BIOMATERIALS OF INTERPOSITIONAL ARTHROPLASTY – A SYSTEMATIC REVIEW

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BIOMATERIALS OF INTERPOSITIONAL ARTHROPLASTY

– A SYSTEMATIC REVIEW

ABSTRACT

Temporomandibular joint (TMJ) ankylosis can occur due to fibrous or bony union of the anatomical joints post trauma, infection, inadequate past surgical treatment, long-term joint inflammation, congenital or idiopathic. It compromises patients' function, appearance, growth of mandible, and oral hygiene care. Different surgical procedures have been introduced to treat TMJ ankylosis issue. The three most described surgical techniques are gap arthroplasty, ramus-joint reconstruction, and interpositional arthroplasty. In this study, different types of biomaterials for interpositional arthroplasty at TMJ region post ankylotic mass resection were reviewed. This systematic review aimed to determine the most utilised biomaterials in TMJ interpositional arthroplasty, and to identify biomaterials that can produce good maximal incisal opening post-surgery, as well as complications that are associated with types of biomaterials used in TMJ interpositional arthroplasty. Papers published up to 16th October 2021 were screened using PICO format, through electronic and hand search. All details reported were collected using Cochrane Collaboration (2014) data collection form before further scrutinised using Revised Cochrane risk-of-bias tool for cluster-randomized trials (RoB 2 CRT) and Risk of Bias in Non-randomized Studies of Interventions (ROBINS-I) for randomised controlled trial (RCT) and non-RCT articles respectively. A total of 26 non-randomised controlled trial (non-RCT) papers and 5 RCT papers were included in this systematic review. The reported biomaterials used for interpositional arthroplasty were temporalis fascia / temporalis muscle, silicone block / sheet, abdominal fat, buccal fat pad, native articular disc, skin graft, costal cartilage, bone wax and porcine accelular dermal matrix and acrylic marbles. The most utilized biomaterials in interpositional arthroplasty

were temporalis myofascial flap / temporalis fascia and fat grafts (buccal fat pad and abdominal fat). All the studied biomaterials were able to produce good post operative mouth opening. Most complications were related to surgical approaches and patients' non-compliance to jaw physiotherapy rather than the biomaterials itself. Each biomaterials has its own pros and cons upon application clinically. Good pre-surgical planning with aid of radiographic imaging can reduce intra- and post-op complications. Compliance of patients to jaw physiotherapy can ensure long term success.

Keywords: temporomandibular joint, ankylosis, interpositional arthroplasty, biomaterials, recurrence

BIO BAHAN *INTERPOSITIONAL ARTHROPLASTY* –KAJIAN SISTEMATIK

ABSTRAK

Ankilosis sendi temporomandibular joint (TMJ) boleh terjadi akibat tisu fibrosis atau pembentukan tulang di sendi anatomi selepas trauma, jangkitan, pembedahan yang tidak lengkap, keradangan sendi jangka panjang, kongenital atau idiopatik. Keadaan ini boleh menjejaskan fungsi, penampilan, pertumbuhan mandibel, dan kebersihan mulut pesakit. Pelbagai teknik pembedahan telah dikemukakan sebagai rawatan bagi pesakit ankilosis TMJ. Tiga teknik pembedahan yang paling dikenali adalah *gap arthroplasty*, rekonstruksi *ramus-joint*, dan *interpositional arthroplasty*. Dalam kajian sistematik ini, bio bahan untuk *interpositional arthroplasty* sendi TMJ dikaji dan dianalisa. Tujuan kajian ini adalah untuk mengenalpasti jenis bio bahan yang paling banyak digunakan, dan menentukan bio bahan yang boleh mencapai bukaan mulut yang memuaskan selepas pembedahan serta mengenalpasti komplikasi yang berkaitan dengan jenis bio bahan *interpositional arthroplasty* yang digunakan. Jurnal-jurnal yang diterbitkan sehingga tarikh 16^{hb} Oktober 2021 disaringi dengan menggunakan format PICO, melalui pencarian elektronik dan manual. Kesemua butiran yang dilaporkan telah dikumpulkan dengan menggunakan borang pengumpulan data Cochrane Collaboration (2014) sebelum diteliti dengan menggunakan *Revised Cochrane risk-of-bias tool* untuk *cluster-randomized trials* (RoB 2 CRT) dan *Risk of Bias in Non-randomized Studies of Interventions (ROBINS-I)* untuk *randomised controlled trial (RCT) and non-RCT* masing-masing. Sebanyak 26 jurnal *non-randomised controlled trial* (non-RCT) dan 5 jurnal RCT telah dimasukkan dalam kajian sistematik ini. Bio bahan untuk *interpositional arthroplasty* yang telah dilaporkan adalah fasia / otot *temporalis*, blok / kepingan silikon, lemak abdomen, lemak bukal, diskus articular, graf kulit, rawan kostal, lilin tulang dan matriks kulit khinzir tak bersel, guli akrilik. Bio bahan yang paling banyak digunakan untuk *interpositional*

arthroplasty adalah fasia / otot *temporalis* dan graf lemak, (lemak *buccal* dan lemak *abdomen*). Kesemua bio bahan yang dikaji boleh mencapai bukaan mulut yang memuaskan selepas pembedahan. Kebanyakan komplikasi adalah berkaitan dengan teknik pembedahan dan ketidakpatuhan pesakit terhadap fisioterapi rahang selepas pembedahan. Setiap bio bahan mempunyai kebaikan dan keburukan tersendiri bagi penggunaan kes klinikal. Perancangan yang teliti sebelum pembedahan dengan bantuan pengimejan radiografi boleh mengurangkan komplikasi semasa dan selepas pembedahan. Pematuhan pesakit terhadap fisioterapi rahang boleh menjamin kejayaan rawatan jangka panjang.

Kata kunci: sendi temporomandibular, ankilosis, *interpositional arthroplasty*, biobahan, *recurrence*

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS AND ABBREVIATIONS

3D-CT	:3D computed tomography
AHI score	:Apnea-hypopnea index score
ATRT	:Arakeri's TMJ Release Technique
B/L	:Bilateral
BSSO	:Bilateral sagittal split osteotomy
BTX-A	:Botulinum toxin type A
CBCT	:Cone-beam computed tomography
CPAP	:Continuous Positive Airway Pressure
CT scan	:Computed tomographic scan
DNA	:Deoxyribonucleic acid
F	:Females
IA	:Interpositional arthroplasty
IL-1	:Interleukin-1
IL-10	:Interleukin-10
IL-2	:Interleukin-2
M	:Males
MeSH terms	:Medical Subject Headings terms
MIO	:Maximal incisal opening
MRI	:Magnetic resonance imaging
Non-RCTs	:Non-randomized controlled trials
NSAIDS	:Non-steroidal anti-inflammatory drugs
OPG	:Orthopantomogram
OSAHS	:Obstructive sleep apnea and hypopnea syndrome
PA cephalogram	:Postero-anterior cephalogram

PEG-PLGA-PEG	:(poly-ethylene glycol–b-(DL-lactic acid-co-glycolic acid)–ethylene glycol) triblock
PICO format	:Population, Intervention, Comparison, Outcomes format
PRISMA	:Preferred Reporting Items for Systematic Review and Meta-Analyses
PTFE	:Polytetrofluoroethelene
RCTs	:Randomized controlled trials
RoB 2 CRT	:Revised Cochrane risk-of-bias tool for cluster-randomized trials
ROBINS-I	:Risk of Bias in Non-randomized Studies of Interventions
SD	:Standard Deviation
TMF	:Temporalis myofascial flap
TMJ	:Temporomandibular joint
VAS	:Visual Analog Scale
VEGF	:Vascular endothelial growth factor
VRO	:Vertical ramus osteotomy

CHAPTER 1: INTRODUCTION

1.1 Background of the study

Temporomandibular joint (TMJ) comprises of mandibular condyle, articular disc, glenoid fossa, joint capsule, ligaments (temporomandibular ligament, stylomandibular ligament, sphenomandibular ligament) and muscle (lateral pterygoid muscle). It allows sliding hinge movement of mandible, and hence allowing protrusion, retrusion, lateral deviation, elevation and depression of the mandible. TMJ ankylosis occurs as a result of bony or fibrous union of the anatomical joint components following trauma, infection, inadequate surgical treatment, chronic inflammation in joint related disease (eg: rheumatoid arthritis, Paget's disease, ankylosing spondylitis, pseudohypoparathyroidism, psoriasis, burns) and syndromic patients. It is rarely due to congenital (Ajike et al., 2006) or idiopathic (Elgazzar et al., 2010).

Most cases of TMJ occurred as a sequela of trauma (26% - 75%), followed by infection (44% - 68%) (Chidzonga, 1999). TMJ ankylosis following trauma occurs due to hemarthrosis, which is then followed by fibro osseous reorganisation that leads to formation of ankylotic mass. This ankylotic mass shows aggressive regrowth capacity, in which inadequate resection may cause reorganisation (Arakeri et al., 2012; Salins, 2000). For infection, researchers believe that it happens due to spread from adjacent infection otitis media or mastoiditis site, or hematogenous infection spread such as tuberculosis, gonorrhoea and scarlet fever (Fonseca, 2000). Ankylosis due to infection has reduced in number tremendously in the era of antibiotics, yet still prevalent among those patients in developing countries due to poor awareness and difficult to access to health facility for prompt treatment and intervention.

TMJ ankylosis compromises oral function (mastication, speech, digestion), aesthetic, psychology, oral hygiene care and more importantly normal mandibular growth among

growing paediatric patients (Brusati et al., 1990; Chidzonga, 1999; Kaban et al., 1990; Moorthy & Finch, 1983; Roychoudhury et al., 1999; Smith et al., 1999; Su-Gwan, 2001).

In view of the multiple complications in untreated TMJ ankylosis patients, operative procedures such as gap arthroplasty, interpositional arthroplasty and total joint reconstruction have been described. In the procedures of interpositional arthroplasty and total joint reconstruction, alloplastic or autogenous materials have been utilised (Balaji, 2003; Brusati et al., 1990; Smith et al., 1999; Su-Gwan, 2001)

Abbe introduced gap arthroplasty to treat TMJ ankylosis (Abbe, 1880). This procedure involves removal of a block of bone either the complete condyle or a full-thickness section of bone leaving a minimum gap distance of around 1cm between the ascending ramus and the temporal bone, to prevent reankylosis (Moorthy & Finch, 1983). Complications such as reankylosis or inability to achieve satisfactory maximal interincisal mouth opening that necessitate coronoidectomy (unilateral / bilateral procedures) have been reported (Felstead & Revington, 2011).

To reduce the incidence of reankylosis, interpositional arthroplasty was introduced and gain popularity since 1983. Autogenous tissue or alloplastic material is adopted and inserted into the gap created to separate bone ends (Moorthy & Finch, 1983). Other than the widely used temporalis muscle, the use of other autogenous graft materials such as costochondral graft, dermis fat pad, skin graft, fascia lata, masseter muscle, and auricular cartilage have been reported (Feinberg & Larsen, 1989; Tuncel, 2011). Alloplastic interpositional grafts that have been used are silastic, proplast / Teflon, metallic fossa implants, and acrylic marbles (Erdem & Alkan, 2001); however, the outcome with alloplastic material was less favourable.

However, studies show that these two procedures can only achieve functional restoration but not the reconstruction of resected joints, in which condyle reconstruction is important to prevent open bite, establish posterior facial height and avoid

pseudoarticulation that may promote reankylosis (Nayak et al., 1999). Hence, joint or ramus-joint reconstruction can be achieved by using autogenous (fibula, metatarsal, clavicle, iliac crest, sternoclavicular, and costochondral) and alloplastic (acrylic, compressible silicone rubber and total joint systems) options (Cope et al., 1993; Kent & Misiek, 1994). Joint reconstruction does have its drawback. For example, if costochondral rib graft is harvested, there will donor site morbidity (Ohara et al., 1997), and graft weaken due to long-term steroid (Saeed et al., 2001); for sternoclavicular graft, it has significant risk of haemorrhage from the major vessels which lie deep to the clavicle, scarring and high possibility of keloid formation (Sidebottom, 2013).

Interpositional arthroplasty is more preferred than gap arthroplasty as studies reported that gap arthroplasty results in higher re-ankylosis complication post-operatively. This happens because there is no "separating" inert or biocompatible material in between the bony ends (Moorthy & Finch, 1983). The primary objective of interpositional arthroplasty is to create space in between glenoid fossa and condyle in order to allow mandible movement and function, while inserting a suitable biomaterial in the space created to prevent re-ankylosis of condyle to surrounding structures in future. Various biomaterials have been used as interpositional material, however, varying long-term outcomes and complications have been reported with these materials.

