Journal of Cranio-Maxillo-Facial Surgery xxx (xxxx) xxx

Contents lists available at ScienceDirect

Journal of Cranio-Maxillo-Facial Surgery

journal homepage: www.jcmfs.com

On the reinsertion of the lateral pterygoid tendon in total temporomandibular joint replacement surgery☆

Maurice Y. Mommaerts

European Face Centre (Head: Prof. Maurice Y. Mommaerts), Universitair Ziekenhuis Brussel, Vrije Universiteit Brussel, Laarbeeklaan 101, B-1090, Brussels, Belgium

ARTICLE INFO

Article history:
Paper received 18 May 2019
Accepted 20 November 2019
Available online xxx

Keywords:
Temporomandibular joint
Arthroplasty
Joint replacement
Tendon
Pterygoid muscle
Mastication

ABSTRACT

This report aims to present the concept of reestablishing lateral pterygoid muscle function during total temporomandibular joint (TMJ) replacement surgery. The key feature is a lattice structure (scaffold) located in the condylar neck of a titanium, three-dimensionally (3D)–printed mandibular component that houses morselized autologous bone from the resected condyle and osteogenic stem cells from iliac bone marrow aspirate, and to which the fibrous enthesis component (collagen attachments to a bone fragment) is fixed via suture cerclage prior to the development of the bony union. Five TMJs were replaced using enthesis reconstruction in three patients who were followed for 1 year and more. Laterotrusion to the contralateral side measured on average 6.4 mm preoperatively, 2.3 mm at 1 month, 3 mm at 3 months, 4 mm at 6 months, and at 1–1.5 years (62,5% of the preoperative laterotrusion/40% of a normal laterotrusion). Subjective normalization of mastication after 1 year was present in all patients. A successful reattachment of the enthesis to an alloplastic endoprosthesis suggests that patients will not only be able to open and close their mouths properly with reduced pain but will also be able to actually chew. The technique has potential applications in orthopedic alloplastic reconstruction.

© 2019 Published by Elsevier Ltd on behalf of European Association for Cranio-Maxillo-Facial Surgery.

1. Introduction

Contemporary alloplastic total temporomandibular joint reconstruction (TJR) comprises replacement of the mandibular condyle by a metallic component that abuts a polymeric temporal component (De Meurechy et al., 2018). A postoperative decrease in pain score and an increase in mouth opening and food intake scores are commonly reported (Giannakopoulos et al., 2012; Leandro et al., 2013; Idle et al., 2014). However, improvements in key masticatory movements such as protrusion (cutting) and laterotrusion (grinding) are seldom reported. These movements relate to the action of the lateral pterygoid muscle.

Classically, the tendon of the lateral pterygoid muscle has been stripped or cut from the collum and not reattached to the mandibular metallic component. The tendon insertion site (the enthesis) in the pterygoid fovea was not repaired because it was not possible to permanently reattach the tendon to metal.

Entheses allow for the transmission of contractile forces from the belly of the muscle to the bony attachment, while dissipating force away from the enthesis itself to the bone (Benjamin et al., 2002). Failure to reattach the lateral pterygoid tendon and loss of its contractile action led to severe reductions in laterotrusion and protrusion (Wojczyńska et al., 2016). Dimitroulis (2014) reported an average maximal laterotrusion of 1.6 mm at 1–4 years after prosthetic replacement, whereas normal patients exhibit an average maximal laterotrusion of 10 mm during adolescence (Stoustrup et al., 2016). It is commonly known that limitations in laterotrusion in a diseased, surgically repaired, or replaced joint can overload the contralateral joint (Yuan et al., 2010).

We propose the use of an anatomically and functionally parametrized, patient-specific mandibular component made of titanium alloy, with a lattice structure of 500 μm diamond unit cells, deep in the collum and connected to the lattice on the top of the lateral surface of the ascending ramus, to promote bone formation to the osteotomized, reattached lateral pterygoid enthesis.

☆ Presented in part at the annual ESTMJS meeting 2019 in Marburg, Germany.

