTPF did not differ when comparing the first side to the second side, except in cases where the osteotome was applied prior to any horizontal osteotomies. In these latter cases, the second side demonstrated worse fractures.

7. In certain cases, during the sequence of steps of the Le Fort I osteotomy, the maxilla was found to be quite mobile prior to PTMS. In these subjects the author states that PTMS would have undoubtedly been better achieved via simple manual downfracture rather than by use of an osteotome in the PTM junction.

The author recommended that the use of the Obwegeser curved osteotome be abandoned on the basis of the high rate of PTPF demonstrated with its use in this study. The oscillating saw was recommended to achieve PTMS, or if the surgeon does not have access to this instrument, a small straight curved osteotome through the maxillary tuberosity as the initial bone cut should be considered.

Lanigan is in favor of the manual downfracture technique without use of an osteotome, only if the maxilla is fairly mobile after the initial osteotomy cuts to section the lateral maxillary walls. If the downfracture appears difficult, he recommends that PTMS be performed first via the oscillating saw, or osteotomy through the tuberosity. This is recommended in order to avoid untoward fractures extending to the base of the skull and the orbit. Although the incidence of these latter fractures is undoubtedly low, in light of the significant complications which would arise, every effort should be made to reduce their occurrence.

The conclusion of this paper states that it is unlikely that untoward fractures can be prevented during PTM disjunction and maxillary downfracture due to anatomical variability with respect to thickness of the PTP, superior/inferior and medial/lateral position of the PTM junction and its length, as well as variability in the junction of the maxillary tuberosity, the pyramidal process of the palatine bone, and the pterygoid plate.

This paper reviews the literature pertaining to the issues surrounding PTMS during Le Fort I osteotomy. The discussion of the paper addresses the main issues currently being discussed in regards to this topic. The experimental component appears to have been well organized and documented. In order to derive clinically useful information from this study, the techniques described would have to be applied in a randomized clinical trial with appropriate postoperative imaging to assess definitively the status of the PTP.

IMAGING STUDIES

The first study utilizing computerized tomography (CT) to characterize the incidence and anatomical pattern of PTPF post Le Fort I osteotomy was published by Rennick and Symington[2] in 1991. CT was used to assess the pterygomaxillary region in 12 orthognathic surgery patients who underwent Le Fort I osteotomy in which PTM separation was performed in the standard fashion with use of the pterygoid osteotome. CT images of the PTM region were obtained between one and seven days after the surgery utilizing 3 mm cuts in the coronal and axial planes. The CT observations as well as the clinical impression of PTP integrity were considered in the results. PTPF detected via CT were classified as low if they occurred inferior to the Le Fort I horizontal osteotomy, and high if they occurred superior to this level. The results in this study were reported considering the right and left side of the maxilla within the same patient as a separate unit. PTMS was considered "successful" in all cases, with 41.6% of the sides not having a PTPF. Of the seventeen plates judged to be intact clinically, seven were actually found to be fractured on CT examination. Low horizontal fractures were noted in nine of twenty-four sides (37.5%), high horizontal fractures in six of twenty-four sides (25%), and a tuberosity fracture was detected in one of twenty-four sides. No fractures other than those of the pterygoid plates or the tuberosity were detected.

Upon examining the statistical methods of this study it can be noted that the right and left side of the maxilla are considered as independent units in the calculation of incidence of PTPF. The assumption is made that a pterygomaxillary fissure on one side of a maxilla is completely independent of its contralateral partner. This is statistically questionable. This approach presumably stems from the observation of, and comparison to, results of cadaver specimen studies using hemisected heads, as these results are necessarily reported in terms of the number of PTPF per number of operated sides. The experimental unit should be considered the patient, (ie. the maxilla). The pterygomaxillary fissures of each patient should not be assumed to be independent of each other. If the results of the Rennick and Symington study are recalculated using both sides of one maxilla as the experimental unit, the incidence of PTPF is 91.7%. In other words, 91.7% of patients in their study had a unilateral or bilateral PTPF, eleven of twelve patients had a PTPF, three of twelve had bilateral PTPF, eight of twelve had unilateral PTPF.

The authors state that PTM disjunction using the classic technique is frequently complicated by fractures of the PTP. They acknowledge that many of these fractures go unrecognized at the time of surgery, and state that the clinical assessment of PTP integrity should not exclude plate fracture as a contributing factor in postoperative complications. Compromised access to the PTMF due to restriction by the cheek, or extreme medial location of the pterygoid plates is addressed as a long-recognized impediment to achieving ideal PTMS. This has led to numerous modifications of the technique of PTMS. They conclude that further evaluation of proposed modifications of PTMS should be investigated with postoperative CT imaging, and that refinement of the PTM disjunction technique may further reduce the incidence or severity of intraoperative complications related to the Le Fort I osteotomy.

The ensuing discussion of this study by Precious raises a number of interesting questions regarding the relationship of PTPF to the occurrence of complications, viz. the presence of a causal relationship between the use of the pterygoid chisel and the occurrence of PTPF. The PTPF, and the maneuver causing these fractures are both individually considered as potential, direct causes of nerve or vessel damage. The clinical significance of PTPF is questioned in light of the relatively small incidence of complications compared to the higher incidence of PTPF. Precious also points out that given the small patient sample in this study, it is not reasonable to establish a relationship between PTPF and intraoperative or postoperative complications.

In a subsequent study by Precious et al[3] CT was used to compare the incidence of PTPF among two groups of patients with a variety of dentofacial deformities undergoing Le Fort I osteotomy. The study population consisted of fifty-eight adult patients, forty-nine women and nine men. PTM separation was accomplished with the pterygoid osteotome in thirty patients and without osteotome in twenty-eight patients. In the latter group PTMS was effected with the use of Tessier spreaders as described in the technique article by Precious, Morrison, and Ricard.[23] The PTM area was assessed within three to five days after the surgery via coronal and axial CT scans using 2 mm slices.

CT scan demonstrated that PTPF occurred in 87% of cases in which the osteotome was used and in 82% of the cases in which PTMS was achieved without the use of the pterygoid osteotome. All fractures were reported to have occurred in the lower half of the PTP. No high level fractures, or fractures of the cranial base were noted to have occurred in either group. In none of the fifty-eight cases did complications of intraoperative vascular or nerve injury, gross bony comminution, inability to reposition the maxillary segments, or postsurgical bleeding occur.

As in the other studies utilizing CT to assess the PTM area postoperatively, a high percentage of the fractures detected on CT went undetected at the time of the surgery. The surgeon noted that acceptable separation between the maxilla and the pterygoid process took place in 80% of cases in which an osteotome was used, and in 86% of those in which the osteotome was not used. In the cases that were not considered acceptable, minor osseous adjustment was required, particularly in the region of the palatine bone adjacent to the pterygoid process of the sphenoid bone.

