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RESEARCH ARTICLE

INDUCED OSTEOGENSIS BY PERIOSTEAL DISTRACTION IN CRANIO-MAXILLOFACIAL REGION: A SYSTEMATIC REVIEW

***Ahmad Al Nashar, Hekmat Yakoob and Elias Boutros**

PhD Student, Researcher, The Scientific Research Center of Al Andalus University for Medical Science

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ABSTRACT

Objective: The aim of this work is to review the literature on the role of periosteal distraction in osteogensis (PDO) in the cranio- maxillofacial region.
Design: Using related key words, electronic search of English-language papers was conducted on PubMed and Science Direct data-bases in March /2016. Studies that assessed the role of periosteal distraction in osteogensis in the cranio- maxillofacial region were included. The retrieved articles were thoroughly reviewed according to the type of distraction (static/ dynamic), the used device, protocols, the adjunctive technique, and the obtained results.
Results: A total of 28 articles matched the inclusion criteria of this study. Eighteen out of 28 experiments were performed on rabbits. The reviewed papers presented evident heterogeneity with respect to several aspects including the surgical technique, the used device, the distraction rate, the latency period, the length of consolidation period and the adjunctive techniques.
Conclusion: periosteal distraction could be considered as a reliable technique for bone regeneration and it might be applicable in cranio-maxillofacial surgery. PDO can produce a new bone formation which derives from both, the periosteum and the underlying bone.

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INTRODUCTION

Reconstructive management of osseous defect in cranio-maxillofacial surgery continues to pose a clinical challenge. Bone grafting and alveolar distraction osteogenesis have been widely used in this field. Autogenous grafts are still considered the gold standard to which all other biomaterials are compared (Dimitriou *et al*., 2011). However, the use of autogenous tissue involves the need of harvesting it from a donor site, with the consequent drawbacks in terms of costs, procedure time, patient discomfort and possible complications (Dimitriou *et al*., 2011; Zouhary *et al*., 2010). To overcome these limitations, a variety of exogenous substitute materials, including allografts, xenografts and alloplasts have been introduced in clinical practice (Bauer and Muschler, 2000; De Long *et al*., 2007). Unfortunately these materials act just as scaffolds, supporting the migration of cells from the periphery of the grafted area (Finkemeier, 2002; Taba *et al*., 2005).

****Corresponding author: Ahmad Al Nashar,***
PhD Student, Researcher, The Scientific Research Center of Al Andalus University for Medical Science

Distraction osteogenesis (DO) is an alternative method that uses a biological process in which new bone formation occurs between segments that are gradually separated (Chin and Toth, 1996; Takahashi *et al*., 2004). However, distraction osteogenesis requires a corticotomy and the placement of a distractor that are difficult in some cases (Oda *et al*., 1999; Block, 1996). Recently, osteogenesis by "periosteal distsraction (PDO)" or "periosteal elevation" without corticotomy has been suggested as a technique for bone augmentation. This method is based on the concept that tensile strain on the periosteum, which causes tenting of the subperiosteal capsule, is sufficient to produce bone formation without corticotomy or local harvesting of the bone (Kostopoulos and Karring, 1995; Schmidt *et al*., 2002; Yamauchi *et al*., 2008; Sencimen *et al*., 2007; Kessler *et al*., 2007). This is due to the highly vascularised internal osteoblastic layer of periosteum which is composed of mesencymal stem cells (Chin *et al*., 1996), which is believed to be more important than endosteum in distraction osteogenesis. (Oda *et al*., 2009; Kojimoto *et al*., 1988). The aim of this paper is to review the literature on the role of PDO in the cranio-maxillofacial region.

MATERIALS AND METHODS

Review question

This study was conducted to assess the role of periosteal distraction osteogensis in bone regeneration .Secondarily, to evaluate the methods and protocols used in this new technique.

Search strategy

An electronic search of papers was conducted in PUBMED and SCIENCE DIRECT databases including English-language papers published until Marcc 2016 by using the following key words separately and in combination: cranio-maxillofacial region, periosteal distraction, periosteal elevation , periosteal expansion. In addition the references of the searched articles were evaluated for other related studies.