E-mail addresses: maurice.mommaerts@uzbrussel.be, mauricemommaerts@me.com.

https://doi.org/10.1016/j.jcms.2019.11.018
1010-5182/© 2019 Published by Elsevier Ltd on behalf of European Association for Cranio-Maxillo-Facial Surgery.

Please cite this article as: Mommaerts MY, On the reinsertion of the lateral pterygoid tendon in total temporomandibular joint replacement surgery, Journal of Cranio-Maxillo-Facial Surgery, https://doi.org/10.1016/j.jcms.2019.11.018

2. Materials And Methods

2.1. Technique

The approaches were previously described by Biglioli and Colleti (2008) and Blythe and Mommaerts (2016). Each "Parametro Classico" TMJ prosthesis was designed for individual patients by CADskills Inc. (Ghent, Belgium), taking individual anatomy and function (condylar path, Bennet shift, Bennet angle) into account, as well as the surgeon's preferences (number of screws, direction of screws related to the preferred approach, groove or tunnel for suture fixation, mandibular angle augmentation, extension of the neck scaffold toward the lateral pterygoid enthesis, type of lateral surface finishing, etc.).

The temporal component was constructed out of capitulum-specific computer numeric controlled (CNC) milled ultra-high-molecular weight polyethylene (UHMWPE), and cranial base–specific three dimensional (3D)–printed titanium fixed to the temporal bone with titanium screws. The UHMWPE contained vitamin E (α-tocopherol) as an antioxidant to counter aging while simultaneously maintaining wear resistance and fatigue strength (Bracco and Oral, 2011). The polyethylene filaments were crosslinked using 100-kGy γ-ray irradiation. The titanium grade 23 Extra Low Interstitials (ELI) base plate was treated with alumina sand blasting and oxalic acid etching (SLA), and activated with plasma to promote secondary stability via osteointegration into the skull base.

The mandibular component was 3D-printed and contained a similar scaffold at the bony interface. The capitulum was designed for a specific function and pretreated/coated with diamond-like carbon (HadSat®). In common terms, this carbon coating is harder than diamond, slicker than Teflon, and does not delaminate.

An extra area of scaffolding was provided for deep reattachment of the lateral pterygoid enthesis (Fig. 1). Bone marrow aspirate from the iliac crest was concentrated by centrifugation and mixed with bone dust obtained from the collum of the resection specimen. The paste was manually pressed into the scaffold. A groove around the neck directed the 3-0 poly-p-dioxanone (PDS) suture for fixation of the osteotomized enthesis to the scaffold via a tendon suture technique in the lateral pterygoid muscle stump or via a hole in the bony part of the enthesis (Figs. 2 & 3 Video 1). The area was wrapped with abdominal fat (Van Bogaert et al., 2018) before closing the wound.

Supplementary video related to this article can be found at https://doi.org/10.1016/j.jcms.2019.11.018.

2.2. Patients

Five normal-sized implantations were performed in three patients: two bilateral (March 2018) and one unilateral (June 2018). Informed consent for experimentation was obtained from all patients. The indications for alloplastic reconstruction were based on consensus criteria (Sidebottom and Gruber, 2013). Parameter registration was performed at 1, 3, and 6 months and 1 year or longer postoperatively using both the Helkimo index (Helkimo, 1974) and a patient-reported outcome questionnaire (Mommaerts, 2017). Pathologies necessitating total joint replacement were long-standing degenerative arthrosis, traumatic dislocation with resulting arthritis, and condylar resorption after orthognathic surgery. All patients reported uncontrollable pain and severely decreased mastication prior to surgery. Table 1 displays the patient demographics and surgical indications.