The findings from this systematic review will provide information on the outcomes and complications associated with various types of interpositional arthroplasty biomaterials. Surgeons can then make a better choice of biomaterial when performing interpositional arthroplasty.

1.2 Aim of the study

To identify currently available interpositional arthroplasty biomaterials that can produce good post-operative outcome among patients with TMJ ankylosis

1.3 Objectives of the study

1. To determine the most utilized biomaterials in interpositional arthroplasty
2. To identify biomaterials that can produce good post operative outcomes (mouth opening)
3. To identify the complications associated with biomaterials used in interpositional arthroplasty

CHAPTER 2: LITERATURE REVIEW

2.1 Temporomandibular joint ankylosis

Ankylosis means "joint stiffness" in Greek (Malik, 2002), which occurs due to obliteration of joint space by abnormal bony formation or fibrous tissue growth. The main treatment philosophy of this mandibular hypomobility disorder is early detection and mainly surgical intervention, aggressive resection of ankylotic segment, interpositional spacer placement if needed, early mobilization of joint post-operatively, and aggressive physiotherapy minimum 6 months after operation (Chidzonga, 1999; Kirk & Farrar, 1993; Malik, 2002;).

The goals of treatment for TMJ ankylosis cases are: ankylotic mass release, patients can have normal jaw form and function / restore altered jaw joint mechanics, symmetry growth of mandible especially in children, to correct the associated dentofacial deformity if presents, and prevention of ankylosis in future (Bhardwaj & Arya, 2016). Surgical technique depends on type of ankylosis, patients' age, timing for surgery, uni- or bilateral ankylosis, possible etiologic factors, history of operation, radiographic findings, judging between pros and cons of each treatment option, facilities together with expertise available and patients' or guardians' preference (De Roo et al., 2016).

Kaban et al. (2009) has suggested that ankylosis release could be performed among children 3 years old and older and does not need to wait until growth completion. Some surgeons have suggested for the algorithm of treatment based on proper case selection, yet there is still no consensus of one sole first-rated ideal approach that can ensure best outcome and lowest relapse and complications (Gaba et al., 2012; Kaban et al., 1990; Karamese et al., 2013; Su-Gwan, 2001; Xu et al., 2015). Even the best surgeons also face the main complication of unpredictable re-ankylosis post-operatively at ~6-8% (Erdem & Alkan, 2001; Valentini et al., 2002), in addition to other complications based on the

surgical approaches chosen. Examples are donor / recipients site complications, open bite, asymmetrical facial growth, reduced posterior facial height, hardware failure, foreign body reactions, reduce mouth opening compared to intra-operatively post condylar resection finding. Conditions can become worse with lack of patients' compliance and motivation for post-operative physiotherapy.

There are few possible suggestions of how the re-ankylosis and spontaneous bone regeneration can occur:

-remnant of "bone dust" is retained at surgical bed, which manages to survive and does exhibit osteogenic potential (Fell, 1956)

-soft tissue surrounding fracture site has ample differentiated and undifferentiated mesenchymal cells that can induce new bone formation. Also, fracture haematoma contains angiogenic cytokine vascular endothelial growth factor that promote angiogenesis and hence revascularization for bone repair (Nagase et al., 1985; Street et al., 2000)

-bridging callus at bone injury site, in which remodeling forms mature bone from temporary callus. Osteogenic tissue is believed to come from the periosteum (McKibbin, 1978), or surrounding tissue devitalized bone and remaining mandibular stumps (Kisner, 1980)

-continuous functional stress at surgical site might serve as mechanical factor in promoting osteogenesis (Shuker, 1985)

Hence, post-op long term vigorous physiotherapy is always emphasized to reduce re-ankylosis incidence. Patients are encouraged to do frequent mouth opening exercise either with wooden sticks / spatula, Heister's jaw opener, Shekarrapa's appliance, interincisal acrylic gag, jack screw, TheraBite, or chewing gum exercise after surgery that can help in maintaining mouth opening after surgery (Das et al., 2009; Güven, 2008). There are 2 main broad categories of treatment for TMJ ankylosis: (Figure 2.1)

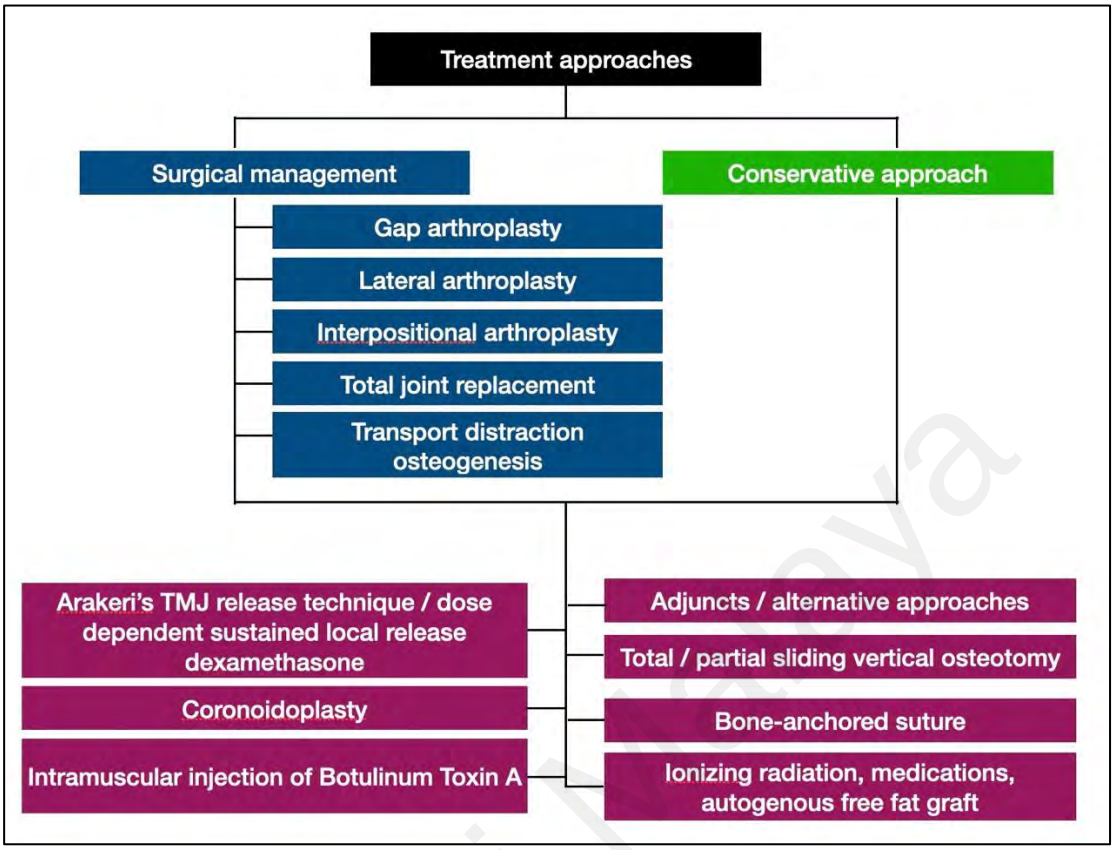


Figure 2.1: Treatment approaches for TMJ ankylosis

There are 2 types of TMJ ankylosis: true / intraarticular and false / extraarticular types. Intraarticular ankylosis types are mostly seen in post trauma or infection cases; while extraarticular ankylosis types can happen due to disorders such as myogenic, neurogenic, inflammatory process, bone and soft tissue tumours (Balaji, 2003; Brusati et al., 1990; Chidzonga, 1999; Kaban et al., 1990; Roychoudhury et al., 1999; Smith et al., 1999; Su-Gwan, 2001).

To ease the communication between the surgeons and determining the severity of the TMJ ankylosis, various classification systems have been developed. The 3 most utilised systems are:

i)Topazian (1964)

Topazian in year 1966 classified TMJ ankylosis:

-Stage 1: Bony ankylosis at condylar process

-Stage 2: Bony ankylosis extends to sigmoid notch

-Stage 3: Bony ankylosis extends to coronoid process

ii)Sawhney (1986)

Sawhney classified TMJ ankylosis into 4 types based on the anatomical relationships between temporomandibular joint and the osseous / fibrous ankylotic fusion mass.

-Ankylosis type I: fibrous adhesion in and around joints (less bone fusion in the TMJ)

-Ankylosis type II: bone fusion around lateral surface of the joint with no additional bone fusion in the central region of TMJ

-Ankylosis type III: caused by any injury to the condyle (whether treated or not). It has bone fusion between the mandibular ramus and glenoid fossa, sometimes involving zygomatic arch. The condyle is medially displaced and may be reduced in size, but the surface of the joint maintains an identifiable anatomical structure

-Ankylosis type IV, the entire joint is replaced by a bone fusion, which can even encroach mandibular coronoid process. It is difficult to identify the anatomical structure of the TMJ

iii)He et al. (2011)

He et al. (2011) has developed a new classification of traumatic TMJ ankylosis based on the computed tomographic (CT) scan:

-A1: fibrous ankylosis without bony fusion

-A2: bony ankylosis in lateral joint, residual condyle fragment is larger than 50% of contralateral normal condyle

-A3: similar to A2, residual condyle is smaller than 50% of contralateral normal condyle

-A4: complete bony ankylosis

2.2 Surgical treatment of temporomandibular joint ankylosis

Surgical intervention is always challenging and technically difficult, and potential effects of treatment choice in growing patients, with myriad possible complications from surgery. Under this category, the approaches are gap arthroplasty, lateral arthroplasty, interpositional arthroplasty, total joint replacement and transport distraction osteogenesis.

2.2.1 Gap Arthroplasty

This was first described by Abbe (Abbe, 1880). Gap arthroplasty is the oldest surgical modality that is used to treat TMJ ankylosis. In this procedure, gap is created at the ankylosed site between the condyle / ramus of mandible with the skull base after complete ankylotic block resection. No tissue or materials is interpositioned between the resected joint bony surfaces (Gundlach, 2010). This can then free the joint for mandibular movement.

Guven has reported that gap arthroplasty without interpositional materials such as spacer and sylastic sheet are desired in TMJ ankylosis cases which did not show severe ankylosis (Güven, 2008). Yet, gap arthroplasty has notoriously high re-ankylosis after the release surgery. Topazian has reported 53% of recurrence rate with gap arthroplasty (Topazian, 1964). However, some surgeons still advocate it for adult patients who presented with small, ankylosed mass and if resection is performed it would not affect the ramus height. Compared to other sophisticated intervention, Zhu et al. (2021) stated that gap arthroplasty is simpler procedure, low cost and expecting short operation time. Yet, improper case selection and philosophy of wide or adequate excision (gap of 10-20mm needed) (Chossegros et al., 1997), with 1.5-2.5cm is considered as adequate resection (Kaban et al., 1990) to reduce recurrence (Chossegros et al., 1999; Roychoudhury et al.,

1999) will inevitably need too much ankylosed block resection and hence shorten the ramus, forward movement of mandibular fulcrum and cause occlusal discrepancy, either anterior open bite (in bilateral TMJ ankylosis cases) or contralateral open bite (in unilateral TMJ ankylosis cases) (Zhu et al., 2013). The minimum gap of 10-20mm creation would also cause jaw deviation upon function (Roychoudhury et al., 1999). The resected large opposing bony surfaces would then heal by dense scar tissue formation, together with the possibility of inadequate bone pathology removal and non-compliance of patients to post-operative physiotherapy contribute to re-ankylosis (Salins, 2000). Extensive ankylosed block removal on the other hand, risks injuring adjacent structures such as internal maxillary artery, facial nerve, carotid vessels, jugular vessels and base of skull (Chossegros et al., 1999).

Matsuura et al. (2001) did study the functional and anatomy of temporomandibular joint changes post gap arthroplasty in animal models. They found that gap arthroplasty did not regain pre-ankylosis TMJ functionally and histologically. Also, gap arthroplasty has high reported 53% recurrence rate due to osteoblastic growth between the resected bony surfaces (Roychoudhury et al., 1999). It is believed that after resection of ankylosed mass, network capillaries derived from remaining bone stump and adjacent host tissues of the op site can aid in revascularization. Osteogenic cells are then recruited and can act as foci of new bone formation (Nwoku, 1980). Due to this unfavourable result, and as more promising approaches are being explored and discovered, the gap arthroplasty has gradually fall out of favour of most surgeons.

2.2.2 Lateral Arthroplasty

According to Sawhney (1986), the condyle process in Type III TMJ ankylosis cases is displaced medially due to fracture or improper treatment; bony bridge formation occurs between the ramus and zygomatic arch and forms ankylotic mass. If this bony bridge is

resected, surgeons can notice that the surgical bed of upper articular surface and articular disc deeper surface are always intact. Meanwhile, even when the condyle is displaced medially to its normal anatomical position, this reduced size condyle does have potential to function normally.