The authors concluded that avoiding use of the pterygoid osteotome will not prevent PTPF, and that neither technique of PTMS is associated with a greater degree of danger. They stated that, based on their clinical experience, PTMS can be accomplished safely and easily without the use of the pterygoid osteotome.

The description of the above study design gives no indication of whether patients were randomly assigned to either study group, or whether the decision regarding use or non-use of the pterygoid osteotome was made prior to, or during the surgery. Neither the time span over which this study was carried out, nor the number of surgeons involved was indicated. The results are reported as percentage of cases in which PTPF occurred, but it is not specified whether this is considering the entire (both sides) of the maxilla as the experimental unit. These are relevant issues in evaluating the results of such a study.

The two latter studies represent a significant advancement over previous studies on PTMS. The use of postoperative CT scanning greatly enhances the validity of the assessment of osseous structures in an area that is generally inaccessible for direct examination during Le Fort I osteotomy.

MATERIAL AND METHODS

Patient Selection

Fifty-one adults ranging from 18 to 42 years of age, 34 female and 17 male, with dentofacial deformities, were admitted to the oral and maxillofacial surgery service of the Montreal General Hospital to undergo LeFort 1 osteotomy as part of their treatment. Patients, with craniosynostosis, cleft palate, or history of previous surgery or trauma to the maxillary area were excluded from the study. Patients were assigned to the osteotome or non-osteotome group in random fashion. These patients were distributed proportionately with respect to method and gender in the two study groups, consisting of twenty-six and twenty-five patients in the osteotome and non-osteotome group respectively.

Surgical Technique

Standard Le Fort I osteotomy cuts and pterygomaxillary separation with the pterygoid osteotome were performed as described by Bell[1] for the osteotome group. The lateral wall of the maxilla was osteotomized with a reciprocating saw and the lateral nasal wall was osteotomized with a guarded Silver chisel. The cartilaginous septum and vomer were separated with a nasal septum osteotome, and the pterygoid osteotome was used to separate the maxilla from the pterygoid plates.

In the non-osteotome group, after osteotomizing the lateral wall of the maxilla and lateral wall of the nose, and separating the cartilaginous septum and vomer, PTM separation was achieved manually as described by Epker and Fish.[29] Firm digital pressure in the area of the premaxilla was applied in an inferior direction in order to downfracture the maxilla. If the applied force did not result in downfracturing of the maxilla, the osteotomies were reexamined to ensure that they were complete.

Manual pressure was then used again to produce separation. After completion of the downfracture and mobilization of the maxilla, a measurement of lateral maxillary wall thickness, and a subjective evaluation of the ease of downfracture were recorded for both groups. The condition of the pterygoid plates and adjacent structures was determined by visual and digital examination. Clinical assessment of the location of fractures (if present), and the presence or absence of complications both intraoperatively and postoperatively, were noted.

Bone Thickness Measurements

Bone thickness was measured at four points identified at specific locations on each side of the maxilla. Measurements were made with the maxilla in the downfractured position using a Twansson's gauge caliper. (Figure 1) These points were:

A. Piriform rim at the point of greatest thickness.

B. A point midway between the piriform rim and the zygomatic buttress.

C. Zygomatic buttress at its greatest cross-sectional point of thickness.

D. A point midway between the zygomatic buttress and the pterygomaxillary fissure.

This information was recorded on a patient data sheet provided to the surgeon. (Table 2).

Computerized Tomography Technique

Patients underwent coronal and axial CT scans of the pterygomaxillary region between the seventh and tenth postoperative day. The imaging technique utilized 5 mm thick slices and 5 mm table increments. The CT scans were evaluated by a radiologist and by two surgeons in order to determine the status of the pterygoid plates and adjacent osseous structures.

Classification of Fractures

Fractures of the pterygoid plates were classified according to the level of the fracture relative to the horizontal osteotomy cut in the lateral wall of the maxilla. A fracture of the pterygoid plate was classified as high if the line of fracture was above the level of the maxillary osteotomy. A fracture was classified low if the line of fracture was at, or below, the level of the osteotomy.(Table 1)

Fractures of the horizontal process of the palatine bone were also recorded. These were considered major if the entire horizontal process of the palatine bone separated from the palatal process of the maxilla. Fractures of the palatine bone were considered minor if only a small cuff of the horizontal process adjacent to the descending palatine neurovascular bundle fractured away from the larger segment of the palatine bone. In contrast to pterygoid plate fractures, the detection of palatine bone fractures was based on clinical assessment rather than CT assessment. These fractures were more reliably detected clinically with the maxilla in the downfractured position than on CT examination.

Figures 2 through 6 demonstrate coronal and axial CT views of the pterygiod plates and PTM region. These were selected CT images obtained after Le Fort I osteotomy providing examples of the various outcomes and status of the pterygoid plates postoperatively.

Figure 2: Ideal, intact pterygoid plates.

Figure 3: Ideal separation of maxilla from pterygoid plates. (axial view)

Figure 4: Low level PTPF. (bilateral)

Figure 5: Non-ideal separation, unilateral non-separation of the PTM junction.

Figure 6: High level fracture of the right pterygoid plate

RESULTS

OUTLINE:

1. **Distribution of subjects by surgeon, gender, and method.**
2. **Incidence of pterygoid plate fractures:**
    a. Relationship of method of PTM separation to status of the PTP

    b. Relationship of gender to incidence of PTPF

    c. Clinical detection of PTPF vs CT detection

    d. Relationship of surgeon to incidence of PTPF
3. **Incidence of palatine bone fractures:**
    a. Relationship of method to incidence of palatine bone fracture.

    b. Relationship of palatine bone fracture relative to PTPF
4. **Bone thickness of the lateral wall of the maxilla:**
    a. Usefulness as a predictive factor for occurrence of pterygoid plate fractures

    b. Mean thickness values.

    c. Relationship of gender to bone thickness.

    d. Subjective evaluation of thickness by surgeon.
5. **Subjective evaluation of difficulty of downfracture:**

    Predictive value for occurrence of pterygoid plate fractures.

The Chi-Square test was applied to comparison tables to assess the statistical relationship between PTPF and the variables of method of pterygomaxillary separation, gender, surgeon, and subjective ease or difficulty of downfracture. The relationship of palatine bone fractures to PTPF, and to the method of pterygomaxillary separation was also evaluated. An Analysis Of Variance (ANOVA) was used to establish the presence or absence of a relationship between mean thickness of the lateral wall of the maxilla and the incidence of pterygoid plate fracture.