3. Results

Table 2 displays the surgeon- and patient-reported outcome measures. Laterotrusion to the contralateral side of the TJR increased slowly over the first 6 months. Physiotherapy showed great influence in patient 1. Patient 2 refused to exercise, expressing satisfaction with a decrease in pain severity. Her joints were mobilized during a short general anesthesia, 14 months postoperatively, after which she continued physiotherapy. While patient 3 regained an 8-mm laterotrusion to the contralateral side after 3 months, this patient stopped exercising and the shift subsequently decreased to 6 mm at the 6-month and 1-year follow-ups (Video 2). Patient 2 continued to complain of pain in the temporalis muscles up to 1 year postoperatively. At the 15-month follow-up record taking, she was pain free. As pain records do not add to the illustration of the efficacy of the technique, these data are presented in a simplified way. Normal or near-normal diets were resumed in all cases.

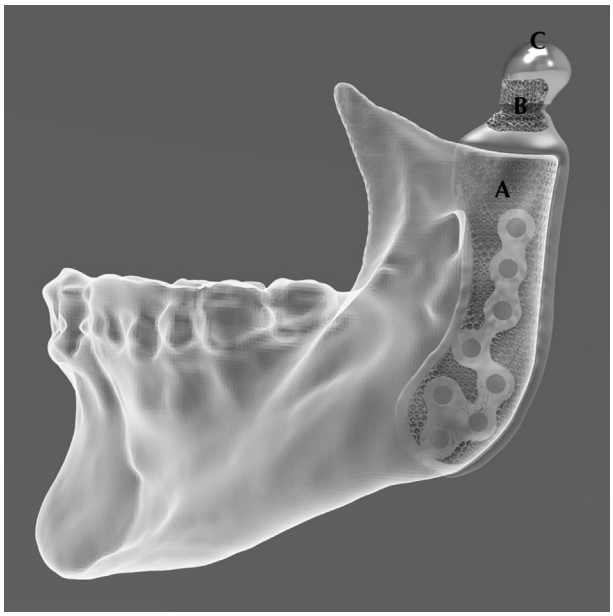

Fig. 1. Medial view of a right-side mandibular component. (A) Scaffold in the mandibular component for osseointegration. (B) Scaffold for enthesis integration. (C) Diamond-like carbon-coated capitulum.

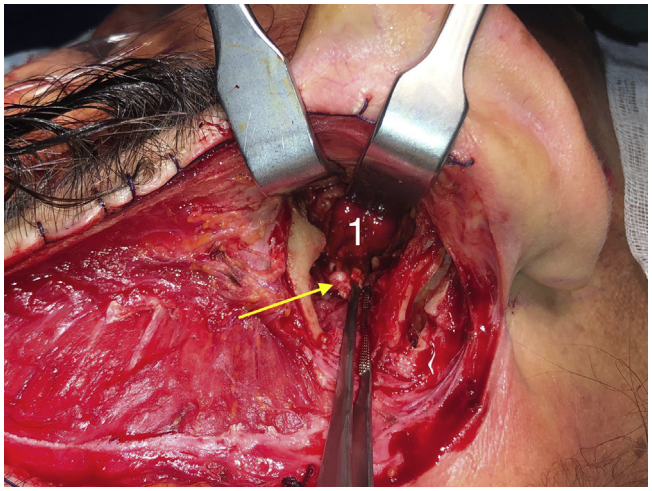

Fig. 2. Yellow arrow pointing at the bony part of the enthesis and (1) indicating the lateral pterygoid muscle. The picture is taken from a patient who is not included in the series described.

Please cite this article as: Mommaerts MY, On the reinsertion of the lateral pterygoid tendon in total temporomandibular joint replacement surgery, Journal of Cranio-Maxillo-Facial Surgery, https://doi.org/10.1016/j.jcms.2019.11.018