The commonly performed surgical technique for this Type III and Type IV ankylosis cases is total ankylotic mass resection with special attention to medial aspect of joint remnants (Zhi et al., 2009). This treatment of generous removal of lateral ankylotic mass and medial non-ankylotic portion could adversely affect the mandibular growth especially in growing paediatric patients, risk of causing reduced posterior mandibular ramus height due to excessive bony removal and re-ankylosis if no interpositional material is placed post-resection.

Nitzan et al. (1998) revolutionized the treatment approach in managing Type III TMJ ankylosis cases by utilisation of Type III lateral arthroplasty procedure. The main idea of this approach is to avoid the possible unfavourable consequences of conventional surgical approach, yet still adequately resect the ankylotic mass at affected site meanwhile remaining the unaffected site to maintain mandibular form and function integrity. Yang et al. (2017) has proved that this approach shows promising results of normal condyle-ramus growth after ankylotic mass removal with no significant difference seen between the ankylosed site and the unaffected side.

If both the condyle and disc are salvageable, they should be preserved to aid in mandibular function, growth and jaw rehabilitation. This awkward shaped and medially positioned condyle can be retained to maintain ramus height post lateral arthroplasty. Harvold et al. (1983) has reported before that even deformed condyle in hemifacial microsomia cases could show functional and growth potential after released, and hence the condyle should be retained whenever possible before resorting other more aggressive

treatment approach. This condyle can show upright remodelling ability after bony fusion removal (Yang et al., 2017).

Case selection is important with this Type III lateral arthroplasty approach, and operation should be performed as early as possible once ankylotic mass is detected to prevent worsening jawbone growth deformity. In this approach (Singh et al., 2014), the adopted principle is to determine the integrity of displaced disc and location or depth of medially displaced condyle through pre-operative radiographic images, such as CBCT (cone-beam computed tomography) or coronal CT (computed tomographic) images. Sometimes, MRI (magnetic resonance imaging) might be needed to view the meniscus or disc.

When the fracture traverses below the lateral pterygoid muscle insertion, both the condyle process and disc are pulled towards anteromedial-inferior direction. The pre-operative radiographic images can help in case evaluation and provides osteotomy guide for surgeons before exploration of surgical site to retrieve the medially displaced condyle. Also, this is to avoid unintentionally excessive bone resection that can weaken the condyle neck.

Surgeons need to select the suitable Type III TMJ ankylosis cases for this approach. However, if patients already presented with pre-operative severe jawbone deformity, the affected condyle could not be able to grow significantly to overcome or counteract the pre-existing deformity. These cases should then have holistic plan after patients have stopped growing to determine overall deformity and deciding further comprehensive surgical intervention then (Yang et al., 2017).

If intra-operative mouth opening does not reach 30mm, ipsilateral or bilateral coronoidectomy can be performed to improve mouth opening then. Post-operative repetitive jaw exercise can then promote the displaced condyle growth and remodeling

especially in growing patients. This double hump-shaped condyle can also perform all normal mandibular movement and function normally as growth site (Singh et al., 2014).

2.2.3 Interpositional Arthroplasty

According to Verneuil (1860), Percy and Barton in 1826 was first to propose arthroplasty technique; Verneuil (1860) then utilised muscle and fascia interpositioned at arthroplasty gap to prevent ankylosis. It was then gaining popularity such as reported by Risdon (1934), Eggers (1946), Borcbakan (1968) and Sawhney (1986). These early attempts of mobile spacers used more on alloplastic material such as gold foil, tantalum foil and acrylic spacers to enable movement of mandible after the 2 segments distracted, which then allowed free posterior, anterior, medial and lateral jaw movements. There were failures reported regarding alloplastic materials such as instability after implantation and materials loosening (Mercuri, 2000). As a result of the inconsistent outcomes of these materials, researchers and surgeons have been searching for suitable biomaterials for interpositional arthroplasty that can function to prevent re-ankylosis, high success rate, maintain jaw function, easy to harvest / access and manipulation, low morbidity and cost to patients. These biomaterials can be broadly categorized into autografts, allografts, xenografts and non-biologic materials. Examples of these biomaterials are shown in Figure 2.2.

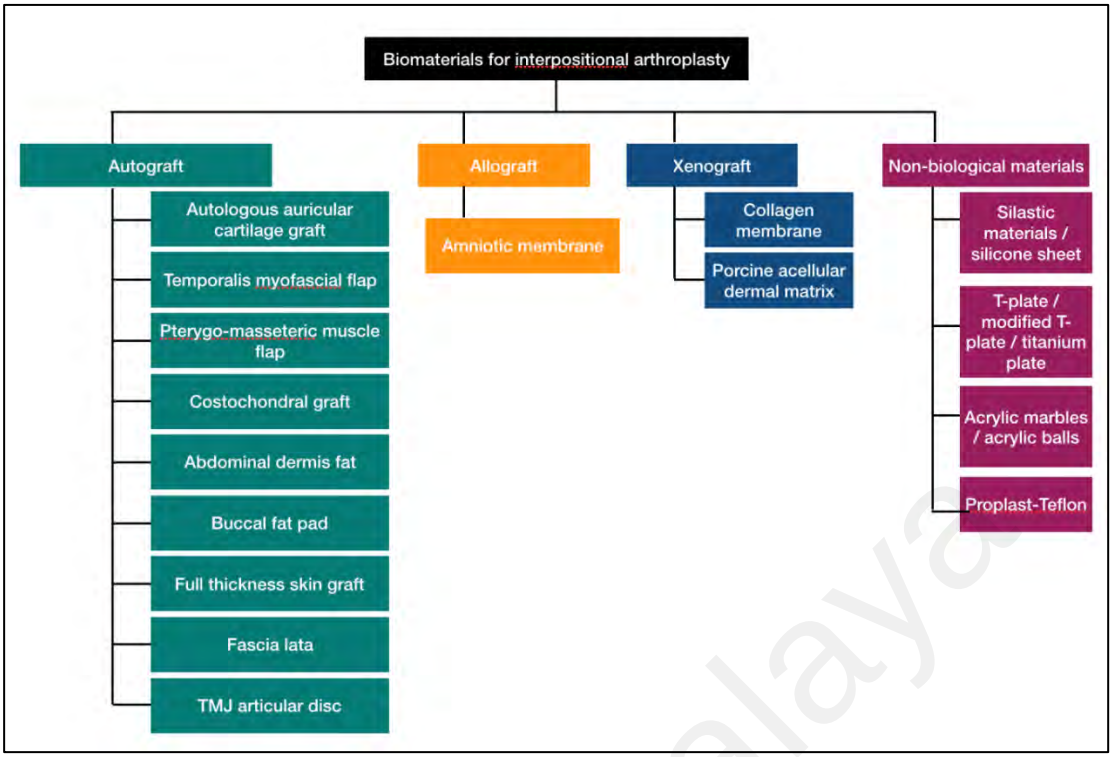


Figure 2.2: Types of interpositional arthroplasty biomaterials

2.2.4 Total Joint Replacement

Whether or not to perform TMJ reconstruction, and either autogenous or alloplastic reconstructive material should be chosen, rely on the factors of: patients' age upon presentation for intervention, cause of damage, history of any surgical intervention (Sidebottom, 2013). The aim of reconstruction is to restore mandibular form, maintain ramus vertical height, improve function, minimise debilitating ankylosis complications, reduce pain, to hamper disease progression, encourage growth and remodelling, avoid further morbidity and finally minimise re-ankylosis post-surgery (Bhardwaj & Arya, 2016; Sidebottom, 2013).

Autogenous graft can be obtained from vicinity of the surgical site such as coronoid process and ramus, or from a distant site donor such as costochondral, fibular and iliac crest (Krishnan, 2008). Autogenous grafts have lower infection rate compared alloplastic materials, easy for surgical bed uptake and adaptation to host site, remodelling over time, cost effective and shows "growing" potential when used in growing patients (Bhardwaj

& Arya, 2016). Paediatric and adolescents preferably have autogenous graft reconstruction. If the autogenous grafts show lack or deficient growth with patients and hence causes facial asymmetry or occlusal discrepancy, these issues can then later be dealt with orthognathic surgery, distraction osteogenesis or alloplastic prosthetic replacement after cessation of growth (Sidebottom, 2013). In the event that autologous graft failed, surgeons can consider alloplastic or vascularised free flap reconstruction. It is not advisable to re-use other autogenous graft for revision surgery as free graft need good vascular bed to ensure good uptake. Capillaries can infiltrate the maximum thickness of 180-220 microns of tissue. Failed surgical wound bed is always scarred with less vascularity then, with operated site scar tissue around 440 microns depth (Sidebottom, 2013). Success rate of revision surgery with autogenous graft is sceptical then.

Autogenous grafts do have its long list of limitations depends on site of harvest for autogenous grafts: such as unpredictable growth of costochondral graft and visible scarring at donor site; donor sites complications which consist of altered gait, pneumothorax, pleural effusion, clavicle fracture, numbness and great toe flexion (Khadka & Hu, 2012).

Alloplastic TMJ reconstruction is preferred among adults as it shows long term good outcome, no donor site morbidity, reduce time of surgery, close resemblance of normal joint anatomy if prosthesis is custom-made, and facilitates early mobilization for post-operative jaw physiotherapy (Saeed et al., 2002; Sidebottom, 2013). The prosthetic reconstruction choices are: silastic sheeting material, TMJ condylar prosthesis, articular eminence implants, custom made TMJ prosthesis, custom glenoid fossa implants, mandibular reconstruction plate with condylar heads. However, these alloplastic biomaterials do have drawbacks: wear and tear or failure, foreign body reaction, implant or device loosening that necessitate second corrective or revision surgery, displacement of fracture, higher cost, lack of growth of device and sometimes dystrophic bone

formation (Mercuri, 2000; Saeed et al., 2002). Autologous fat transplantation and 10Gy irradiation to alloplastic TMJ reconstruction sites has been suggested to minimize heterotopic calcification and excessive joint fibrosis (Reid & Cooke, 1999; Wolford & Karras, 1997).

2.2.5 Transport Distraction Osteogenesis

Ilizarov is the pioneer of distraction osteogenesis and McCarthy introduced the concept of distraction osteogenesis to be used in mandible in year 1922. Stucki-Mccormick (1997) introduced transport distraction osteogenesis for TMJ reconstruction in condyle tumour cases. It is an inductive and regenerative technique which can have new bone formation in between two osteotomized vascularised segments that are moved apart gradually with sufficient force. The devices used are based on the intended deformity and size of defects to be corrected, such as uni- or multi-directional OR intra- or extra-oral distractors (Diner et al., 1996; Block et al., 1996).

Today, distraction osteogenesis has been applied widely in treatment of craniofacial microsomia cases; syndromic micrognathia cases, such as Treacher Collins syndrome, Nager's syndrome, Pierre Robin Syndrome; and developmental transverse mandibular deficiency cases (Niederhagen et al., 2000). It is exclusively useful in these cases with underlying retrognathia of mandible, hypomobility of mandible due to ankylosis, micrognathia, impaired facial aesthetics due to deficiency in ramus height and mandibular length (Zhu et al., 2013), dental occlusion discrepancy, narrowing of upper airway and recurrent upper airway tract infections (Adekeye, 1983; Ayoub et al., 2002).

Patients with micrognathia issue are often troubled with obstructive sleep apnea and hypopnea syndrome (OSAHS) (Baldwin et al., 2001). Continuous Positive Airway Pressure (CPAP), the gold standard for OSA treatment might not be feasible in these group of retrognathia patients due to mask fitting in severely retruded mandible, and

compliance of patients in using the CPAP device which is always challenging especially in paediatric patients (Spicuza et al., 2015).

With distraction osteogenesis, it can be a surgical option for paediatrics / growing young patients without need to wait for growth cessation, so that early intervention can be done to hinder the facial asymmetry and compromised appearance (Kaban et al., 2009). It can also be helpful in OSA cases by opening up the posterior airway space and improve the apnea-hypopnea index (AHI) score. In severe compromised airway, it has been reported that distraction before ankylotic joint release might omit the invasive surgical airway of tracheostomy then (Bi et al., 2018). Pre-arthroplasty is preferred as it allows distraction against stable fixed point and hence better vector control for direction of distraction (Chellappa et al., 2015; Ko et al., 2004). If arthroplasty for ankylosis mass releases is performed prior to distraction, patients with narrow pharyngeal airway would have trigemino-cardiac reflex (respiratory distress, bradycardia, reduce oxygen saturation) on post-operative physiotherapy (Andrade et al., 2012).