1. Distribution of subjects:

Randomized assignment of patients to either study group resulted in an even distribution of subjects according to surgeon, gender, and method. (Tables 3,4,5)

2. Incidence of PTPF:

There was no significant difference in incidence of PTPF when comparing the two techniques of pterygomaxillary separation used in this study.(Table 6) The incidence of PTPF (unilateral and bilateral combined) in the osteotome group (O) was 61.5% versus 60.0% in the non-osteotome (NO) group. These were all classified as low level PTPF, with the exception of two high level fractures in the osteotome group. In both of these cases, the PTPF was accompanied by a contralateral low PTPF and the pterygoid process was separated from the maxillary tuberosity. A trend was noted for the NO group to have a higher incidence of bilateral PTPF at 36.0% (9 of 25 subjects), compared to the osteotome group at 23.08% (6 of 26 subjects). However, this was not statistically significant ($p=0.454$) due to an overall low number of subjects.

In this study each patient's maxilla was considered as one unit, as it was felt that it would be statistically and clinically inappropriate to consider each pterygomaxillary junction independent from its contralateral side. For the purposes of comparison to previous studies, these results are also presented as the number of PTPF per side of the maxilla. The incidence of PTPF in the osteotome group was 42.3% (22 of 52 sides), versus the non-osteotome group incidence of 48.0% (24 of 50 sides). Of the PTPF in the osteotome group, 54.5% (12 of 22 fractures) were bilateral, compared to the non-osteotome group, where 75.0% (18 of 24 fractures) were bilateral.

As previously mentioned, ideal PTM separation entails separation of the maxillary tuberosity from the intact pterygoid process. The status of separation of the fractured pterygoid plate relative to the maxillary tuberosity was recorded from the CT observations. In the osteotome group, 5 of 22 PTPF were separated, and only 2 of 24 PTPF in the non-osteotome group were separated.

Since there was no significant difference in the incidence of PTPF between the two groups, the males and females were pooled together in the assessment of the relationship between gender and incidence of PTPF.(Table 7) The incidence of PTPF for males was 76.5%, versus 52.9% for females. There was a strong trend for men to have bilateral pterygoid plate fractures and for women to have ideal pterygomaxillary separation upon downfracture, regardless of the technique utilized. Using a Chi-Squared test, the p value for this test approached statistical significance. ($p=0.115$)

The surgeons' ability to detect the presence of PTPF intraoperatively was poor compared to the incidence of PTPF detected via CT. Only 35.5% of PTPF were detected at the time of surgery. There was a 57.1% chance that a case considered ideal by the surgeon actually had a PTPF, i.e., 20 of 35 cases clinically termed ideal actually had a unilateral or bilateral PTPF on CT evaluation. This was statistically significant with a Chi-Square p value of 0.001. (Table 8)

The incidence of PTPF did not differ between surgeons with either method of pterygomaxillary separation.(p=0.827) (Table 9)

3. Incidence of palatine bone fractures:

There was no relationship between the method of pterygomaxillary separation and the incidence of palatine bone fracture or separation.(Table 10) The incidence of palatine bone fracture overall was 15.6%, 8 of 51 patients having a unilateral or bilateral palatine bone fracture. Minor palatine bone fractures were not included in the above calculations. (p= 0.897)

Palatine bone fractures and PTPF tended to occur in a mutually exclusive distribution. Cases which had bilateral PTPF had no palatine bone fractures. Cases which had palatine bone fractures tended to have no PTPF. In cases where unilateral PTPF occurred with unilateral palatine bone fractures, these occurred contralaterally to each other.(p=0.002) (Table 11)

4. Mean thickness of the lateral wall of the maxilla:

According to ANOVA no relationship was found between the mean thickness of the lateral wall of the maxilla and the incidence of PTPF or type of fracture produced for both groups combined. If the methods of pterygomaxillary separation are considered separately, observation of mean thickness of the maxilla for each type of fracture outcome (ideal, unilateral, bilateral) indicates that unilateral fractures in the osteotome group had a significantly greater mean thickness (2.88 mm) than unilateral fractures in the non osteotome group (1.68 mm). $p = 0.02$ The other two outcomes of ideal and bilateral PTPF did not demonstrate a significant difference in mean thickness values.

With respect to bone thickness, a trend was also noted for greater mean thickness values to be seen in men compared to women. This trend is accentuated if the mean thickness values for the maxilla are restricted to the piriform rim and zygomatic buttress.(Table 12,13) With a one-sided T-test, the p value approaches statistical significance for this measurement. ($p=0.095$)

A Spearman correlation analysis was performed to assess the correlation between the surgeon's subjective assessment of bone thickness, and the actual mean value measurements of the lateral wall of the maxilla. This test indicated a poor correlation between the two variables with a coefficient of 0.49. (1 indicates perfect correlation).

5. Subjective evaluation of difficulty of downfracture:

The subjective assessment of ease or difficulty of downfracture demonstrated no relationship to the incidence of PTPF.($p=0.308$) Interestingly, in the NO group, downfractures classified as EASY, demonstrated a strong trend to have PTPF. ($p=0.186$) This was an unexpected finding as it would have been expected that difficult downfractures would have a higher incidence of PTPF. The osteotome group conversely demonstrated a trend where EASY downfractures tended to have ideal pterygomaxillary separation.(0.186) (Table 14,15,16)

DISCUSSION

The results of this study indicate that both techniques of PTM separation can be safely utilized with a correctly applied technique, without great apparent risk of major complications. The incidence of pterygoid plate fractures was high for both the osteotome, and non-osteotome groups, 61.5% and 60.0% respectively, and no major complications occurred in this series of 51 patients. In all cases, a clinically acceptable result of maxillary positioning was attained. The preferential selection of use or non-use of the osteotome prior to manual downfracture of the maxilla during the Le Fort I osteotomy cannot be justified on the basis of the results of this study.

The trend for a higher incidence of bilateral PTPF in the non-osteotome group compared to the osteotome group may be a reflection of the difference in the timing of pterygomaxillary separation with both techniques. With the manual downfracture technique, pterygomaxillary separation of the right and left sides should theoretically occur simultaneously if it is successful. Conversely, this would suggest that if the patient has a predisposition for PTPF to occur, both sides would fracture simultaneously. With use of the osteotome, each side is sequentially osteotomized, theoretically independent of the other side. In both methods however, downfracturing of the maxilla is followed by manual mobilization from one side to the other, to ensure full passive freedom of movement. The question then arises whether it is the downfracturing of the maxilla, mobilization of the maxilla, or the use of the osteotome, that actually causes the fractures or the complications associated with these fractures? This question has previously been alluded to by Precious, and it remains unanswered.[3]

The clinical significance of PTPF and in particular, their role in life-threatening complications has been appropriately questioned on the basis of the frequency with which they occur in contrast to the very low incidence of reported life-threatening complications.[3] No fractures involving the base of the skull were documented in this study, or in the two other studies using CT to assess the status of the pterygoid plates after Le Fort I osteotomy.[2,3] The possibility of a causal relationship between PTPF and major complications during Le Fort I osteotomies certainly cannot be rejected at this time.