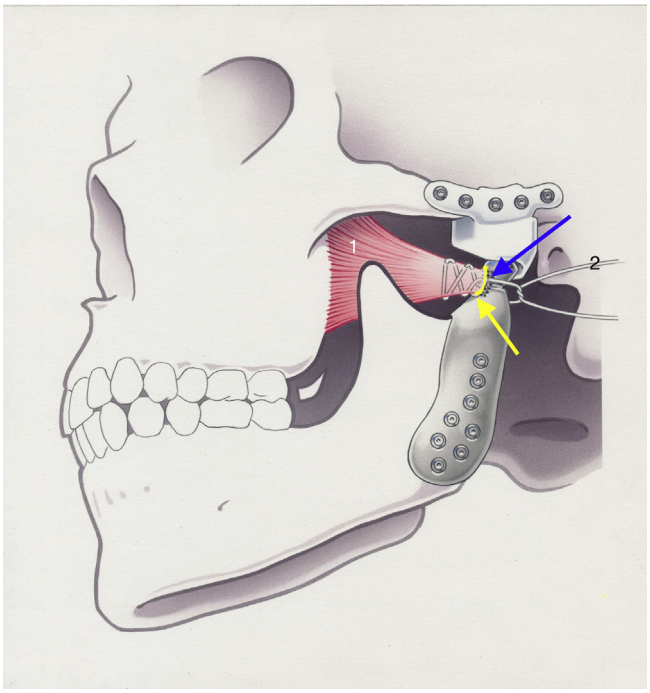

Fig. 3. Adaptation of the lateral pterygoid muscle (1) with the bony part (yellow arrow) of the enthesis to the scaffold (blue arrow) in the condylar neck using a 3-0 poly-p-dioxanone (PDS) tendon suture (2).

Supplementary video related to this article can be found at https://doi.org/10.1016/j.jcms.2019.11.018.

Protrusion was difficult to measure due to its asymmetry. However, all patients demonstrated an end-to-end occlusion at the 1-year follow-up as well as proper mastication abilities. Cone-beam computed tomography (CBCT) imaging in patient 2 supported the finding of a functional enthesis after 1 year (Fig. 4).

4. Discussion

The condyle on the balancing side protrudes and shifts medially toward the working side via the action of the lateral pterygoid muscle. Some recruitment of the medial pterygoid muscle on the balancing side may contribute (Bumann and Lotzmann, 2000). The deep portion of the masseter muscle on the working side can pull the mandible slightly laterally, whereas the superficial portion of this muscle on the balancing side can cause slight protrusion of the jaw (Lieberman, 2011). During a lateral movement, the condyle on the working side rotates and immediately shifts laterally (Bennett shift) in the direction of the movement by approximately 0.5 mm–2.75 mm (Lundeen and Mendoza, 1984; Zakaria, 2014).

The lateral pterygoid muscle has both superior and inferior heads and sometimes a third intermediate belly (Fujita et al., 2001). The inferior head always inserts into the condyle (pterygoid fovea); in 60% of human patients, it also inserts medially into the disk–capsule complex (Bade et al., 1994). During total joint replacement, the proper reconstruction of the enthesis in the condylar neck of the mandibular component on the balancing side may contribute substantially to laterotrusion on the working side. This laterotrusion is necessary to attain working contacts of 1–3 mm (Kerstein, 2015; Okeson, 2000), which are necessary for the proper grinding of food. The amount of protrusion that is necessary for proper cutting is largely dependent on the magnitude of the incisor overjet.

Pores that are 600 μm in diameter were found to allow quicker bony ingrowth in New Zealand White rabbits compared with smaller pores of 300 or 100 μm in diameter. This difference because of size appears to diminish over time (Prananingrum et al., 2016;

Table 1
Demographics and end-stage pathology.

Patient no.	Sex	Indication	Age at date of surgery	Surgical side	Coronoidectomy
1	Female	Bilateral condylar resorption after bimaxillary repositioning osteotomy	26 y 4 m	Bilateral	Bilaterally
2	Female	Bilateral degenerative osteoarthritis	42 y	Bilateral	Right
3	Male	Post-traumatic condylar resorption	35 y 5 m	Right	No

Table 2
Surgeon- and patient-reported outcome measures.