Study selection

Due to the number of studies that had been performed no strict inclusion criteria could be applied. All studies that investigated the role of periosteal distraction in bone formation were included in this review .Titles and abstracts were retrieved and assessed independently by two examiners as to their relevance to the desired subject. Disagreements were resolved by a discussion with a third reviewer . Duplicate articles were identified and removed. Subsequently, full texts of relevant papers were assessed for data extraction.

Data extraction

Identification information, such as journal name, publishing date and authors' names were blocked out during the assessment. Data regarding animal model, evaluated site, used device, distraction protocol, duration of the study, and reported results of each study were extracted from the articles and organized in a tables (Tables I, II). A quick review of Tables I, II reveals that the studies differ in all of these criteria. The studies then were compared according to the type of distraction (static/ dynamic), the used device, protocols, and the adjunctive technique

RESULTS

The initial search resulted in 17491 articles. Following the screening of the titles, abstracts and full texts, 28 papers formed the basis of this systematic review.

Static vs. Dynamic PDO

The elevation technique of periosteum combines aspects of distraction osteogensis (DO) and Guided Bone Regeneration (GBR) (Oda *et al*., 1999; Bosch *et al*., 1995; Wiltfang *et al*., 1998; Tudor *et al*., 2010). This technique is not considered as an invasive procedure because it doesn't require osteotomy or corticotomy and there is no risk of donor site morbidity (Schmidt *et al*., 2002; Kessler *et al*., 2007). A different methods to distract the periosteum either immediately (Weng *et al*., 2000; Lundgren *et al*., 2000; Yamada *et al*., 2003; Takiguchi *et al*., 2009; Dziewiecki *et al*., 2016), or gradually (Schmidt *et al*., 2002; Yamauchi *et al*., 2008; Sencimen *et al*., 2007; Kessler *et al*., 2007; Oda *et al*., 2009) have been described previously and reported different results regarding to the quality and quantity of the newly generated bone. Kessler *et al*. (2007) compared between static and dynamic PDO in cranial bone in Goettingen minipig model by elevation of periosteum up to 5mm, the immediate elevation of the titanium mesh resulted in a comparable amount and quality of the new bone. However, after a consolidation time of 17 days, the ratio of newly formed bone underneath and above the mesh was considerably higher in the dynamic than in the immediate group. Later, Tudor *et al*. (2010) assessed the periosteal bone-forming capacity in elevation heights 5, 10, 15 mm, and they studied whether the dynamic procedure has provable advantages compared to the static shielding. They concluded that there is no major difference in bone formation could be observed between the two techniques.

The devices used in dynamic PDO

It can be considered that Schmidt *et al*. (2002) the first to demonstrate a device for dynamic periosteal distraction; many other studies had used the same device in their experiments (Sencimen *et al*., 2007; Altug *et al*., 2011; Suer *et al*., 2014; Bayar *et al*., 2012). However, Schmidt et stated that there is need to further modification of this device to eliminate the dislodging action of the distracted tissues on the distracting end. The incision of the periosteum from 3 sites during the application of this distractor damaged the osteogenic activity of the periosteum and led to imposition of fatty tissue (Altug *et al*., 2011). This is in concordance with the findings of Sencimen *et al*. (2007), Estrada *et al*. (2006) used a device that consists of a plate supported by a screw.

They reported; device instability, displacement and perforation of soft tissue with plate exposure and subsequent site infection. Casap *et al*. (2008) developed a new device similar to the one designed by Schmidt *et al* and also reported difficulty of device placement. Oda *et al*. (2009) reported technical problems with the distraction device in their study which included a loosening of 1 screw and a transformation of the titanium mesh. All the micro-meshes were transformed into the shape of a tent so that the periosteal distraction resulted in insufficient elevation from the mandible. Yamauchi *et al* (2008; Yamauchi, 2009) investigated the utility of periosteal expansion osteogenesis by using a highly purified b-tricalcium phosphate (b-TCP) block, instead of titanium devices. The b-TCP block, acted as a space-maker under the periosteum.