Besides, distraction osteogenesis might be a better desired option over bilateral sagittal split osteotomy (BSSO) in orthognathic cases that need large advancements >8mm. Relapse is reported to be lower in distraction osteogenesis cases as gradual active histiogenesis allows surrounding soft tissue envelope to adapt with progressive advancement. Not only new bone formed at the osteotomised gap, active histiogenesis also occurs in adjacent gingiva, vessels, ligaments, cartilage, muscles and nerves. These adaptive changes reduce relapse incident post-operatively (Sadakah et al., 2006; Spagnoli & Gollehon, 2006). Risk of inferior alveolar nerve injury also lower. Also, there would not be any donor site complications or bone grafting recipient site issues (Bouchard et al., 2009).

With transport distraction osteogenesis at ramus, patients can open and close the mouth and perform mastication normally during the distraction process for functional remodelling (Bansal et al., 2014). It is less invasive, with shorter operation duration and admission time. Procedure is not limited to patients who have stop growing. With proper planning, it is a versatile procedure to lengthen the deformed mandible even though the mandible is asymmetry. Improvement of OSA AHI score can also boost patients' confidence and motivation to cooperate for intensive jaw physiotherapy after arthroplasty ankylotic mass release.

Yet, distraction osteogenesis is not the ultimate almighty solution and does have shortcomings. In transport distraction osteogenesis the growth centre is not transplanted. Even though it can be applied in cases with occlusal derangement, in severe malocclusion cases might still need additional orthognathic surgery and prosthodontic intervention as orthodontic alignment for complicated cases after distraction osteogenesis is inadequate (Chugh et al., 2021). In spite of no jaw movement restriction, patients in early post-operative period usually have restricted mouth opening that would take time to improve. This would then jeopardize the aggressive post-operative jaw physiotherapy among patients who have arthroplasty that need active jaw exercise to prevent ankylosis. Deviation of mandible might be seen as no lateral pterygoid muscle attaches to distracted neo condyle (Chugh et al., 2021). Also, it is a lengthy procedure that need close monitoring. It also necessitates 2 surgeries solution for patients. A second surgery is needed for distractor removal. Also, there is pin tract infection risk, wound bed bone or gingiva or skin infection. Incorrect vector can defeat the whole treatment purpose then (Chugh et al., 2021). Although low recurrence in distraction / lengthening mandible, transport distraction osteogenesis showed ironically 48-50% relapse due to reduction of reconstructed / transported condylar height (Gabbay et al., 2006; Xiao et al., 2012). Reduction of neo-condyle height then causes ramus shortening, mandibular rotation and

hence open bite uni- or bilaterally. It has been postulated that reduction in neo-condyle height can be attributed to (Xia et al., 2020):

-post-operative infection that leads to callus disruption and hence resorption.

-compromised blood supply at distracted osteotomy segments

-unstable or improper vector direction during distraction

-inadequate strength of device / distractor to stabilise the distracted segments

Other complications reported are tooth bud injury in growing patients with mixed dentition, device failure, screw loosening and scarring disfigurement if surgeons employ for extraoral approach (Chugh et al., 2021).

Myriad research and extensive studies brought new innovations in treating TMJ ankylosis with distraction osteogenesis, such as Matthews external craniomandibular device as introduced by Dr Matthews in year 2008 (Denadai et al., 2016). Considering the pros and cons of other surgical options, conventional surgical methods are more "comfortable" and familiar to surgeons, as there is learning curves for distraction osteogenesis prior to real application in patients. It seems that other surgical approach for TMJ ankylosis is more appealing than transport distraction osteogenesis. Nevertheless, with proper cases selection, distraction osteogenesis still plays vital role in OSA patients, lengthening of mandible in syndromic patients, large mandibular advancement cases. Proper pre-operative planning with virtual surgical planning software can ensure correct advancement distance and vector direction.

2.3 Non-surgical treatment of temporomandibular joint ankylosis

Anyanechi et al. (2015) has reported the attempt to apply conservative approach under conscious sedation to manage extra-capsular TMJ ankylosis cases, with the purpose of avoiding surgical related complications. This approach can reduce financial burden for

patients / guardians from spending more on extensive surgical procedures with additional general anaesthetics fees, biomaterials cost if autografts are not selected, and ward stays charges from pre-surgery until discharge from ward.

Only cases with short duration of TMJ uni- or bilateral fibrous ankylosis (< 1 year) and no facial deformity are included. Depending on patients' tolerance level, patients are then placed under conscious sedation or general anaesthesia. Different dental instruments are then used to prop open the mouth, such as Ferguson's mouth gag, periosteal elevators, Coupland elevator, handle of extraction forceps (all these instruments were padded with gauze); either option of this list of dental instruments is then activated and placed in-situ for 30 minutes – 1 hour. Then, once the mouth opening can accommodate Fergusson's mouth gag, same manoeuvrer is then repeated at posterior teeth to ensure wider mouth opening can be achieved. After the acceptable mouth opening is gained (35-45mm), wooden spatula then replaces Ferguson's mouth gag for prop up mouth opening for another 1 hour. Prior to discharge, analgesic prescribed, and patients are reminded for importance of compliance to jaw physiotherapy with wooden spatula, by applying it for 30 minutes – 1 hour, and to perform 4-5 times per day until next review session in clinic.

Anyanechi et al. (2015) believed that the jaw exercise can stretch and cause fatigue of fibrous ankylotic mass, and the shorter the duration of ankylosis, the better the prognosis and success rate with this conservative approach.

This approach so far does not get wide acceptance until now as most of the time patients presented late (> 1 year) to hospitals, paediatric patients have compliance to accommodate for frequent jaw exercise regimen, most of the cases have bony / combination of bony and fibrous ankylotic components with concomitant dentofacial deformity that need to be addressed with invasive surgical approaches. Also, some extreme fear / pain patients may not be able to tolerate sedation which eventually necessitate procedure to be done under general anaesthesia. Anyanechi et al. (2015) also

reported one case of tooth avulsion in their study that need re-implantation and hold with splint followed by root canal treatment.

Proper study design and long term follow up is needed to confirm if this approach is feasible among these patients.

2.4 Adjuncts / other approaches

It is worth to discuss briefly here for some adjuncts / alternative approaches taken to minimise the possible complications / risk of post-operative relapse or re-ankylosis.

2.4.1 Dose-dependent sustained local release dexamethasone to prevent re-ankylosis

Post-surgery acute inflammatory reaction with expression of multiple inflammatory mediators (such as prostanoids, leukotrienes); together with neutrophilic and serofibrinous hemorrhagic exudation, are responsible for stimulating the osteogenic precursor cells to form ankylotic bone mass. When corticosteroid is administered, it can suppress inflammation by interfering diapedesis, capillary dilatation, edema, fibrin deposition, disruption arachidonic acid cascade and prevent prostaglandin formation, leukocyte migration, phagocytosis and interfering with the multiple signaling pathways in inflammatory response at local surgical microenvironment.

Dexamethasone is preferred due to high potency and long half-life (Graziani et al., 2006). The local drug delivery of PEG-PLGA-PEG (poly-ethylene glycol–b-(DL-lactic acid-co-glycolic acid)–ethylene glycol) triblock co-polymers, is a dose dependent sustained local release of dexamethasone to prevent TMJ re-ankylosis post ankylotic mass release, in which the whole concept is termed ‘Arakeri’s TMJ Release Technique, ATRT’. This medicament is a free-flowing aqueous solution at room temperature and turns to transparent gel at body temperature, serves as an effective injectable drug delivery depot that retain for >1 month in-situ (Jeong et al., 2000).

The hypotheses of Arakeri's TMJ Release Technique in prevention of TMJ re-ankylosis can be explained in 3 mechanism pathways (Arakeri & Brennan, 2012). With the presence of sustained and local release of dexamethasone in resected TMJ space:

i) it interferes with multiple inflammatory signalling pathways and inhibits expressions of multiple inflammatory mediators. This will then reduce the osteogenic precursor cells stimulation and interrupts post-operative initial vital step of bone regeneration cascade and provides the preliminary unfavourable environment for bone regeneration.

ii)there is down-regulation on vascular endothelial growth factor (VEGF), follows by inhibition of angiogenesis at local tissue and delays healing priocess and osteogenic vessels ingrowth.

iii)it prevents local tissue fibrosis; also anti-inflammatory effect reduce edema and pain. Patients can then have unimpeded jaw movement and physiotherapy, in which the aggressive post-operative physiotherapy is deleterious to the nascent vasculature and prevents vasculars ingrowth.

All these 3 pathways eventually lead to atrophic non-union of TMJ apparatus and prevents TMJ re-ankylosis then: (Figure 2.3)

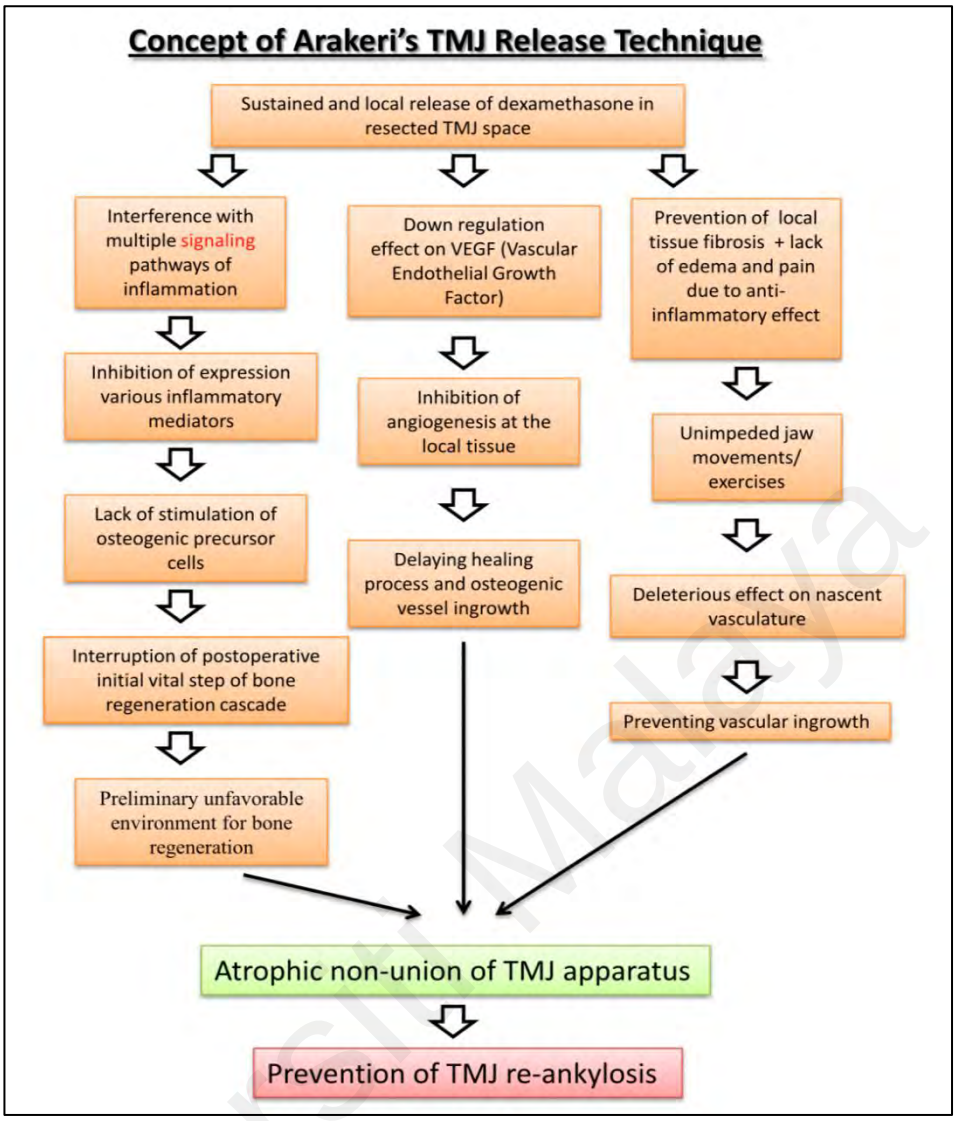


Figure 2.3: Concept of Arakeri's TMJ release technique (adapted from Arakeri & Brennan, 2012)

2.4.2 Coronoidoplasty during surgery to overcome open bite issue post-operatively due to coronoidectomy

Kaban protocol advocated coronoidectomy for ipsi- or contralateral sides if mouth opening post gap arthroplasty / ankylotic mass removal is <30mm. However, Selvaraj et al. (2020) then noticed that patients might have tendency to show open bite due to loss of temporalis muscle attachment and action in mandible elevation for mouth closure. The open bite issue was more prominent if bilateral coronoidectomy is performed.