	Preoperative	1 Month postoperatively	3 Months postoperatively	6 Months postoperatively	≥1 Year postoperatively
MMO					
Patient 1	28 (including 6 mm frontal open bite)	19	31	36	37 (15 months)
Patient 2	32	11	24	22	25 (15 months)
Patient 3	45	21	41	47	47 (12 months)
Laterotrusion to the contralateral side					
Patient 1left prosthesis	5	0.5	2	4	2 (15 months)
Patient 1 right prosthesis	4	1	1	3	5 (15 months)
Patient 2 left prosthesis	5	2	2	3	3 (15 months)
Patient 2 right prosthesis	8	2	3	4	4 (15 months)
Patient 3	10	6	8	6	6 (12 months)
Pain (VAS: 0 = none to 10 = excruciating)					
Patient 1	10	1	1	0	0 (15 months)
Patient 2	8	10	2	3	0 (15 months)
Patient 3	10	3	2	0	0 (12 months)
Diet					
Patient 1	2.5	obligatory restriction	3	3	3 (15 months)
Patient 2	1	obligatory restriction	2	2.5	2.5 (15 months)
Patient 3	1,5	obligatory restriction	3	3	3 (12 months)

Legends. MMO, maximal mouth opening, VAS, visual analogue scale.
Diet scores: 1 = liquid, 1.5 = liquid/soft, 2 = soft, 3 = solid; 2,5 = between soft and solid.
All measurements given in millimeters (mm).

Please cite this article as: Mommaerts MY, On the reinsertion of the lateral pterygoid tendon in total temporomandibular joint replacement surgery, Journal of Cranio-Maxillo-Facial Surgery, https://doi.org/10.1016/j.jcms.2019.11.018

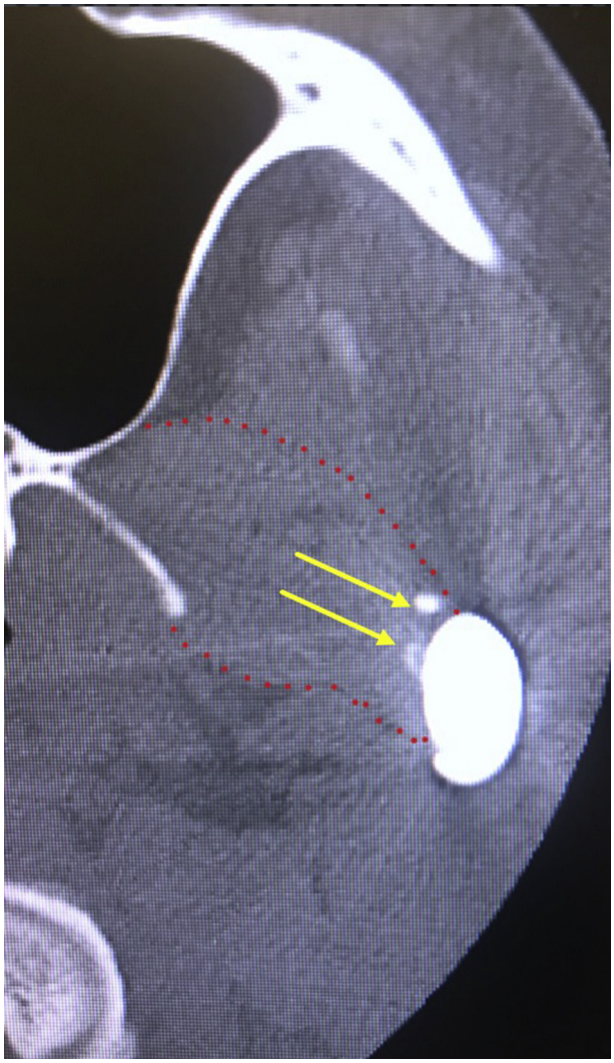

Fig. 4. Axial cone beam computed tomogram (CBCT) of patient 2, showing the right side of the mandible at the level of the enthesis. Red dots mark the lateral pterygoid muscle. Yellow arrows indicate the bony part of the enthesis fused to the bone in the scaffold.