The same group developed a self-activated mesh device composed of NiTi shape memory alloy (SMA) for periosteal expansion to create an ideal space without the need for manual activation. They advocated that this device might resolve many complications of previous devices, such as wound dehiscence, exposure of the devices and eliminate the need to manual mechanical activation to create the space between the periosteum and the underlying bone (Yamauchi *et al*., 2013). Sotobori *et al*. (2014) elevated the periosteal by using a conventional orthodontic wire and an unsintered hydroxyapatite mesh in rabbit frontal bone. The wire created a continuous force during the entire distraction periods, so that the surgeon did not need to adjust the screws later.

Table 1. Included articles according to authors, animal model, the used device, the distraction protocol

Authors	Animal model	The used device	Distraction protocol
Kostopoulos et Karring (1995)	Rats (mandible)	(PTFE) balls, 1 cm diameter were hemisected and hollowed out	Static elevation
Weng *et al*.(2000)	Monkeys (mandible	Custom-made hemispherical titanium mesh, covered with ePTFE membrane in test side	Static elevation
Schmidt *et al*. (2002)	Rabbits (mandible)	U-shaped with 2 legs which rigidly fixed to the lateral aspect of the mandiblular ramus using 1.3-mm screws	LP* (7days) , DR (1 mm every 3 days for 15 days)
Yamada *et al*. (2003)	Rabbits (calvarial bone)	Hemispherical titanium cap, either with or without small holes (1.5 mm in diameter)	Static elevation
Estrada *et al*. (2007)	rabbits, dogs	The device consisted of a plate supported by a screw, was placed on the cortical bone.	LP (10days) , DR (0.25mm , 0.5mm a day (up to 8 mm).
Sencimen *et al*. (2007)	Rabbits (mandible)	A custom-made, stainless steel device was used as in the study conducted by Schmidt *et al*	LP (7days) , DR (0.25 mm twice a day for 10 days)
Kessler *et al*. (2007)	Goettingen minipigs (cranial bone)	Laser-perforated microtitanium meshe (35mm×35 mm, 0.25mm thick) with two threads through the mesh to raise the mesh	LP (5days) ,DR (0.5 mm once a day for 10 days)
Casap *et al*. (2007)	Rabbits (mandible)	U-shaped device, The horizontal bar holds a screw connected at its end to a titanium-meshed plate, which is placed subperiosteally.	LP (14 days) , DR (1 mm/ day for 7 days)
Takiguchi *et al*.(2009)	Rats (calvarial bone)	Polytetrafluoroethylene tube was placed under the periosteum	Static elevation
Oda *et al*. (2009).	Rabbits (mandible)	Titanium micromesh and a distraction screw	LP (7 days) , DR (0.5 mm/ day for 8 days)
Yamauchi *et al*. (2009)	Dogs (mandible)	TCP block at the lateral surface of mandibular, and 2 titanium screws from the lingual aspect to push the block to the buccal side	LP (8 days) , DR (0.5 mm/ day for 6 days)