It is noteworthy that cases of major complications recorded in the literature were frequently attributed to improper use of instruments, or anatomic variation in the PTM region.[5,7,12,44] It has also been stressed that careful application of technique in PTM separation is important if one wishes to avoid unfavorable results.[6,40,54] The potential for the occurrence of major complications related to PTM separation in the absence of PTPF has been alluded to by Lanigan.[4] It has been suggested that the transmission of excessive forces from the PTM area to the base of the skull may produce serious complications.[4]

Variation in the length of the PTM fissure which has been noted in cadaver specimen studies[18] may influence the ease of PTM separation and the incidence of PTPF. A practical method of measuring the length of the PTM fissure clinically may be useful. Consideration should be given to identification of abnormal osseous anatomy via preoperative CT imaging if indicated, in cases such as syndromal deformities, previous operation, past history of trauma, etc..

PTPF may also be of clinical significance from a mechanical point of view with respect to impeding desired movements of the maxilla. Anteroposterior, superoinferior, or lateral orthognathic movements of the maxilla may be difficult as a result of the effect of pterygoid muscle attachment to the unseparated pterygoid plates. The pterygoid musculature may exert an effect on the most inferior portion of the pterygoid plates that remain attached to the maxillary tuberosity in the presence of a fracture. An increased incidence of postoperative relapse has been proposed to occur as a result of this persistent muscle attachment.[22] This latter phenomenon has not, as of yet been shown to occur. The use of rigid internal fixation to stabilize the maxilla may diminish the probability of maxillary relapse as a result of low level PTPF.[22] PTPF may also cause mechanical interference with reduction of the mobilized maxilla during autorotation of the maxillo-mandibular complex. Hinging of the complex on a contact point in the area of a PTPF may occur. If unnoticed, this may predispose to condylar distraction during the final positioning of the mobilized maxilla, and immediate malocclusion upon release of the intermaxillary fixation.

PTPF may also indirectly result in damage to adjacent neurovascular structures. If a portion of the plates remains attached to the maxillary tuberosity, i.e., a PTPF occurs without pterygomaxillary separation occurring, it may damage structures in the pterygopalatine fossa during mobilization of the maxilla.[28] An evaluation of cases with PTPF indicated that the presence of this fracture usually implied an absence of separation of the pterygoid process from the maxillary tuberosity. As previously mentioned, in the osteotome group 5 of 22 fractured sides(PTPF) were separated from the maxilla compared to 2 of 24 fractured sides in the non-osteotome group. This indicates that PTM separation does not occur in significant numbers of cases when PTPF occurs. This may be of some concern as the results of this study indicate that the majority of PTPF are not detected at the time of surgery.

The results of this study indicate that there was a strong trend for males to have bilateral pterygoid plate fractures and for females to have ideal pterygomaxillary separation upon downfracture with both techniques. No explanation was found for the higher incidence of PTPF in males of 76.5% versus 52.9% for the females. When mean thickness of the lateral wall of the maxilla was considered, a trend was detected indicating greater thickness values in males. Using an analysis of variance (ANOVA) no relationship was found between the mean thickness of the lateral wall of the maxilla and the incidence of PTPF or type of fracture produced. Therefore thickness of the lateral wall of the maxilla was of no predictive value for the occurrence of PTPF. It is theoretically possible that differences in bone density may contribute to this difference in incidence of PTPF between genders.

The examination of the relationship of mean thickness of the lateral wall of the maxilla to the incidence of PTPF is a test of the hypothetical relationship between this measurement and characteristics of the PTM junction. The hypothesis is suggested that thicker bone in the region of the lateral wall of the maxilla may entail a higher degree of osseous union of the PTM junction. The affirmation of this relationship would provide the surgeon with information regarding the characteristics of the PTM fissure prior to downfracturing of the maxilla during Le Fort I osteotomy.

The absence of a relationship between surgeon and incidence of PTPF indicated that the participation of two surgeons did not present a confounding variable to the interpretation of these results. It can be seen that the differences in PTPF in both O and NO group is maintained within each surgeon patient group.(Table 9)

The subjective assessment of ease or difficulty of downfracture demonstrated no relationship to the incidence of PTPF. Interestingly, in the NO group, downfractures classified as EASY, demonstrated a strong trend to have PTPF. This was an unexpected finding as it would have been expected that difficult downfractures would have a higher incidence of PTPF. The above finding could possibly be accounted for by variability in the morphology of the pterygoid plates[18,28], such that very thin pterygoid plates may have existed in these cases. No characterizing features were found to be associated with the patients in the category of easy downfractures. Admittedly, one of the weaknesses of this type of categorization of downfractures lies in the subjectivity, and hence variability of the categorization.

The ease or difficulty of downfracture was recorded so that this variable could be correlated to the potential occurrence of unexplained immediate or postoperative complications. Establishing the presence of a relationship between the subjective evaluation of downfracture and the probability of occurrence of a PTPF would also theoretically provide the surgeon with additional information at the time of surgery regarding the status of the pterygoid plates.

Fractures or separation of the horizontal process of the palatine bone from the palatal process of the maxilla were much less frequent than PTPF. The detection of palatine bone fractures was based on the intraoperative assessment rather than on the CT evaluation because these fractures were grossly obvious with the maxilla in the downfractured position. Axial CT sections did not consistently demonstrate these fractures.

There was no relationship between method and the incidence of palatine bone fracture or separation. The incidence of palatine bone fracture overall was 15.6%; eight of fifty-one patients had a unilateral or bilateral palatine bone fracture. Interestingly, palatine bone fractures and PTPF occurred in a mutually exclusive distribution. In those cases with bilateral PTPF, the horizontal process of the palatine bone invariably remained intact and attached to the horizontal process of the maxilla. In cases of unilateral PTPF with unilateral palatine bone fracture, these were invariably found to be contralateral to each other.

Fractures of the horizontal process of the palatine bone in the absence of PTPF may indicate that the transverse palatine suture, (union of palatine process of maxilla and horizontal process of palatine bone) represents a potential point of weakness susceptible to separation or fracture during mobilization of the maxilla. Incorrect angulation of the pterygoid osteotome may cause separation of the horizontal process of the palatine bone from the palatal process of the maxilla.[21,22] If the vector of force produced by the osteotome is directed too anteriorly, the pyramidal process of the palatine bone may separate from the maxillary tuberosity. Bell[42] has attributed this separation to inadequate cutting of the pyramidal process during pterygomaxillary separation.

Palatine bone separation in the absence of use of the osteotome in this study, supports the suggestion that an inherent line of weakness may exist at the junction of the pyramidal process of the palatine bone and the maxillary tuberosity, extending through to the palatomaxillary suture. Fractures of the horizontal process of the palatine bone may hinder orthognathic movements of the maxilla. Parasagittal sectioning to increase the transverse width of the maxillary dental arch may be difficult as lateral movement of the hemi-maxilla with the separated, or fractured horizontal process may be impeded due to firmly adherent palatal mucosa. In contrast to PTPF, these fractures are readily visible with the maxilla in the downfractured position therefore facilitating their management.