To maintain temporalis muscle attachment, Selvaraj et al. (2020) suggested doing coronoidoplasty. The osteotomy site was marked 1cm below the coronoid base along internal angle of ascending ramus; only lateral and anterior temporalis muscle was released, maintain the lateral and anterior temporalis attachment at coronoid. Screw holes made and plate (preferably 4-hole plate) adapted in-situ at proximal segment of coronoid, meanwhile plate held with tie wire. The osteotomy of 1cm bone at coronoid base then performed at marked area. The post resection mobile proximal segment was then brought down to meet with distal segment of ascending ramus and fixed with screws then. This can "shorten" the ascending ramus to prevent obstruction from elongated coronoid process without interrupting temporalis position and function.

The purpose of coronoidoplasty is to retain temporalis muscle posterosuperior muscle pull function post-operatively to elevate mandible during function and hence reduce uni- or bilateral open bite issues; meanwhile to offset the medial pterygoid and masseter muscles pulling antero-superiorly to avoid premature posterior occlusal contact. Also, other more invasive surgical procedures related complications could be avoided then.

However, this case report only reported on TMJ ankylosis at unilateral joints. Also, TMJ ankylosis is not always causing merely the coronoid process elongation. The ankylotic mass from condyle might be huge enough to encroach sigmoid notch, coronoid, zygomatic arch, and adjacent skull base. Other than proper cases selection for this approach, more study is still needed to convince surgeons if this intervention is practical.

2.4.3 Pre-operative intramuscular injection of Botulinum Toxin A to reduce discomfort and pain

Regardless of the types of surgical approach chosen, unpredictable post-operative re-ankylosis could happen due to low compliance of patients to aggressive jaw exercises. Continuous persistent jaw physiotherapy is hindered due to pain at surgical site, discomfort mouth opening exercises and stretching of chronic spasms of fibrotic masticatory muscles. Patients with chronic trismus issue would have ultra-structural masticatory muscle changes that further impede mouth opening and mandibular movement (el-Labban et al., 1990).

Botulinum toxin type A (BTX-A) is a Clostridium botulinum anaerobic bacterial toxin that inhibits acetylcholine release at neuromuscular junctions. It has been used in muscular disorders cases such as recurrent TMJ dislocation, masseteric muscle hypertrophy, temporalis muscle hypertrophy, myofascial pain, facial paralysis, and muscular dystonia (Dhanrajani & Jonaidel, 2002). This muscle paralying agent can reduce the force in tonic overactive muscles, reduce muscle contraction in spastic dystonia cases, inhibit stretch reflex of masticatory muscles through flaccid paralysis of muscles, reduce myofascial masticatory muscle pain with direct analgesic BTX-A (Abbound et al., 2017; Grazko et al. 1995; Liguori et al., 1997; Ranoux et al., 2008; Robiony, 2011).

Shandilya et al. (2020) in their controlled clinical trial has injected BTX-A into masseter and temporalis muscle 2 weeks prior to the TMJ surgery for ankylotic mass release. The 100U BTX-A is mixed with 2.5ml normal saline, to prepare for a solution of 40U/mL, in 26G 12mm long needle. 5 injections at masseter muscle, each 1 x 4U, which 2 injections located at 1cm above inferior border of mandible, 2 injections at 1cm below inferior to zygomatic arch, and 1 injection at center of masseter muscle. Meanwhile, 3 injections at temporalis muscle, each 1 x 4U, located at junction of scalp and non-hair

bearing skin of temporal region OR 1cm below level of temporalis muscle origin in horizontal line. (Figure 2.4)

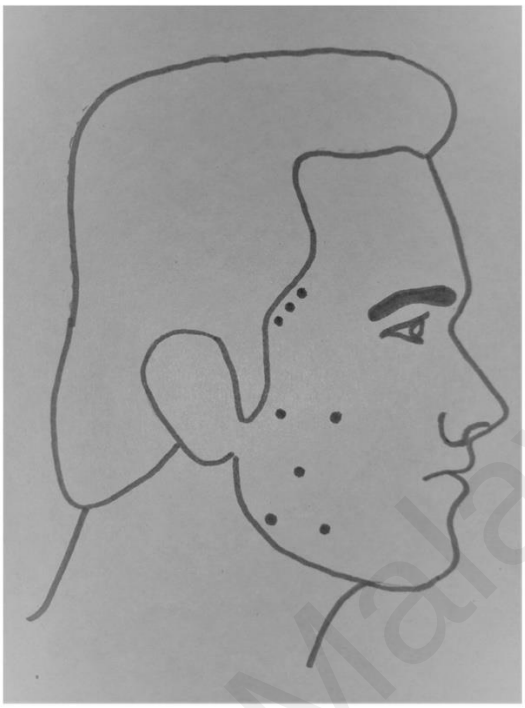


Figure 2.4: Injection sites on bilateral temporalis and masseter muscles (adapted from Shandilya et al., 2020)

Other alternatives for pain control are NSAIDS, moist heat pads, ultrasound therapy and transcutaneous electrical nerve stimulation therapy (Nelson & Ash, 1988; Syrop, 1995). These modalities of pain management are of short duration of action and some approach is technique sensitive. BTX-A can be a great adjunct to conventional surgical modalities with longer duration of action in surgical sites. Three to seven days days after injection, it starts to show clinical effect, peaks 1-2 weeks (hence injection 2 weeks prior operation), and reduces until disappearance in 3-6 months (Majid, 2010).

Some patients may show erythematous at injection point after 2-3 hours of drug administration, hence patients in the study of Shandilya et al. (2020) are compulsory to undergo subcutaneous hypersensitivity testing. Post injection jaw physiotherapy only

commenced around 1 week after BTX-A injection to ensure initial healing phase has taken place and pain of surgical site has subsided.

Unless there is contraindication to BTX-A usage, such as allergic reaction, otherwise surgeons could consider BTX-A injection for optimal outcome post ankylotic mass resection to improve patients' compliance to jaw exercise.

2.4.4 Total and partial sliding vertical osteotomy for reconstruction of condyle using posterior border of mandibular ramus

Conventional orthognathic surgery of vertical ramus osteotomy (VRO) is done to correct mandibular prognathism, mandibular asymmetry, post traumatic reconstruction, distraction osteogenesis of mandible and reconstruction of neo condyle with pleasing post-op TMJ function (Martinez-Lage et al., 2004).

Liu et al. (2011) has modified the VRO method for neo condyle reconstruction through total and partial sliding vertical osteotomy. Compared to conventional non-pedicled free grafts placement at arthroplasty site, the objective of these total and partial sliding vertical osteotomy is to get pedicled graft for TMJ ankylosis, with lesser chance of resorption, decrease ramus height, facial asymmetry, deviated mouth opening and subsequently relapse. Liu et al. (2011) has seen no re-ankylosis cases during follow up of their patients.

Either intervention chosen depends on clinical and radiographic assessment (Martinez-Lage et al., 2004; Song et al., 2009).

- Total sliding vertical osteotomy (Figure 2.5): patients in this group had evident antegonial notch / angle hypertrophy. Digastric and mylohyoid muscles are responsible for this marked notching in front of masseter and medial pterygoid muscle insertion (Sawhney, 1986). After ankylotic mass releases, the surface of arthroplasty ramus and cranial base / temporal surface / glenoid fossa are shaped accordingly. Posterior ramus is then osteotomized vertically and slides superiorly; arthroplasty gap then interpositions

with either native articular disc or temporalis myofascial flap; coronoidectomy is performed if needed. The prominent edge of lower border of mandible is then smoothened to get flush border of mandible. Titanium miniplates and screws are then used to fix the bone graft.

- Partial sliding vertical osteotomy (Figure 2.5): patients without prominent antegonial notch would have this intervention. The ankylotic mass is resected, followed by recontouring of gap arthroplasty ramus and glenoid fossa are contoured. Then vertical osteotomy at posterior ramus is performed from sigmoid notch inferiorly until 1.0cm above to angle of mandible. The reverse L-shaped osteotomy then enables the osteotomized segment to move up. Meanwhile, the residual gap after segment moving up is filled up with ipsilateral autogenous coronoid. Interpositional arthroplasty with disc or temporalis myofascial flap can be done at articular surface. Then, the bone graft is then fixed with titanium miniplates.

With either intervention, there are no donor site complications and hence shorter hospital stay for patients. Lesser possibility of neo condyle resorption or necrosis seen as utilizing the pedicled bone graft, with adequate blood supply from medial pterygoid of posterior border of ramus. The neo condyle remodels is of same histology, and close adaptation of osteotomized ramus ensures callus formation and restores mandible continuity (Liu et al., 2010; Martinez-Lage et al., 2004; Skouteris & Sotereanos, 1989). It can omit the time-consuming effort in transport distraction osteogenesis for daily activation of device and allows adequate time for consolidation prior device removal. Patients with severe mandibular asymmetry might need second surgery such as orthognathic surgery after distraction osteogenesis. Yet, for the sliding vertical ramus osteotomy, it resolves some secondary mandibular asymmetry (Holmlund et al., 2004). Also, Liu et al. (2011) has seen re-restoration of mandibular growth spurs of growing patients after sliding vertical ramus osteotomy, which then allow continue growth of

ramus and body of mandible. If long term follow-up shows promising results, this sliding vertical ramus osteotomy should be advocated to be used in future.

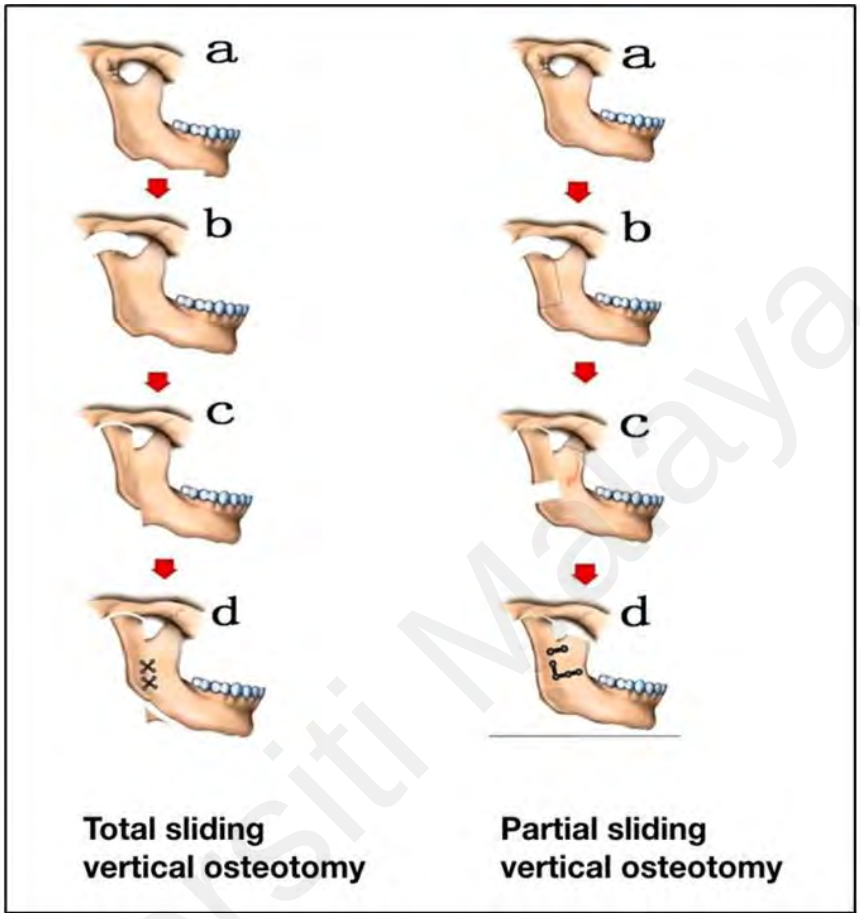


Figure 2.5: Total and partial sliding vertical osteotomy (adapted from Liu et al., 2011)

2.4.5 Using bone-anchored suture to increase stability of temporalis myofascial flap positioning

The concept of bone-anchored suture in securing temporalis in-situ is as per the idea in stabilizing the TMJ repositioned articular disc by Wolford (1997). Other than bone-anchored suture, silastic devices and Proplast-Teflon had been used too for anchorage purpose, yet Wolford (1997) reported these alternatives caused severe foreign-body giant-cell reaction, severe bony and soft tissue destruction, and possibility of particles migration to other body areas.

Nestal-Zibo et al. (2012) are the first one to advocate bone-anchored suture in maintaining the interpositional arthroplasty biomaterials in-situ in degenerated TMJ. The principle is to have the endosseous implants anchored at posterior condylar head, with artificial ligaments attached were then used to fasten the articular disc or interpositional arthroplasty biomaterials (Nestal-Zibo et al., 2012; Wolford, 1997). Authors adopted this technique surgically as they noticed that the conventional way of anchoring temporalis myofascial flap is via the suture's fixation to nearby capsule or ligaments structures. However, in cases which these 2 structures are degenerated, there are no stable points to secure the interpositional arthroplasty biomaterials in-situ. Bone-anchored suture can then help to fix the temporalis myofascial flap to condyle head and serves like a normal articular disc.