Yamauchi *et al*. (2010)	Dogs (mandible)	TCP block at the lateral surface of mandibular, and 2 titanium screws from the lingual aspect to push the block to the buccal side	LP (8 days) ,distraction rate (0.5 mm/ day for 6 days)
Sato *et al*. (2010)	Rabbits (parietal bone)	Bayonet-shaped titanium miniplate, a mesh plate and a titanium screw	LP (7 days) , DR (0.5 mm/ day for 20 days)
Tudor *et al*. (2010)	Goettingen minipigs (cranial bone)	0.25 mm thick laser-perforated titanium mesh was fitted with threads to carry three distraction screws .	LP (3 days) , DR (0.5 mm twice per day for 5, 10 and 15 days
Altug˘ *et al*. (2011)	Rabbits (mandible)	A custom-made, stainless steel device was used as in the study conducted by Schmidt *et al*	LP (1 or 7 days),DR 0.25 mm twice/day for 10 days
Zakaria *et al*. (2011)	Rabbits	Biodegradable mesh with 3 holes,2 holes for fixation screws and 1 for distraction screw	LP (7 days) , DR(0.5 mm) every 12 hours for 5 days
Zakaria *et al*.(2012)	Rabbits	Titanium mesh with 3 holes ,2 holes for fixation screws and 1 hole for distraction screw	LP (7 days), DR (0.5 mm) every 12 hours for 5 days
Zakaria *et al*.(2012)	Rabbits	Titanium mesh covered with silicone membrane that fixed by a plastic ring to the underlying bone	LP (1 week) , DR (1 mm/day) for 5 days
Bayar *et al*. (2012)	Rabbits	A custom-made, stainless steel device was used as in the study conducted by SCHMIDT *et al*	LP 7 days, DR (0.25 mm) twice a day for 10 days.
Saulacicc *et al*. (2012)	Rats	perforated distraction plate covered with a resorbable collagen barrier membrane.	LP (7 ,10days) ,DR (0.4 mm/day) for 10 days
Yamauchi *et al*. (2013)	Rabbits	Ni-Ti pre curved mesh (5 * 25 mm), 0.275 mm thickness the middle point was 4-mm above from the baseline.	LP (14 days), self-activated
M. Sotobori *et al*. (2014)	Rabbits	Orthodontic wire and an unsintered hydroxyapatite /poly-L-lactic acid mesh	After 1 week,
Suer *et al*. (2014)	Rabbits	A custom-made, stainless steel device was used as in the study conducted by SCHMIDT *et al*	LP (7-days), DR 0.25 mm twice a day. for 6 days,
Yamauchi *et al*. (2015).	Rabbits	Ni-Ti pre curved mesh (5 * 25 mm), 0.275 mm thickness the middle point was 4-mm above from the baseline.	LP (14 days), self-activated
Saulacic *et al*. (2015)	Rabbits (cranial bone)	Custom made distraction devices	LP (7 days), DR 0.25 and 0.5 mm/24 h for 10 days
Pripatnanont *et al*. (2015)	Rabbits	Hyrax devices were modified for use as periosteal distractors	LP (3 days), DR (0.5 mm twice a day) for 7 days.
Kahraman *et al*. (2015)	Rabbits	Titanium device consist of mesh, the distractor, and the fixation plate.	LP (7-days), DR (0.35 mm/day) for 10 days
Dziewiecki *et al*. (2016)	Goettingen minipigs	Every animal received three devices: one Ti device and two biodegradable devices	Static elevation