Two other points of weakness where separation or fracture is likely to occur during pterygomaxillary separation are the pterygomaxillary fissure, where separation should ideally occur, and low horizontal fractures of the pterygoid plates, which are known to occur quite commonly during the standard Le Fort I osteotomy. High level PTPF were rare in this study, only 2 of 22 fractures in the osteotome group, and none of the fractures in the non-osteotome group being classified as high. Hence, there appear to be three areas where separation or a fracture is likely to occur with the following order of likelihood. (Table 17)

1.Low level PTPF,

2.Ideal pterygomaxillary separation at the pterygomaxillary fissure,

3.Separation or fracture of the horizontal process of the palatine bone.

The results of this study generally agree with those two previous studies in which computerized tomography was used to assess the incidence of PTPF after Le Fort I osteotomy.[2,3] (Table 18)

In all three studies, the incidence of PTPF was high regardless of the technique of pterygomaxillary separation utilized. The incidence of surgeon detection of PTPF was low. As previously mentioned in the review of these studies[2,3], a direct comparison of the results cannot be made because of differences in the statistical unit selected in one of the studies. In the Rennick and Symington[2] study the percentage incidence of PTPF is based on each side of the maxilla individually. If readjusted, these results are more appropriately reported as the percentage of patients having had a PTPF. The experimental unit in this study was considered to be the patient (i.e. the maxilla); the two pterygomaxillary fissures of each patient were not assumed to be independent of each other.

The incidence of PTPF reported by Precious et al is also high. Pterygomaxillary separation in the non-osteotome group in the Precious et al[3] study was achieved with the use of Tessier spreaders which are used to apply a vertical force to the maxilla at the Le Fort I osteotomy site. Use of this instrument has been questioned because it is suggested that it is too easy to produce comminution of fragile bony edges of the lateral wall of the maxilla.[55] Precious described the use of Tessier spreaders in a large series of patients without major complications.[19] The incidence of PTPF did not differ between their osteotome and non-osteotome groups which was 87% and 82% respectively. The experimental unit in this study was not specified. It would appear from the wording of the results (percent of cases in which a PTPF occurred), that as in this study, both sides of the maxilla were appropriately considered as one experimental unit.

The surgeon's ability to detect PTPF intraoperatively was limited. This was evidenced by the fact that the incidence of PTPF detected on CT was much higher than that detected at the time of surgery in all three of the above mentioned studies.

An informal retrospective survey of the experience of three surgeons that have performed Le Fort I osteotomies for a period of 15-20 years at the institution where this study was performed produced no reports of major, or life threatening complications relating to PTM separation. Combined with the results of this study, it is concluded that either the O or NO technique of pterygomaxillary separation can be safely utilized. However, this does not diminish the significance of reported life threatening complications occurring with Le Fort I osteotomy.

Studies recommending alternatives to pterygomaxillary separation may be well justified since recent clinical studies,[2,3] including this study, have demonstrated with CT that ideal pterygomaxillary separation does not occur reliably with standard techniques. In addition, studies using cadaver specimens have indicated through macroscopic, and microscopic analysis that because of the complexity of the articulations between the maxilla, the pyramidal process of the palatine bone, and the pterygoid plates, ideal pterygomaxillary separation is possible, but does not occur in all cases.[18] This latter finding supports the recommendation made by many authors to achieve posterior osseous freedom of the maxilla at a location other than the PTM fissure.

The outcome of PTM separation and downfracture with the techniques described in this study remains unpredictable. The relationship between PTPF and the maneuvre producing these fractures to severe complications remains a point of speculation.

The development and refinement of the Le Fort I osteotomy should be encouraged since this may lead to improvements in the precision, predictability, and stability of maxillary movements. A decrease in the already low incidence, and in the severity of major complications would also be anticipated. Alternative techniques to pterygomaxillary separation that have been proposed should be investigated with appropriate clinical studies assessing the incidence of complications and utilizing appropriate postoperative imaging.

SUMMARY AND CONCLUSIONS

The relationship between two methods of PTM separation to the incidence of PTPF was investigated through a prospective randomized study utilizing postoperative CT to assess the status of the PTM region.

Relationships between the incidence and type of PTPF and variables of mean thickness of the lateral wall of the maxilla, subjective ease or difficulty of downfracture, and gender were investigated.

There was no significant difference in the incidence of PTPF between the osteotome and non-osteotome group. The majority of PTPF were unrecognized at the time of surgery. Palatine bone fractures tended to occur in the absence of PTPF.

However, the following trends were identified:

1. The non-osteotome group demonstrated a trend for bilateral PTPF.
2. Male subjects demonstrated a strong trend towards having bilateral PTPF.
3. Females tended to have ideal PTM separation.
4. Downfractures identified as easy tended to demonstrate bilateral PTPF.

No severe or lifethreatening complications were recorded in this study. If correctly applied, either technique of PTM separation appears relatively safe.

Based on the review of the literature, it may be preferable to minimize the amount of force transmitted to the pterygoid plates and hence to the skull base given the severe nature of potential complications. Further refinement and improved predictability of PTMS is desirable. Therefore further study of alternative techniques of PTM separation is recommended.

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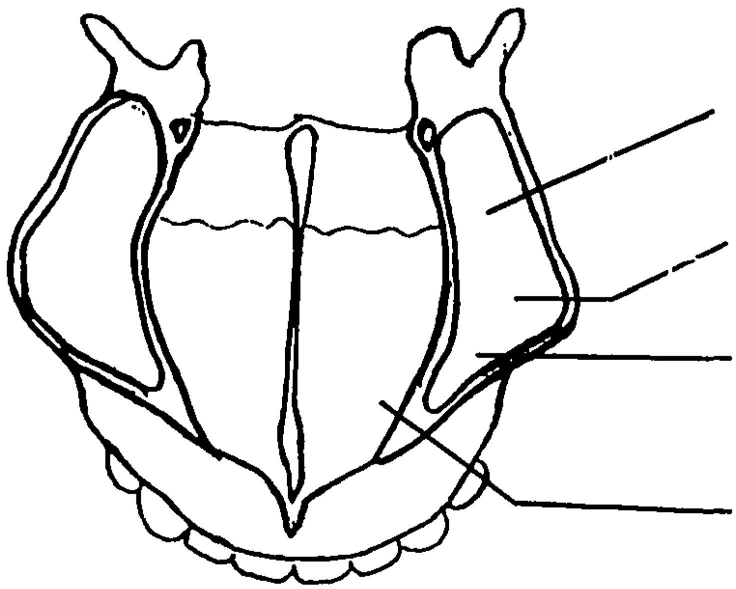
Appendix A: Figures 1 to 6