Taniguchi et al., 2016). Providing a scaffold with interconnecting pores that are filled with autologous bone will allow fusion to the bony part of the osteotomized enthesis, as shown by our studies of implants used for facial contouring (Mommaerts, 2016) and from the experiences of orthopedic and neurological surgeons using porous interbody cages filled with bone chips for spinal fusion (Jain et al., 2016). The scaffold in a facial-contouring implant fills quickly with new bone at its osseous interface, originating from local mesenchymal stem cells and the local blood supply. Filling the scaffold at the condylar neck with bone dust could be a requirement, however. Viable bone within the scaffold then fuses to viable bone in the enthesis, leading to re-education of the lateral pterygoid muscle. The addition of concentrated bone marrow aspirates may hasten this process. To maintain the stem cells within the scaffold and to prove the efficacy of this extra intervention remains a challenge. Although patient 3 showed maximal laterotrusion, CBCT confirmed a fibrous rather than bony union between the enthesis and the bone-grafted scaffold. The thickness of the fossa is an important consideration in that respect. The enthesis may not be pulled sufficiently against the grafted scaffold in the prosthetic collum. Rather than reducing the height of the scaffold, the creation of a tuberous extension of the scaffold to the neck may be an option to achieve good bony contact.

Young patients, bony ankyloses, and pre-existing heterotopic ossification preclude the use of this experimental technique. Further fine-tuning and animal research are necessary to substantiate these preliminary results. Differentiation between medial pterygoid muscle recruitment and lateral pterygoid muscle action also remains to be studied.

5. Conclusion

Enthesis reattachment seems possible to achieve under certain conditions (proper indication, flawless surgical technique). Future clinical research is necessary to increase access to the internal part of the scaffold for improved grafting, to create a tuberous extension of the scaffold toward the enthesis, and to develop a better personal training device to monitor lateral movements and the effects of physiotherapy (De Meurechy et al., 2019).

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Interest disclosure

Professor Mommaerts is innovation manager and co-owner of CADskills bvba.

Acknowledgements

None.

References

Bade H, Schenck C, Koebke J: The function of discomuscular relationships in the human temporomandibular joint. Acta Anat 151: 258–267, 1994

Benjamin M, Kumai T, Milz S, Boszczyk BM, Boszczyk AA, Ralphs JR: The skeletal attachment of tendons—tendon "entheses". Comp Biochem Physiol Mol Integr Physiol 133: 931–945, 2002

Biglioli F, Colletti G: Mini-retromandibular approach to condylar fractures. J Cranio-Maxillofacial Surg 36: 378–383, 2008

Blythe J, Mommaerts MY: Extended retroauricular access to the medial temporomandibular joint space. Br J Oral Maxillofac Surg 54: e64–e66, 2016

Bracco P, Oral E: Vitamin E-stabilized UHMWPE for total joint implants- a review. Clin Orthop Relat Res 469: 2286–2293, 2011

Manuelle Funktionsanalyse. In: Bumann A, Lotzmann U (eds), Funktionsdiagnostik und Therapieprinzipen, vol. 53. Stuttgart: Thieme Verlag, Stuttgart, 2000

De Meurechy N, Braem A, Mommaerts MY: Biomaterials in temporomandibular joint replacement: current status and future perspectives—a narrative review. Int J Oral Maxillofac Surg 47: 518–533, 2018

De Meurechy NKG, Loos PJ, Mommaerts MY: Postoperative physiotherapy after open temporomandibular joint surgery: a 3-step program. J Oral Maxillofac Surg 77: 932–950, 2019

Dimitroulis G: Comparison of the outcomes of three surgical treatments for end-stage temporomandibular joint disease. Int J Oral Maxillofac Surg 43: 980–989, 2014

Fujita S, Iizuka T, Dauber W: Variation of heads of lateral pterygoid muscle and morphology of articular disc of human temporomandibular joint–anatomical and histological analysis. J Oral Rehabil 28: 560–571, 2001

Giannakopoulos HE, Sinn DP, Quinn PD: Biomet Microfixation Temporomandibular joint replacement system: a 3-year follow-up study of patients treated during 1995 and 2005. J Oral Maxillofac Surg 70: 787–794, 2012