Zakaria *et al*, developed a device consisted of either a titanium mesh (Zakaria *et al*., 2012), or a biodegradable mesh (Zakaria *et al*., 2012), in which there were 3 holes, 2 holes for fixation screws and one serrated hole for distraction screw. They advocated that this device can potentially be used for vertical and horizontal ridge augmentation in the oral cavity. Later the same group developed a new device consisted of titanium mesh covered with silicone membrane that was fixed

Table 2. Included articles according to authors, evaluation periods, results

Authors	evaluation periods	Results	Comments
Kostopoulos et Karring (1995)	7,14 days and 1, 2, and 4 months	The outer surface of periosteum, exhibits significantly more bone fill than the inner surface	
Weng *et al*. (2000)	4 months	The mean percentage of new bone was 77.2±7.5% for the test sides and 68.6±8.4% for the control sides	New bone formation was enhanced by the additional use of an ePTFE membrane
Schmidt *et al*. (2002)	28, 35, 42, and 56 days after surgery	An average of 2.86 ± 0.56 mm of new bone height was formed.	The unoperated, contralateral side served as the control
Yamada *et al*. (2003)	1,3 month of healing	Amount of new bone under the cap in the 3- month specimens were 55.9%±7.4% with holes vs. 89.9%±6.5% without holes	
Estrada *et al*. (2006)	10,20,30,40,50,60 days after surgery	Newly bone formed was observed in 5 of the 12 rabbits	Lack of stability of the device reported in dogs trial
Sencimen *et al*.(2007)	15, 30, 60 days of consolidation	Amount of newly formed bone was 14.4 mm^2 in the PDO groups.	Amount of newly formed bone was 25.4 mm^2 in the DO groups
Kessler *et al*. (2007)	7, 17, 45 days of consolidation	Immediate elevation resulted in a comparable amount and quality of new bone.	The study compared between dynamic and static PDO
Casap *et al*.(2008)	60 day of consolidation	Distraction without VEGF led to an 18% increase in total tissue volume, whereas addition of VEGF caused an increase of 32%	Animals in test groups received injections of 100 mL of rVEGF165 into the forming callus for 4 days
Takiguchi *et al*. (2009)	1,2,6,8 weeks after surgery	New bone formation was observed from 2 weeks after the operation when the periosteum had preserved, and till 6 weeks when the petiosteum had removed	In control group the periosteum was removed
Oda *et al*. (2009).	4 and 8 weeks after consolidation	The area of new bone formation averaged 25.7 ± 5.1 mm^2 and 12.9 ±3.2 mm^2 (mean ± SD) with and without decortication	Control group without decortication and test group with decortication
Yamauchi *et al*. (2008).	8,16 weeks After consolidation	Newly formed bone comprised 20.2 ± 7.2% at 8 weeks and 33.5 ± 9.5% at 16 weeks	Bone volume was not stable after implant placement.
Yamauchi *et al*. (2010).	8 weeks after After consolidation	b-TCP had been absorbed (mean decrease 28%) and new bone had formed (mean increase 43%) a on both sides	Veneer graft using a b-TCP block was performed on control side
Sato *et al*. (2010).	3 weeks After consolidation	The experimental group showed significantly increased volume, height, BMD, and BMC in newly formed bone	Animals in test group received injections of (MSCs) into the center of the distracted gap
Tudor *et al*. (2010)	14,28, and 42 days of consolidation	Dynamic and static periosteal elevation have some advantages compared with conventional augmentation	Conventional augmentation with an autogenous bone block served as control
Altug˘ *et al*. (2011)	15, 30, 60 days after consolidation	Mean area of newly formed bone formation was 2.62 cm^2 in group 1 and 3.26 cm^2 in group 2	No statistically significant differences between the two groups.
Zakaria *et al*. (2011)	4,6 weeks After consolidation	The new device simplified PDO and reduced its invasiveness, it successfully induced new bone formation .	The study evaluated a new device composed of a thin biodegradable mesh
Zakaria *et al*. (2012)	4,6 weeks After consolidation	The new device effectively induced osteogenesis and successfully distracted the soft tissue after 6 weeks.	The maximum vertical bone formation was given at the distraction rate of 0.33 mm/d
Zakaria *et al* (2012)	2,4 months After consolidation	The amount of de novo bone formation (68.2 ± 22 mm3 after 2 months and 70.3 ± 14 mm3 after 4 months	The goal of this study was to evaluate the efficacy of combination PDO and GBR
Bayar *et al*. (2012),	15, 30, and 60 days after consolidation	The mean area of newly formed bone in sham-operated group was 17.58 mm^2, and it was 15.04 mm^2 with delayed callus formation and less mineralization in test group	The aim of study was to evaluate the effects of estrogen deficiency on newly formed bone obtained by PDO
Saulacicc *et al*. (2012)	2, 4,6 weeks after distraction	The application of a barrier membrane may be considered beneficial for new bone formation induced by periosteal distraction	The aims of the study was to identify the contribution of a collagen membrane to PDO.
Yamauchi *et al*. (2013)	5- 8 weeks after surgery	Some newly formed bone was observed and most of the sub-periosteal space underneath the device was filled with fibrous tissue,	The study evaluated the use of self-activated shape memory alloy (SMA) device in PDO.
Sotobori *et al*. (2014)	2, 3, 5 and 9 weeks 5- 8 after surgery	Bone regeneration can be induced by PDO using a conventional orthodontic wire and an uHA/PLLA mesh.	This study evaluated bone regeneration by PDO using continuous forces.