Figure 1 Bone Thickness Measurements



A. Midway between zygomatic buttress & PTM fissure.

B. Zygomatic buttress at point of greatest thickness.

C. Midway point between piriform rim & zygomatic buttress.

D. Piriform rim at point of greatest thickness.

FIGURE 2 CORONAL VIEW
IDEAL PTERYGOMAXILLARY SEPARATION
INTACT PTERYGOID PLATES

FIGURE 3 AXIAL VIEW
IDEAL PTERYGOMAXILLARY SEPARATION

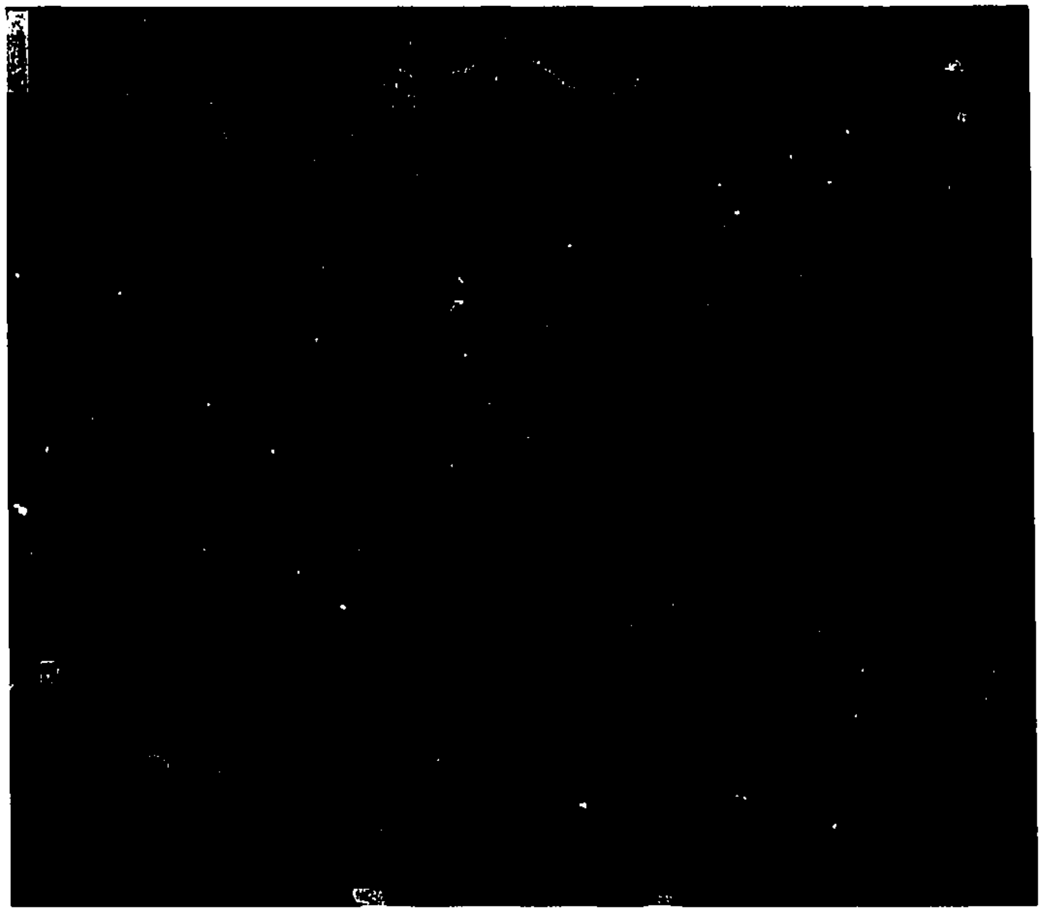


FIGURE 4 CORONAL VIEW
LOW LEVEL PTERYGOID PLATE FRACTURE
(BILATERAL)

FIGURE 5 AXIAL VIEW
NON-IDEAL SEPARATION
(UNILATERAL, LEFT)

FIGURE 6 CORONAL VIEW
HIGH LEVEL PTERYGOID PLATE FRACTURE
(RIGHT SIDE)

Appendix B: Tables 1 to 18

TABLE 1 PATIENT DATA RECORD

PTERYGOMAXILLARY SEPARATION WITH OR WITHOUT OSTEOTOME

DATA SHEET:

PATIENT:

SURGEON:

GROUP: 1 or 2

DEFORMITY:

Intra-op evaluation:

Bone thickness (mm's):

Piriform rim (at greatest thickness) _______

1/2 way from pirif. rim to zyg. buttress _______

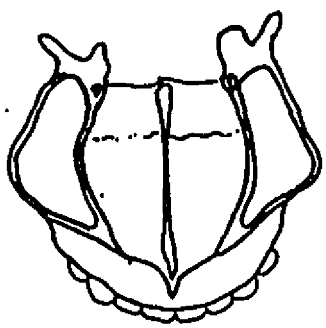
Zyg. buttress _______

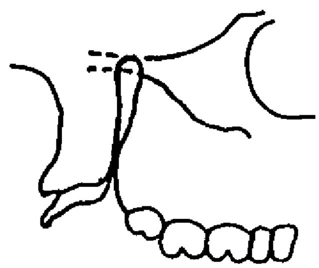
1/2 way from zyg. buttress to pt. max. fissure _______

General assessment of bone thickness (subjective):
thin, average, thick.

Difficulty in achieving down-fracture: easy, average, difficult

Location of fracture:
- **Ideal, pt. max. fissure**
- **Pt. plates**
- **Max. tuberosity**
- **Palatine bone**
- **Other**





CT EVALUATION:

Location of fracture:
- **Ideal, pt.max. fissure**
- **Pt. plates**
- **Max. tuberosity**
- **Palatine bone**

TABLE 2 CLASSIFICATION OF FRACTURES

Ideal PTM separation:	*Complete separation of the maxilla from the intact pterygoid process. Tuberosity is intact and the horizontal process of the palatine bone remains with the maxilla.*
Low PTPF:	*Fracture of the pterygoid plate below the level of the Le Fort I osteotomy.*
High PTPF:	*Fracture of the pterygoid plate above the level of the Le Fort I osteotomy.*
Palatine Bone Fracture:	*Major: Entire horizontal process of the palatine bone remains attached to the pterygoid process of the sphenoid bone.* *Minor: Small cuff of horizontal process of palatine bone adjacent to greater palatine neurovascular bundle remains attached to pterygoid process of sphenoid bone.*

TABLE 3
DISTRIBUTION OF PATIENTS BY METHOD BETWEEN SURGEONS

	Osteotome	Non-Osteotome
Surgeon A	15 53.57%	13 46.43%
Surgeon B	11 47.83%	12 52.17%
Total	26	25