The device used for anchorage utilizes non-absorbable 2.0 Suture Mini QUICKANCHOR® PLUS (DePuy Mitek). This mini anchor is made up of titanium alloy, size 5mm in length and 1.8mm in diameter. There are 2 nickel-titanium wings that function in intra-bony locking when screwed into condyle head. The eyelet at body of the screw allows suture attachment and serves as "artificial ligaments" for attachment (Wolford, 1997). (Figure 2.6 to 2.8)

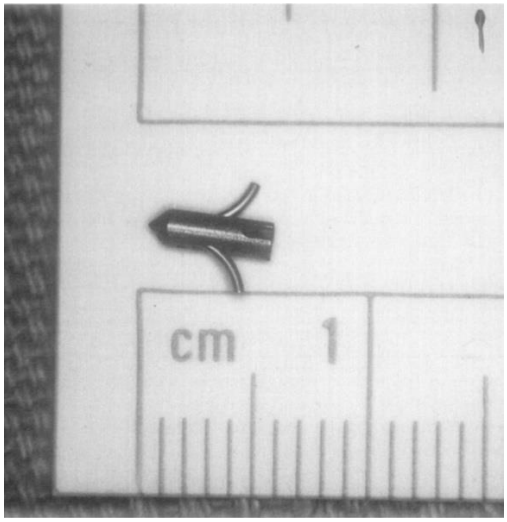


Figure 2.6: Mitek anchor screw: 5mm in length, 1.8mm in diameter (adapted from Wolford, 1997)

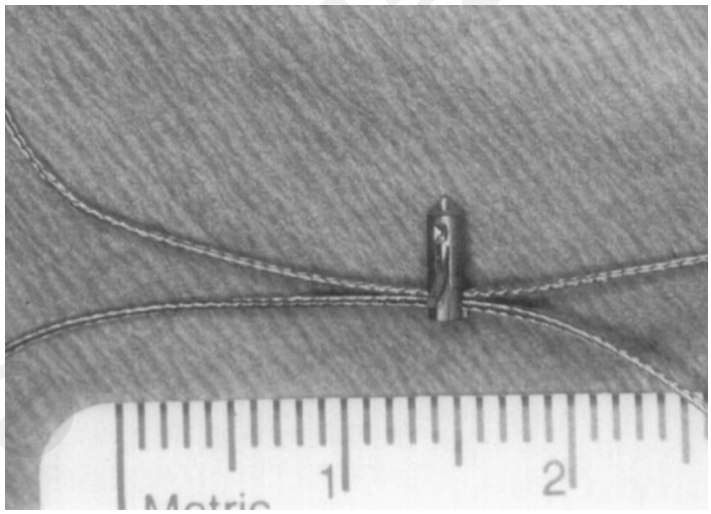


Figure 2.7: 2 strands of 0-Ethibond suture passed through the eyelet and served as artificial ligaments for disc anchorage (adapted from Wolford, 1997)

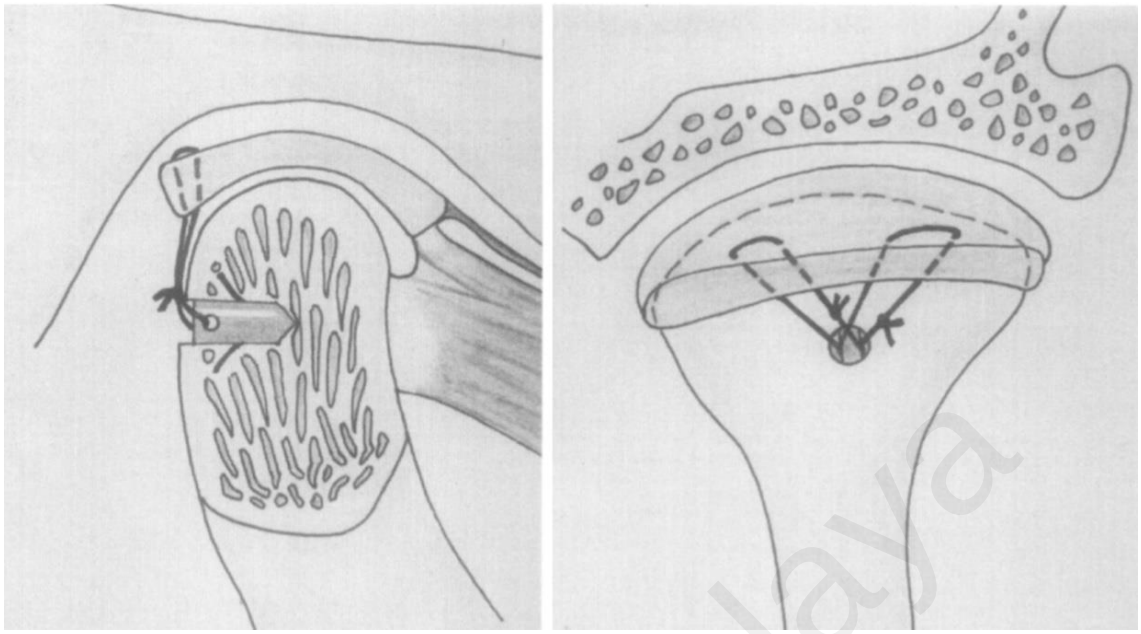


Figure 2.8: After bone-anchored suture placement at posterior head of condyle, the wings compressed against the body until the anchor positioned beyond cortical bone, and the wings spring outwards to lock the anchor below cortical bone. 2 sutures are tied to posterior band of articular disc in mattress fashion: 1 suture applied medially while the other suture is more toward the lateral aspect of disc (adapted from Wolford, 1997)

Fields and Wolford (2001) had investigated the histomorphology of the implanted bone-anchored-suture after 3 months to 59 months of placement. The authors noticed that all the anchors were biocompatible which healed and osseointegrated well within surrounding condyle; also, no evidence of inflammatory and fibrous tissue formed, no anchor fracture, and no particulation seen as well.

2.4.6 Delivery of ionizing radiation, medications, and autogenous free fat graft to prevent heteroptopic bone formation / reformation

Heterotopic bone formation was first introduced by Riedel in year 1883. It is identified as abnormal mature lamellar bone formation in soft tissue (Board et al., 2007). From patients who have undergone total hip arthroplasty / total knee replacement to TMJ ankylosis patients, this heterotopic bone formation is known as the culprit for partial or complete bony ankylosis at the operated joints, causing pain and discomfort to patients. It also reduces the range of mandibular movement in TMJ ankylosis patients during post-op jaw physiotherapy (Monje et al., 2012).

Heterotopic bone formed at operated joints due to unorganized pluripotent mesenchymal stem cells differentiation through the coordination between local and systemic factors. With that, growth factors and bone morphogenetic protein are recognized to influence the initiation, differentiation, and proliferation of osteogenic cells (Reid & Cooke, 1999). Meanwhile, other possible aspects for heterotopic bone formation in TMJ ankylotic mass resected patients are trauma history with condylar fracture; history of multiple surgeries; inadequate gap created (with critical size defect of bone-from-bone gap 2.5-3.5 cm) to ensure no callus bridging; too much periosteal stripping of nearby bony structures intra-op; inadequate debridement of devitalized tissues and loose bony fragments; poor haemostasis control during surgery; and post-op non-compliance of patients to jaw exercise (Lindqvist et al., 1992; Wolford & Karras, 1997; Mercuri et al., 2008).

Knowing the detrimental effects of heterotopic bone at surgical sites, additional approaches are then recommended to minimize post-op pain and re-ankylosis.

Ionizing radiation can interfere with active dividing cells nuclear DNA and interfere with osteoprogenitor cells differentiation for heterotopic bone formation and re-ankylosis (Durr et al., 1993). Yet, the scattered radiation could also harm the nearby soft and hard

tissue, and especially harmful to growing patients brain and other vital structures development (Durr et al., 1993). It is hence not gaining popularity among surgeons.

Prescribing medications such as NSAIDS can inhibit prostaglandin production, especially prostaglandin E2. It can then help to reduce heterotopic bone aggregation from 1/2 to 2/3 among patients and reduce the incidence of post-operative relapse (Steenmeyer et al., 1986).

Prophylactic usage of bisphosphonates can prevent heterotopic bone formation after total hip arthroplasty, by inhibiting mineralization of osteoid and not osteoid formation inhibition. However, it is no longer practiced now as studies have proved that bisphosphonate also slows ossification until patients terminate taking it (Francis et al., 1969; Padgett et al., 2003).

Post ankylotic mass resection, there will be dead space formed at the confirmed area of TMJ, followed by haematoma collection. Murphy (1914) reported that autogenous free fat graft could be transplanted to TMJ area. By packing the fat into post TMJ arthroplasty space, it could help in haemostasis by plugging at bleeding points and reduce hematoma formation; also, fat could serve as a factor to prevent scar formation (Wolford & Karras, 1997). Due to ease to harvest and manipulation with reduce donor site morbidities, fat is always use together with other surgical techniques to reduce post-operative relapse, for example interpositioned in between prosthetic TMJ and glenoid fossa or use concurrently with temporalis myofascial flap as interpositional biomaterials.

2.5 Biomaterials for interpositional arthroplasty

Post arthroplasty of freshly jaw joints wound would induce bleeding and subsequent haematoma formation. This would induce the local pluripotent stem cells, together with the effect of reduced vascularity and oxygen tension at surgical site, all these could then

promote differentiation of cells into fibroblast and osteoblast and hence collagen and cartilage / bony deposition and cause re-ankylosis (Thangavelu et al., 2011).

The purpose of interpositional arthroplasty is to fill up the dead space post arthroplasty and prevent the direct contact of both the articulating bone surfaces of temporal / glenoid fossa and ankylosed condyle / ramus region. Depending on the source of the biomaterials, it could be categorized into autograft, allograft, xenograft and non-biologic materials. However, there is no ideal biomaterials, and each biomaterial would be discussed further as below:

2.5.1 Autograft

Autologous auricular cartilage graft

Auricular cartilage for disc replacement was first described by Perko (1973), before Ioannides and Freihofer (1988), Matukas and Lachner (1990) utilised auricular cartilage as interpositional biomaterials post TMJ discectomy.

The inspiration of using auricular cartilage was from the normal anatomy of TMJ. Cartilage is present on the normal condyle surface and separates the condyle from nearby tissues. Hence post TMJ ankylotic mass resection, the operated surfaces are raw and exposed without cartilage coverage, in which fibrosis and ossification can occur on the raw surfaces (Lei, 2002).

Auricular cartilage could be used as a barrier for the cut articulating bony edges or replacement of the torn articular disc. This auricular cartilage is harvested either cartilage alone or in combination with perichondrium or full-thickness skin; then inserted at joint space created and secured with sutures to soft tissues (Lei, 2002; Lello, 1990). Pincock and Dann (1993) suggested auricular cartilage to be harvested together perichondrium can ease the suturing work at surgical site without much tearing as compared to cartilage

alone; and the perichondrium layer theoretically can maintain chondrogenic potential and hence regeneration of auricular cartilage potential (Eisemann, 1983; Zalzal et al., 1986).

Comparing to other biomaterials, use of auricular cartilage shows low donor site morbidity, provides safe and viable graft, non-antigenicity, same field of donor and recipient sites, no obvious scar, adequate graft dimension to be harvested (more than $1x2cm^2$), cartilage shape fits condyle process well, reduced / no risk of facial nerve motor function loss (Krishnan, 2008; Lei, 2002). Also, both Laskin et al. (1952) and Sarnat and Laskin (1954) showed that the pre-existing low metabolic rate and anaerobic metabolism of auricular cartilage permits hypoxia during functional loading.

However, long term follow-up shows that patients that the use of auricular cartilage have risk of cauliflower deformity of pinna even with primary closure of donor site wound, grafts fragmentation, fibrous adhesions at condyle articulating surfaces, graft displacement, chronic tissue damage due to internal injurious movements (Lei, 2002; Lello, 1990; Takatsuka et al., 1996; Yih et al., 1992). Muñoz-Guerra et al. (2018) mentioned that this long list of drawbacks, together with factors such as pre-existing diagnosis of joint inflammation and articular surfaces osteoarthritic surfaces change, multiple attempts of operations prior and inadequate post-operative jaw physiotherapy, all these then contribute to high relapse risk, and gaining less popularity now.

Temporalis superficial fascia flap / temporalis myofascial flap / temporalis muscle flap / temporalis fascia flap

Temporalis myofascial flap is the most popular interpositional arthroplasty biomaterials in TMJ surgery. It started with Verneuil in 1872 who reported the first temporalis muscle and fascia flap as interpositional biomaterial in TMJ ankylosis case, then Yolovine (1898) utilised temporalis fascial flap in orbital reconstruction; Murphy (1913) then advocated this flap for TMJ surgery, with latest modification come from

Feinberg and Larsen (1989) who described the concept of pedicled temporalis muscle and pericranial flap in interpositional arthroplasty.