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Suer *et al*. (2014)	4,6,8 weeks after consolidation	PDO with HBO could be used to increase the quality and the quantity of the bone newly formed by PDO.	The study investigated the effect of (HBO) therapy on bone formation during (PDO).
Saulacic *et al*. (2015)	10 and 20 days of consolidation period	No statistically significant differences BD,BV, and total bone height between the two groups	The study compared the bone formation between two protocols of distraction
Yamauchi *et al*. (2015).	5- 8 weeks after surgery	Decortication by perforation of the cortex enhanced new bone formation	The study evaluated decortication with the use of (SMA) device in PDO.
Pripatnanont *et al*. (2015)	4,8 weeks After consolidation	Vertical ridge augmentation was reported and greater bone maturation was achieved with the addition of PRF.	This study evaluated the effect of modified Hyrax device and (PRF) on (PDO).
Kahraman *et al*. (2015)	45 days After consolidation	Local simvastatin made no significant contribution to the procedure.	The study evaluated the effect of local simvastatin on bone formation during (PDO).
Dziewiecki *et al*. (2016)	12th, 28th, and 42th days	Average increases in bone formation from 2 to 6 weeks were 488.1 ± 41.9 above the cabs and 53.1 ± 9.1 under the cabs	No differences between Ti device and biodegradable devices

by a plastic ring to the underlying bone using titanium micro screws (Zakaria *et al*., 2012). The construction of the device combined the occlusiveness of the GBR membrane against cellular invasion and the flexibility of the periosteal distraction in creating a new space. Saulacic *et al*. (2012) developed a device similar to the device of Zakaria *et al*. (2012) but it was covered with a resorbable collagen barrier membrane. They concluded that the application of a barrier membrane may be considered beneficial for the new bone formation induced by periosteal distraction. Pripatnanont *et al*. (2015) used modified Hyrax device and stated that this device was used successfully for PDO in a rabbit model to gain vertical ridge augmentation.

The protocols followed in reviewed articles

Distraction osteogenesis consists of 5 sequential periods: osteotomy, latency, distraction, consolidation, and remodeling (Cope *et al*., 2002). Studies of periosteal distraction with different protocols have been reported; however, optimal activation conditions have not yet been clarified (Sencimen *et al*., 2007). In previous periosteal distraction studies, the distraction rates varied from 0.25 –1 mm/day, the distraction period ranged from 5–15 days and the latency period ranged from 1–14 days, whereas consolidation period ranged from 7 to 60 days (Schmidt *et al*., 2002; Yamauchi *et al*., 2008; Sencimen *et al*., 2007; Kessler *et al*., 2007; Oda *et al*., 2009; Altug *et al*., 2011; Suer *et al*., 2014; Bayar, 2012; Estrada, 2006; Casap *et al*., 2008).

Zakarai *et al* (2012) suggested that the optimal distraction speed is 0.33 mm/d or less which showed the least connective tissue interference, this rate is less than the optimum osteogenic distraction speed (0.5 to 1 mm/d or more) (Wiltfang *et al*., 1998; Ilizarov, 1989; Kessler *et al*., 2005) in osteogenic distraction. This can be explained because cell and nutrition supplies come from both ends of the bone and the surrounding periosteum in osteogenic distraction; whereas, those supplies originate only from basal bone and periosteum in PDO (Altug *et al*., 2011). Sencimen *et al*. (2007) reported dominance of adipose tissue under the periosteum in the PDO. This study clearly demonstrated that the quality of the newly formed bone depended on the distraction speed; the slowest produced bone had the thicker trabeculae, and the least connective tissue and radiopacity which is the closest to the original bone.

The newly formed bone in PDO can be sustained and matured if it receives appropriate level of mechanical stress (Zakaria *et al*., 2012). Altug˘ *et al*. (2011) compared different latency periods along with different consolidation periods in periosteal distraction in rabbit model, Histomorphometric measurements in their study revealed that there were no significant differences between the groups and that the newly formed bone by PDO was mostly filled with a fatty tissue, and they claimed that lack of bone marrow cells might play a role in the occurrence of fatty tissue. Recently, Saulacic *et al*. (2015) evaluated the influence of two protocols of periosteal distraction, 0.25 and 0.5 mm/24 h for 10 days, on bone formation. They concluded that, the two protocols of periosteal distraction resulted in moderate differences in terms of bone formation.