TABLE 4
DISTRIBUTION OF PATIENTS BY GENDER BETWEEN SURGEONS

	Male	Female
Surgeon A	10 35.71%	18 64.29%
Surgeon B	7 30.43%	16 69.57%
Total	17	34

TABLE 5
DISTRIBUTION OF PATIENTS BY METHOD AND GENDER

	Male	Female
Osteotome	8 30.77%	18 69.23%
Non Osteotome	9 36.00%	16 64.00%
Total	17	34

TABLE 6
RELATIONSHIP OF METHOD OF PTERYGOMAXILLARY SEPARATION TO STATUS OF THE PTERYGOID PLATES

	IDEAL	UNILATERAL PTPF	BILATERAL PTPF	TOTAL
NON OSTEOTOME	10 40.00%	6 24.00%	9 36.00%	25
OSTEOTOME	10 38.46%	10 38.46%	6 23.08%	26

PTPF=pterygoid plate fracture

TABLE 7
RELATIONSHIP OF GENDER TO INCIDENCE OF PTERYGOID PLATE FRACTURE

	FEMALE	MALE
IDEAL	16 47.06%	4 23.53%
UNILATERAL PTPF	11 32.35%	5 29.41%
BILATERAL PTPF	7 20.59%	8 47.06%
Total	34	17

PTPF=pterygoid plate fracture

TABLE 8
PTERYGOID PLATE FRACTURE DETECTION ON CT COMPARED TO CLINICAL DETECTION

	IDEAL CLINICAL	UNILATERAL CLINICAL	BILATERAL CLINICAL
IDEAL CT	15 42.86%	4 40.00%	1 16.67%
UNILATERAL PTPF CT	12 34.28%	4 40.00	0
BILATERAL PTPF CT	8 22.86%	2 20.00%	5 83.36%
TOTAL	35	10	6

PTPF=pterygoid plate fracture

TABLE 9
EFFECT OF SURGEON ON INCIDENCE OF PTERYGOID PLATE FRACTURE

	SURGEON A	SURGEON B
IDEAL	12 42.86%	8 34.78%
UNILATERAL PTPF	8 28.57%	8 34.78%
BILATERAL PTPF	8 28.57%	7 30.43%
Total number of subjects	28	23

PTPF=pterygoid plate fracture

TABLE 10
RELATIONSHIP OF METHOD OF PTERYGOMAXILLARY SEPARATION TO INCIDENCE OF PALATINE BONE FRACTURES

	IDEAL PBF	UNILATERAL PBF	BILATERAL PBF	TOTAL
NON OSTEOTOME	20 80.00%	4 16.00%	1 4.00%	25
OSTEOTOME	23 88.46%	2 7.69%	1 3.85%	26

PBF=palatine bone fracture

TABLE 11
COMPARISON OF DISTRIBUTION OF PTERYGOID PLATE FRACTURES (DETECTED ON CT) TO PALATINE BONE FRACTURES

	IDEAL	PBF LEFT	PBF RIGHT	BILATERAL PBF
IDEAL	14	3	1	2
PTPF LEFT	4	0	0	0
PTPF RIGHT	10	2	0	0
BILATERAL PTPF	15	0	0	0

PTPF=pterygoid plate fracture
PBF=palatine bone fracture

TABLE 12
RELATIONSHIP OF GENDER TO BONE THICKNESS: 4 Points per side of maxilla

GENDER	NUMBER OF SUBJECTS	MEAN THICKNESS OF LATERAL WALL MAXILLA	STANDARD DEVIATION
FEMALE	34	2.08 mm	0.71
MALE	17	2.46 mm	1.45

TABLE 13
RELATIONSHIP OF GENDER TO BONE THICKNESS: 2 points of measurement (priform rim and zygomatic buttress)

GENDER	NUMBER OF SUBJECTS	MEAN THICKNESS OF LATERAL WALL MAXILLA	STANDARD DEVIATION
FEMALE	34	2.79 mm	0.961
MALE	17	3.35 mm	1.57

TABLE 14
RELATIONSHIP OF EASE OR DIFFICULTY OF DOWNFRACTURE TO INCIDENCE OF PTERYGOID PLATE FRACTURE (GROUPS COMBINED)

	EASY	AVERAGE	DIFFICULT
IDEAL	6 31.58%	10 40.00%	4 57.14%
UNILATERAL PTPF	6 31.58%	8 32.00%	2 28.57%
BILATERAL PTPF	7 36.84%	7 28.00%	1 14.29%
TOTAL	19	25	7

PTPF=pterygoid plate fracture

TABLE 15
RELATIONSHIP OF EASE OR DIFFICULTY OF DOWNFRACTURE TO INCIDENCE OF PTERYGOID PLATE FRACTURE WITH NON-OSTEOTOME GROUP

	EASY	AVERAGE	DIFFICULT
IDEAL	1 11.11%	6 50.00%	3 75.00%
UNILATERAL PTPF	3 33.33%	3 25.00%	0
BILATERAL PTPF	5 55.56%	3 25.00%	1 25.00%
TOTAL	9	12	4

PTPF=pterygoid plate fracture

TABLE 16
RELATIONSHIP OF EASE OR DIFFICULTY OF DOWNFRACTURE TO INCIDENCE OF PTERYGOID PLATE FRACTURE WITH OSTEOTOME GROUP

	EASY	AVERAGE	DIFFICULT
IDEAL	5 50.00%	4 30.77%	1 33.33%
UNILATERAL PTPF	3 30.00%	5 38.46%	2 66.67%
BILATERAL PTPF	2 20.00%	4 30.77%	0
TOTAL	10	13	3

PTPF=pterygoid plate fracture

TABLE 17
DISTRIBUTION OF FACTURES BASED ON INCIDENCE

	Osteototome	Non-Osteotome
Pterygoid Plate Fracture	61.5% 16 of 26 cases	60.0% 15 of 25 cases
Ideal Pterygomax. Separation	30.8% 8 of 26 cases	28.0% 7 of 25 cases
Horizontal Process of Palatine Bone	7.7% 2 of 26	12.0% 3 of 25

TABLE 18
COMPARISON OF PTERYGOID PLATE FRACTURE INCIDENCE BETWEEN STUDIES

	NUMBER OF PATIENTS	OSTEOTOME	NON-OSTEOTOME
Chehade et al	51	61.5%**	60.0%**
Precious et al (3)	58	87%**	82%** Tessier spreaders
Renick and Symington (2)	12	58.4%* 91.7%**	

* This value is presented as percentage of sides that had the result of a PTPF.