Helkimo M: Studies on function and dysfunction of the masticatory system. II. Index for anamnestic and clinical dysfunction and occlusal state. Sven Tandlak Tidskr 67: 101–121, 1974

Idle MR, Lowe D, Rogers S, Sidebottom AJ, Speculand B, Worrall SF: UK temporomandibular joint replacement database: report on baseline data. Br J Oral Maxillofac Surg 52: 203–207, 2014

Jain S, Eltorai AE, Ruttiman R, Daniels AH: Advances in spinal interbody cages. Orthop Surg 8: 278–284, 2016

Kerstein RB. Handbook of research on computerized occlusal analysis technology applications in dental medicine, vol. 280. Hershey, PA: Medical Information Science Reference–IGI Global, 2015

Leandro LFL, Ono HY, de Souza Loureiro CC, Marinho HA: A ten-year experience and follow-up of three hundred patients fitted with the Biomet/Lorenz

ARTICLE IN PRESS

microfixation TMJ replacement system. Int J Oral Maxillofac Surg 42: 1007–1013, 2013
Lieberman DE. The evolution of the human head, vol. 235. Cambridge, MA: The Belknap Press of Harvard University Press, 2011
Lundeen TF, Mendoza F: Comparison of two methods for measurement of immediate Bennett shift. J Prosthet Dent 51: 243–246, 1984
Mommaerts MY: Guidelines for patient-specific jawline definition with titanium implants in esthetic, deformity and malformation surgery. Ann Maxillofac Surg 6: 287–291, 2016
Mommaerts MY: Wanneer is een kunstgewricht aan de orde vandaag? Tijdschr Geneeskd 73: 769–779, 2017
Okeson JP, 8th ed., Part 1. Management of temporomandibular disorders and occlusion, vol. 60. St. Louis, MO: Elsevier, 2000
Prananingrum W, Naito Y, Galli S, Bae J, Sekine K, Hamada K, et al: Bone ingrowth of various porous titanium scaffolds produced by a moldless and space holder technique: an in vivo study in rabbits. Biomed Mater 11: 015012, 2016
Sidebottom AJ, Gruber E: One-year prospective outcome analysis and complications following total replacement of the temporomandibular joint with the TMJ Concepts system. Br J Oral Maxillofac Surg 51: 620–624, 2013
Stoustrup P, Kristensen KD, Küseler A, Herlin T, Pedersen TK: Normative values for mandibular mobility in Scandinavian individuals 4-17 years of age. J Oral Rehabil 43: 591–597, 2016
Taniguchi N, Fujibayashi S, Takemoto M, Sasaki K, Otsuki B, Nakamura T, et al: Effect of pore size on bone ingrowth into porous titanium implants fabricated by additive manufacturing: an in vivo experiment. Mater Sci Eng C 59: 690–701, 2016
Van Bogaert W, De Meurechy N, Mommaerts MY: Autologous fat grafting in total temporomandibular joint replacement surgery. Ann Maxillofac Surg 8: 299–302, 2018
Wojczyńska A, Lieggenet CS, Bredell M, Ettlin DA, Erni S, Gallo V, et al: Alloplastic total temporomandibular joint replacements: do they perform like natural joints? Prospective cohort study with a historical control. Int J Oral Maxillofac Surg 74: 337–342, 2016
Yuan K, Lee T, Huang J: Temporomandibular joint reconstruction: from alloplastic prosthesis to bioengineering tissue. J Med Biol Eng 30: 65–72, 2010
Zakaria MR: Estimation of the Bennett mandibular immediate side shift in Iraqi full mouth rehabilitation patients (an in vivo study). J Baghdad Coll Dent 26: 54–62, 2014

Please cite this article as: Mommaerts MY, On the reinsertion of the lateral pterygoid tendon in total temporomandibular joint replacement surgery, Journal of Cranio-Maxillo-Facial Surgery, https://doi.org/10.1016/j.jcms.2019.11.018