The source of the newly generated bone in PDO

Previous studies demonstrated that the immediately elevated periosteum of adult animals did not contribute to the supraosteal bone formation (Kostopoulos *et al*., 1995; Melcher, 1971) and the contact between periosteum and bone seems to be essential for the osteogenic capacity of the periosteum (Ronnalis *et al*., 1985). Kostopoulos *et al*. (1995) clarified that the outer surface of the periosteum, exhibits significantly more bone fill capacity than the inner surface of the elevated and repositioned periosteum. Additionally, the new bone which is formed by the periosteum becomes resorbed with time. Weng *et al*. (2000) investigated the role of the periosteum in de novo bone formation by covering a custom-made hemispherical titanium mesh with ePTFE membrane to roll out the effect the periosteum has on bone formation. They concluded that the periosteum does not seem to contribute to the formation of the new bone tissue. These results also were in agreement with Lundgren *et al*. (2000) and Yamada *et al*. (2003). These studies confirmed that the periosteum which has been elevated in a conventional manner does not seem to contribute to the formation of new bone tissue. In the other hand, Takiguchi *et al*.(2009) suggested that the periosteum plays an important role in promoting a new bone formation, and that the removal of periosteum delayed this process. Tudor *et al*. (2010) postulated that the sufficient communication between the periosteum and the underlying space is imperative to bone formation and a solid mesh would prevent, or at least reduce, the healing capacity in the newly created space.

Also Dziewiecki *et al*. (2016) cleaified the importance of the interaction between the periosteum and the underlying bone in bone formation; the periosteum seems to contain the larger share. The enveloping periosteum should be intact and preserved as much as possible during the distraction period. Sencimen *et al*. (2007) and Altug (2011) reported that the newly formed bone by periosteal distraction is rich in interstitial fatty tissue. Altug˘ *et al*. (2011) claimed that the lack of bone marrow cells may play a role in the occurrence of fatty tissue. The role of the mesh-perforations is still a matter of debate. In the dynamic PDO, it seems to be important to have sufficient communication between the periosteum and the underlying bone with appropriate mechanical strength against the overlying soft tissue to encourage new bone formation (Yamauchi *et al*., 2013). On the other hand, it has been reported that the elevation of the periosteum with collagen membrane covering the perforated titanium plate produces more new bone compared to the elevation with the perforated titanium plate alone (Saulacic *et al*., 2012). This is in accordance with Zakaria *et al* studies (Zakaria *et al*., 2012; Zakaria *et al*., 2012) which confirmed that the newly formed bone originated mainly from the basal bone and the progenitor cells of blood vessels .

The adjunctive techniques

The amount of the new bone obtained by PDO seems to be quick and massive (Kessler *et al*., 2007). Although application of this technique results in de novo bone formation, the quality and the quantity of the newly formed bone are less than ideal compared with that produced by DO (Sencimen *et al*., 2007). Oda *et al*. (2000) investigated the role of decortication of bone with PDO in a rabbit model, they concluded that this technique might be effective in promoting bone formation. These results are in accordance with the results of Yamauchi *et al*. (2013), they confirmed that the decortication procedure enhanced early bone formation from the original bone surface. Sato *et al*. (2010) claimed that the administration of mesenchymal stem cells into the gap between bone surface and periosteum improve volume, height, bone mineral density, and bone mineral content significantly .Other attempts to promote bone formation at the gap created by periosteal distraction by adding vascular endothelial growth factor VEGF (2008), Platelet rich fibrin PRF (Pripatnanont *et al*., 2015), and administration of hyperbaric oxygen (HBO) therapy, during PDO (Suer *et al*., 2014) have been investigated and showed positive results. Whereas, the local appilacation of simvastatin to the distraction zone made no significant contribution to the new bone formation (Kahraman *et al*., 2015).

Conclusion

The reviewed papers presented evident heterogeneity with respect to several aspects including surgical technique, the used device, distraction rate, latency period, the length of consolidation period and adjunctive techniques. Periosteal distraction could be considered as a reliable technique for bone regeneration and it might be applicable in cranio-maxillofacial surgery. PDO can produce new bone formation which derives from both, the periosteum and the underlying bone.

To the best of our knowledge no study has evaluated the this technique in humans.

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