** This is the percentage of patients in which PTPF occurred.

Appendix C: Patient data summaries

OSTEOTOME GROUP DATA

AGE SEX SURGEON	CLINICAL EVAL. OF FRACTURE R L	SUBJECTIVE THICKNESS	R 2/4 mm	R 4/4 mm	L 2/4 mm	L 4/4 mm	DOWNFRACTURE EVAL DIFFICULTY	CT EVAL. OF FRACTURE R L
1. 35, M,SA	1 1	THICK	3.5	2.7	2.9	1.9	AVER	2b 2a
2. 23, F, SB	4b 4b	AVER	3.2	2.1	3.5	2.2	EASY	1 1
3. 23, F, SA	4b 1	THICK	4.6	2.9	5.0	2.9	AVER	1 2a
4. 17, F, SB	1 4a	AVER	1.5	1.4	2.5	1.8	EASY	1 1
5. 24, F, SA	1 4b	THICK	6.3	6.0	7.2	8.1	EASY	2a 1
6. 18, F, SA	4a 4a	AVER	2.8	2.7	1.2	1.3	DIFFIC	1 1
7. 23, F, SA	2 1	AVER	2.7	2.0	2.7	2.2	EASY	5a 2a
8. 18, F, SA	1 1	THICK	5.8	3.8	4.9	3.9	AVER	1 1
9. 20, M,SB	1 1	AVER	5.2	3.5	5.6	4.2	DIFFIC	2a 1
10. 18, F,SB	1 1	AVER	2.7	2.0	3.6	3.0	AVER	2a 2b
11. 21, M,SA	1 1	AVER	2.6	1.9	3.2	2.1	AVER	2a 2a
12. 19, F,SB	1 1	THICK	4.6	4.7	3.2	3.4	AVER	2a 1
13. 33, F,SB	1 1	THICK	2.6	2.2	2.3	2.2	AVER	1 2a
14. 26, M,SB	1 4b	AVER	2.2	1.7	2.5	2.2	EASY	2b 1
15. 35, F,SA	1 1	AVER	3.7	2.9	2.7	1.8	EASY	1 1
16. 27, F,SB	2 1	THICK	3.6	2.0	2.8	1.9	DIFFIC	2a 1
17. 21, F,SB	1 1	THIN	1.1	0.9	1.2	1.0	EASY	1 1
18. 21, F,SA	1 4a	AVER	2.9	2.8	2.5	1.8	AVER	2a 1
19. 18, M,SB	2 2	AVER	1.6	1.0	1.5	1.1	AVER	2a 2a
20. 25, M,SA	1 4b	AVER	3.8	2.1	3.0	1.8	EASY	1 1
21. 26, M,SA	1 1	AVER	3.2	1.5	2.7	1.9	EASY	5a 2a
22. 31, F,SB	2 1	AVER	2.2	1.6	2.6	1.5	EASY	2a 1
23. 35, F,SA	4b 1	AVER	2.7	1.9	1.9	1.2	AVER	1 1
24. 32, F,SA	1 1	AVER	5.0	3.8	3.8	2.4	AVER	1 1
25. 26, F,SB	4b 1	AVER	2.3	1.4	2.2	1.5	AVER	1 1
26. 26, F,SA	4b 4b	THICK	3.0	1.9	2.4	1.4	AVER	2b 1

R2/4, L2/4: Mean values from piriform rim and zygomatic buttress points.
R4/4, L4/4: Mean values from all four measurement points.

NON-OSTEOTOME GROUP DATA

AGE SEX SURGEON	CLINICAL EVAL. OF FRACTURE R L	SUBJECTIVE THICKNESS	R 2/4 mm	R 4/4 mm	L 2/4 mm	L 4/4 mm	DOWNFRACTURE EVAL. DIFFICULTY	CT EVAL. OF FRACTURE R L
1. 19, F, SB	1 1	AVER	1.4	1.6	1.4	1.7	EASY	2a 1
2. 20, M, SA	1 1	THIN	2.4	1.6	2.7	1.9	AVER	2a 2a
3. 18, M, SA	1 1	THICK	6.0	4.8	5.4	3.4	AVER	1 1
4. 28, M, SB	1 1	THICK	5.0	3.2	4.8	3.1	EASY	2a 2a
5. 27, F, SB	1 1	AVER	3.3	2.0	3.2	2.0	AV ER	1 1
6. 38, F, SA	1 4b	AVER	2.6	1.7	1.9	1.6	DIFFIC	1 1
7. 36, F, SA	1 1	THICK	1.9	1.5	3.1	1.8	EASY	2b 2a
8. 21, F, SB	1 1	AVER	2.6	2.6	2.0	2.0	AVER	1 2a
9. 21, F, SA	1 4a	THIN	3.2	2.0	2.1	1.8	EASY	1 1
10. 26, F, SA	1 4a	AVER	3.0	1.9	4.0	2.4	AVER	2a 1
11. 18, F, SB	4a 4a	AVER	3.8	2.8	2.9	2.5	AVER	1 1
12. 19, F, SA	1 4b	THICK	5.2	5.0	4.8	2.9	AVER	1 1
13. 34, F, SB	2 2	AVER	2.0	1.5	2.4	1.6	AVER	2a 2a
14. 30, F, SB	1 4b	THICK	2.6	1.7	1.5	1.4	DIFFIC	1 1
15. 30, M, SA	1 4a	AVER	2.0	1.4	1.2	0.9	AVER	1 1
16. 27, F, SB	4a 2	AVER	0.9	0.7	1.9	0.9	AVER	1 2a
17. 24, F, SA	1 1	THIN	2.4	1.6	2.1	1.5	EASY	2b 1
18. 42, M, SB	2 2	THICK	2.8	1.9	2.6	1.9	AVER	2a 2a
19. 26, M, SA	2 1	AVER	2.7	1.9	2.5	1.6	EASY	2a 2a
20. 31, F, SB	2 2	AVER	2.1	1.3	1.8	1.1	AVER	2a 2a
21. 20, F, SB	4b 1	THICK	3.0	3.2	2.9	1.9	DIFFIC	1 1
22. 30, F, SA	1 1	THIN	3.8	1.6	3.0	1.7	AVER	1 1
23. 28, F, SB	2 2	AVER	2.1	1.7	1.9	1.3	DIFFIC	2a 2a
24. 37, F, SA	1 1	THICK	4.7	3.1	4.1	2.9	EASY	2a 2a
25. 18, M, SA	2 1	AVER	2.7	2.0	2.1	1.3	EASY	2a 1

R2/4, L2/4: Mean values from piriform rim and zygomatic buttress points.
R4/4, L4/4: Mean values from all four measurement points.

CODES FOR LOCATION OF FRACTURES IN DATA TABLES

1. Ideal PTM separation

2.a. Low level PTPF without PTM separation

2.b. Low level PTPF with PTM separation

3. Tuberosity fracture

4.a. Major palatine bone fracture

4.b. Minor palatine bone fracture

5.a. High level PTPF without PTM separation

5.b. High level PTPF with PTM separation