Surgeon can opt for fascia alone, or facsia plus muscle of varying thickness, can be harvested as an axial flap (Pogrel & Kaban, 1990). There are variations in the surgical harvesting technique. Feinberg and Larsen (1989) rotated the flap in an anterior direction to articular eminence and sutured posteriorly to retrodiscal tissue. This technique is believed to allow the flap maintain viability and allow satisfactory mandibular excursion during function. Meanwhile, Pogrel and Kaban (1990) utilised fascia or fascia together with muscle, rotated inferiorly over zygomatic arch into joint space. To reduce prominence over zygoma region, the authors suggested zygomatic arch thickness reduction to avoid bulkiness over the flap tunnel site. Other technique performed was as per Bergey and Braun (1994), in which osteotomy of zygomatic arch was done in 2 sites and segment of the arch removed to facilitate the flap rotation and tunnel down to joint space created. Segment of osteotomised arch is then replaced through plates and screws fixation.

Surgeons prefer to use temporalis myofascial flap due to its autogenous origin, good resilience, close proximity to surgical site and hence easy preparation and might be harvested through same incision harvest; also, resilience with good blood supply of middle and deep temporal arteries ensure success of this flap harvest; low degree of friction and good positional stability; and it causes minimal cosmetic and morbidity issue to donor site (Pogrel & Kaban, 1990).

However, donor site does exhibit fibrosis, scar contracture and trismus if no aggressive post-operative jaw physiotherapy is performed; also there is possible temporal hollowing; temporary facial nerve injury and rarely permanent nerve deficit occurs post flap harvest (Dimitroulis, 2004). Also, muscle harvested in flap infrequently causes bulkiness when rotated over the zygomatic arch, in which some surgeons suggested for zygomatic arch

bone trimming to reduce zygomatic arch bone thickness and hence to accommodate the temporalis myofascial flap better (Pogrel & Kaban, 1990).

Pterygo-masseteric muscle flap

According to Huang et al. (2007), usage of this flap was first described by Eschmarc in the second half of 19th century. Anyanechi et al. (2015) have performed the procedure with this flap via intraoral approach. Lateral surface of angle-ramus was exposed and continue superiorly to maxillary teeth occlusal plane until the sigmoid notch was visible. Procedure then continued with soft tissue retraction, ensure no nearby neurovascular bundle injury, flat periosteal elevator placement below the mandible, before osteotomy was carried out above lingula to create gap of 1.5-2cm. (Figure 2.9). Post bony osteotomy, mouth opening was checked, and coronoidectomy was performed if initial maximal mouth opening achieved was less than 30mm. Pterygo-masseteric muscle flap was then sutured across the gap created. (Figure 2.10)

In the same study also, Anyanechi et al. (2015) utilised and compared oral mucoperiosteal flap to the pterygo-masseteric muscle flap. (Figure 2.11) Interestingly both these biomaterials showed almost similar post-op maximal interincisal opening upon 3 years review. This oral mucoperiosteal flap was chosen as rich in vascularity, anatomical proximity to osteotomy site, and ease of flap handling to suture across the space created in condition where either the ramus or angle osteotomy is performed.

Back to the subtopic discussed, the advantages of the pterygo-masseteric flap is the close proximity of flap to the arthroplasty site, vascularised flap to ensure success of flap during function, no scarring from other donor site harvest, no risk of injury to both the facial nerve and maxillary artery. Yet, reduce operative site visibility is the main concern of surgeons and hence no really practised widely then (Khadka & Hu, 2012).

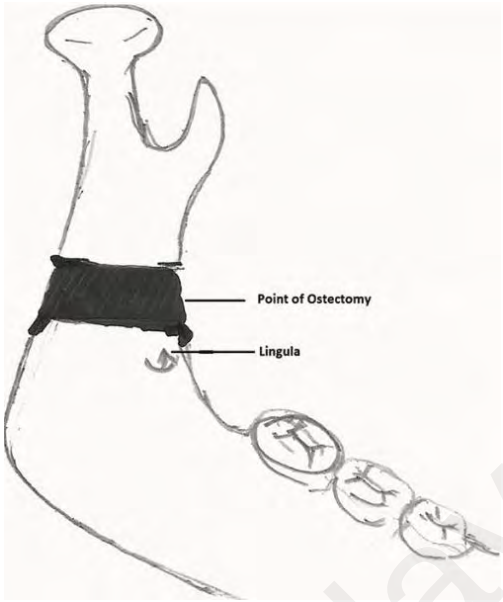


Figure 2.9: Osteotomy site at shaded area (adapted from Anyanechi et al., 2015)

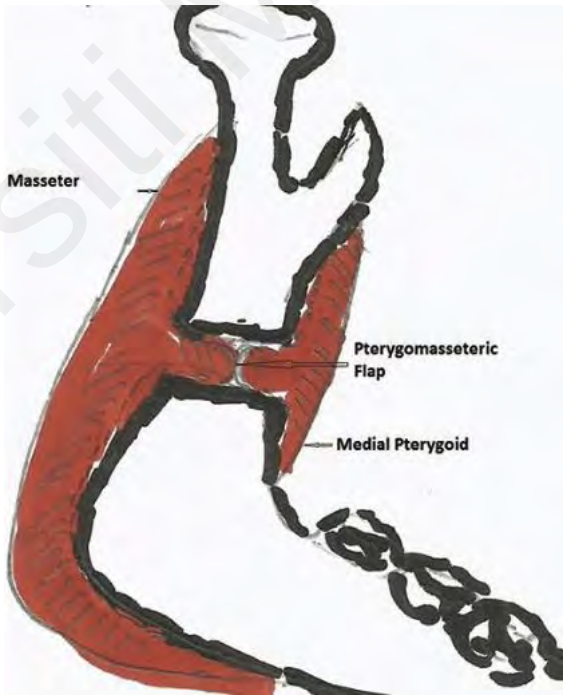


Figure 2.10: Pterygomasseteric muscle flap as interpositional biomaterials (adapted from Anyanechi et al., 2015)

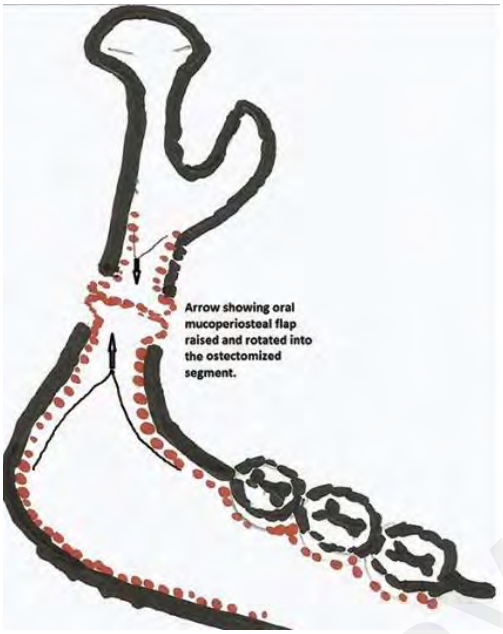


Figure 2.11: Oral mucosa flap raised and tunnel into bone space created and sutured bucco-lingually across the bony gap region (adapted from Anyanechi et al., 2015)

Costochondral graft

Costochondral graft was option for reconstructive joint surgery among growing paediatric patients. The current TMJ replacement technique with costochondral graft was popularised by Poswillo (1987); and the application of interpositioning of lyophilized costochondral cartilage was advocated by Raveh et al. (1989).

Proper shaping of the graft could make it a feasible option for interpositional arthroplasty biomaterial. Raveh et al. (1989) reported good long term results with lyophilised cartilage in TMJ ankylotic mass resected joint, and the biomaterial also integrated well with surrounding tissues with no signs of resorption.

Nevertheless, other options available have replaced costochondral graft due to its underlying unpredicted growth and relapse post-operatively; also, there is long list of donor site morbidity such as pleural effusion at donor site, atelectasis and empyema, and

scarring (Kavin et al., 2020). All these then make costochondral draft a historical biomaterial in TMJ surgery then.

Abdominal dermis fat

Abdominal fat can be harvested from hidden body regions such as abdomen or inguinal areas. Compared to fat grafts alone, dermis fat is more stable and lesser risk of fragmentation during manipulation in the bony space created (Dimitroulis, 2004).

The abdominal dermis fat is easy to harvest, able to be contoured to fit the surgical site, has minimal donor site morbidity, underlying adipogenesis that inhibits new bone and cartilage formation, hidden scar, and allow 2 teams approach during surgery (Dimitroulis, 2004). Studies have done and showed that dermis-fat grafts in non-load bearing areas shows little changes in volume (Mackay et al. 1993); grow in volume together with growing patients (Mackay et al. 1993); yet Dimitroulis (2004) reported that unknown outcome for dermis-fat grafts under long term functional loading.

Compared to buccal fat pad, abdominal dermis fat is not so popular due to its distance from donor to recipient, additional donor site wound, also it would atrophy with 30%-45% volume reduction with time, increase operation time, fragmentation, need for post-op wound care at donor site, seroma / epidermoid cyst development, haematoma, ileus and rarely peritoneal puncture incident (Billings & May, 1989; Chossegros et al., 1997; Keerl et al., 1995, Rattan, 2006).

Buccal fat pad

Rattan (2006) first reported the use of buccal fat pad as interpositional arthroplasty biomaterials. Buccal fat pad consists of a main body and 4 extensions: buccal, pterygopalatine, pterygoid and temporal; and the buccal and main body both occupy 55-70% of total weight of buccal fat pad. The size of the buccal fat pad is almost constant

among different individuals with different body weight and fat distribution. Depends on way of harvesting, the fat flap with capsule is pedicle flap and fat without capsular tissue is termed random fat flap.

Packing of buccal fat pad at recipient site can eliminate dead space, prevent fibrosis / heterotopic bone formation, and isolate residual active tissue such as periosteum and reactive tissue from previous failed treated joints from periphery tissues to reduce the incident of re-ankylosis. Also, this viable autogenous buccal fat pad has adequate bulk (8.3-11.9mL), in close proximity between donor and recipient sites, easy to harvest, and has good vascular supply to ensure good outcome (Gaba et al., 2012; Wolford et al., 2008). With time, buccal fat pad would also have 25-75% volume reduction. Also, it has friable nature and might be easily torn during manipulation (Carpaneda & Ribeiro, 1994). However, the long-term outcome among patients is satisfactory and encouraging.

Full thickness skin graft

Georgiade et al. (1957) first used the skin grafts for TMJ ankylosis surgery. Popescu and Vasiliu (1977) then advocated full-thickness skin graft harvested from retroauricular region for condylar stump coverage and epidermal side facing skull base. (Figure 2.12)

This full-thickness retroauricular skin graft is simple to harvest, autologous origin, resistant to pressure / stretching during function; also, it prevents scarring at operative site, and shows no cosmetic compromised issue at donor region (Chossegros et al., 1999). There were papers that reported infrequent transient facial paralysis or epidermoid cyst with fistula formation to skin (Chossegros et al., 1997; Chossegros et al., 1999) as complications. The authors mentioned that even de-epithelialization of flap cannot promise to have zero incident of epidermoid cyst development.

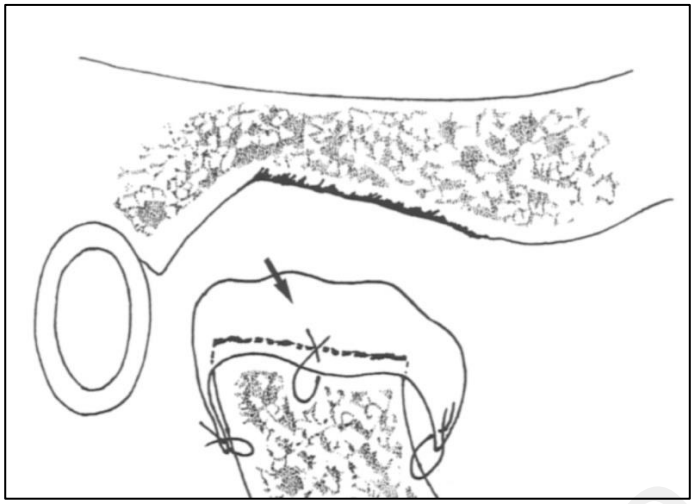


Figure 2.12: Skin graft (arrow) covers the mandibular condyle, epidermal side is against the temporal bone, and dermal side is facing mandibular condyle. Stitches placed at posterior, anterior and lateral to skin graft and surrounding tissue (adapted from Chossegros et al., 1999)

Fascia lata

Lateral thigh fascia lata graft has been adopted in TMJ ankylosis due to its strong inert collagen nature and pliable thick collagen sheets, autologous origin with no risk of foreign body reaction, easy to harvest, low risk of infection and resistant to resorption. (Alemán & Martínez, 2012; Link et al., 2008). During application, the fascia lata can either be folded to envelope the condylar stump or to suture it to nearby tissue.

However, it would need additional incision site and scarring, risk of hematoma formation, wound dehiscence, vastus lateralis muscle herniation, and rarely lateral cutaneous nerve distal branch injury (Alemán & Martínez, 2012; Paterson & Shepherd, 1992).

TMJ articular disc / disc repositioning / meniscus conservation and relocation

Autogenous articular disc is the best interpositional graft that reduce graft complications, maintain homogenous environment and reduce re-ankylosis incident post-

operatively. Complete resection of bony ankylotic mass laterally around residual condyle is paramount important. After ankylotic mass removal of 1.5-2cm distance from neck of condyle to base of skull, the disc can then be retrieved to cover the arthroplasty bony surfaces, by suturing it to capsule. If the native disc tissue is torn, scarred or inadequate disc tissue available for coverage, then the condyle / surgical site can be interpositioned with nearby autogenous biomaterials, such as temporalis myofascial flap. Alternatively, free fat graft can be harvested to fill the lateral osteotomic gap and eliminate dead space can minimise the relapse incident post-operatively (He et al., 2011; He at al., 2011). However, if either condyle or disc or both structures could not be preserved, surgeons might need to consider TMJ reconstruction surgical approach then.

2.5.2 Allograft

Amniotic membrane

The usage of amniotic membrane is not new in medical field. It had been used as arthroplasty material in hip joint tuberculosis, that showed fibrovascular reparative granulation tissue in basal layers with no graft rejection; also, it can serve as wound dressing at burn injury or chronic leg ulcers sites; meanwhile it has also been used in surgical reconstruction of artificial vagina, repairing omphaloceles, and prevent tissue adhesions of abdomen, head, and pelvic surgical sites (Akhter et al., 2016).

The human amniotic membrane is retrieved from the innermost layer of placenta. This cryopreserved human amniotic membrane can be pre-treated using far-infrared rays or microwaves or gamma irradiation, then kept in room temperature prior to use in TMJ ankylosis release surgery (Akhter et al., 2016). The amniotic cells can produce anti-inflammatory factors, such as IL-1 and IL-2 receptor antagonists, IL-10 and endostatin, all of these could inhibit endothelial cell proliferation and angiogenesis. Hence, application of natural biologic properties of human amniotic membrane at TMJ ankylosis

surgery could help in anti-inflammation of inflammatory degenerative jaw joint disorders, reduce scar formation, serve as a cushion layer to prevent re-ankylosis, promote wound healing and reduce pain at resected jaw joint sites (Hao et al., 2000). As amniotic membrane is an avascular tissue, post-surgical haemorrhage incident and haematoma formation can be largely reduced and this decrease the possibility of inflammatory mediators such as bradykinin and prostaglandins accumulation.

Yet, there is still concern if this allograft could cause foreign body reaction in long term. Also, not all patients could accept the implantation of the human amniotic membrane from other donors.

2.5.3 Xenograft

Collagen membrane

This biomaterial is not new in the field of Oral and Maxillofacial Surgery, as collagen membrane has been used extensively in oral cavity soft tissue defects coverage, orbital floor reconstruction, guided bone regeneration prior to implant fixture insertion, and in burns and chronic wounds management.

Collagen membrane can be obtained from bovine, porcine, avian and equine; then purified and treated before use on humans. It is the major insoluble protein in extra-cellular matrix and in connective tissue.

Biologically, collagen membrane has low antigenicity, non-inflammatory, non-toxic, minimal biodegradation, ease of manipulation without additional donor site morbidity, and no second surgery is needed for removal as it is resorbable up to 32 weeks. Physiologically, the collagen membrane is non-permeable to bacterial migration, has elastic property, soft and flexible with good tear strength.

Shetty et al. (2019) used collagen membrane of bovine based which is supplied in gamma-sterilised sheets and wrap around the gel foam and placed at resected joint region.

Direct bony contact can be prevented then through collagen membrane packing in situ at initial healing phase. Authors justified that the absorbable gelatin sponge is needed to provide framework for collagen membrane. This gelatin sponge can also expand by absorption of tissue fluids and further fortify the collagen membrane in situ. When the gelatin sponge gets resorbed, the bony surfaces would have undergone eburnation then.

Reports so far have shown no graft rejections and foreign body reaction post usage of collagen membrane at surgical site.

Porcine acellular dermal matrix

The porcine acellular dermal matrix, together with bone wax were used by authors as physical barriers to isolate the newly formed condylar fossa and post resection reshaped mandibular stump (Zhu et al., 2021). Both materials can prevent re-ankylosis, and have no issue of donor site morbidity, post-op infection or foreign body reaction. Meanwhile, bone wax not only helps in haemostasis by plugging the haemorrhages sites, it also prevent osteogenesis through exclusion of osteoblasts from surgical site (Papay et al., 1996; Solheim et al., 1992).

Same as other xenografts, there is concern if the xenografts might cause foreign body reaction. Also, religious concern might preclude its use due to source of origin.

2.5.4 Alloplast

Silastic materials / silicone sheet

Silastic biomaterials for TMJ surgery are almost obsolete now. Its use initially was to avoid donor site morbidity, to prevent resorption of biomaterials and hence maintain vertical posterior ramus height; also, it is biocompatible to surgical site. There is even modification by invention of ultrathin silicone sheet to replicate the thin articular disc (Aggarwal et al., 2015). This ultrathin silicone resembles articular disc with

characteristics of thin, easy to anchor with sutures to adjacent tissues, avascular and tough structure which can function at resected joint space with reduced amount of foreign material at TMJ space. The ultrathin silicone is pliable, non-absorbable and resistant to ischaemic necrosis.

However, numerous reports have shown that this non-biological material could cause foreign body reactions, extrusion, displacement, and infection, and hence it was being replaced by other biomaterials then (Karaca et al., 2004).

T-plate / modified T-plate / titanium plate

Knowing that the medical grade of silicone also can bring long list of complications, Ahmad et al. (2015) modified the prefabricated T-plate to serve as interpositional arthroplasty biomaterial at ankylotic mass resected sites. (Figure 2.13)

Figure 2.13: Post condylectomy, the re-shaped T-plate is fixed to mandible (adapted from Ahmad et al., 2015)

After condylectomy performed, the pre-fabricated 4-hole T-plate was bent to 90 degree and reshaped so that the vertical limb can be anchored on ramus while the bent T-head was interposed between glenoid fossa and mandibular ramus. (Figure 2.14)

Figure 2.14: 4-hole T-plate is bent to 90^0 (adapted from Ahmad et al., 2015)

Ahmad et al. (2015) reported good surgical outcome as the metallic interposition biomaterial prevent the direct contact of 2 bony ends; lower risk of infection; and no risk of donor site morbidity.

Acrylic marbles / acrylic balls (Sawhney, 1986)

Sawhney (1986) has described that acrylic could be cheaper biomaterial compared to silicone. (Figure 2.15)

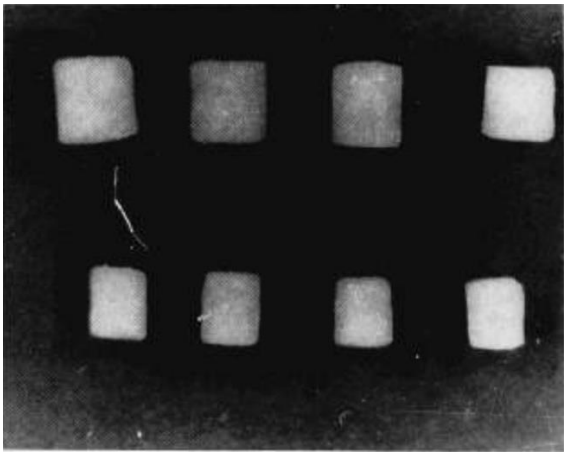


Figure 2.15: Different shapes and sizes of acrylic cylinders commonly used (adapted from Sawhney, 1986)

The acrylic spheres maintain the arthroplasty gap and prevent direct bony contact, meanwhile providing gliding movement of jaw during function. Its rounded shape allowed it to roll anterior-posteriorly in the surgical created articular regions. It could also help in burnishing the resected joint and smoothen the surfaces. (Figure 2.16)

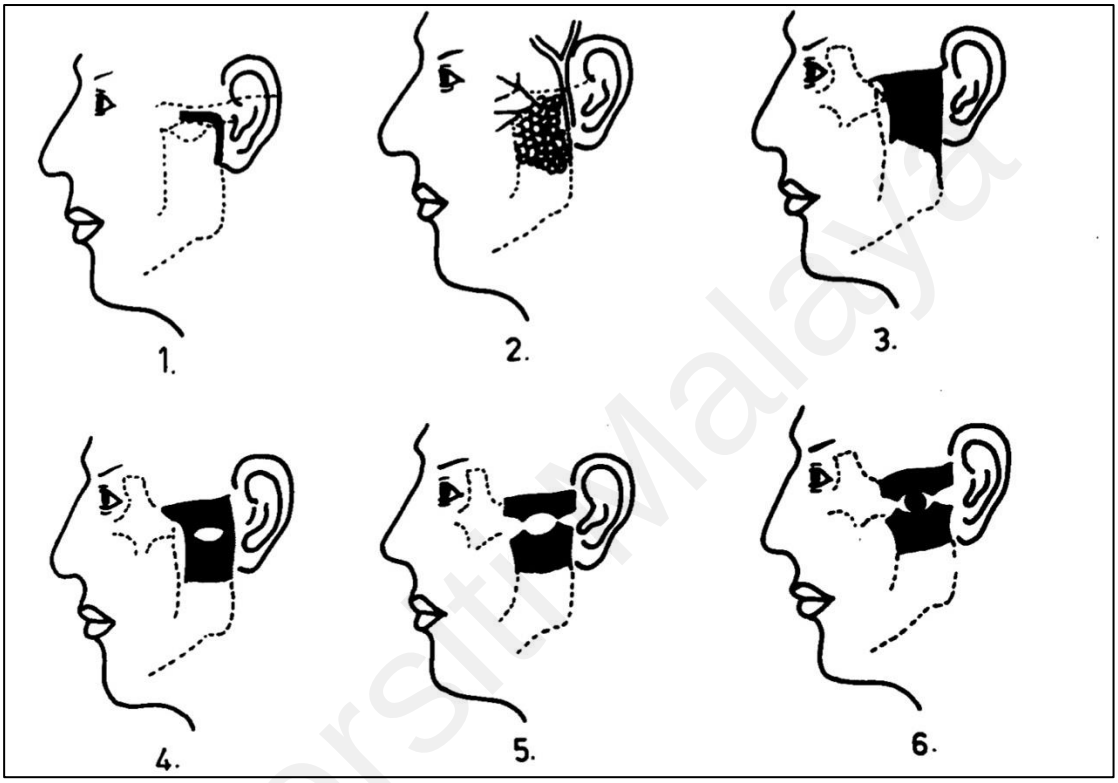


Figure 2.16: 1. Surgical incision; 2. Raising of flap; 3. Ankylotic mass exposure; 4. Creation of a transversely elliptical hole using neurosurgical burr and perforator; 5. Wedges of bone block removed anterior and posterior to the resected joint; 6. Acrylic cylinder placement (adapted from Sawhney, 1986)

Even though Sawhney did not see extrusion and major complications in his study, other papers had refuted the use of acrylic balls due to ease of extrusion, fragmentation of materials that lead to foreign body reaction.

Proplast-Teflon

Initially introduced in early 1980s, there were 2 forms of laminated Proplast interpositional implants reported:

i)Proplast I: black, pyrolytic graphite bonded to non-porous Teflon (polytetrofluoroethelene – PTFE)

ii)Proplast II: white, PTFE bonded to pure aluminium oxide

Both materials were chosen as they were biological tolerant, have porosity on surfaces that allow tissues growth, the ability to spread biting force evenly during function. However, long term study has shown that these alloplastic biomaterials could cause materials degeneration and produce polymer debris and cause giant cell reactions. It is no longer used now as there are other more user friendly and biocompatible biomaterials to be placed at arthroplasty gap sites (Feinerman & Piecuch, 1993).

CHAPTER 3: METHODS

This systematic review was conducted in accordance with the guidelines from the Cochrane Handbook of Systematic Reviews of Interventions (Higgins, 2022). Reporting of this systematic review and meta-analyses was made based on the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) (Page et al., 2021).

3.1 Eligibility criteria

English language articles that were published up to 16th October 2021 involving human studies with a minimum of 5 patients diagnosed with unilateral or bilateral TMJ ankylosis with follow-up period of at least 6 months were included. Details of biomaterial used for interpositional arthroplasty as well as pre- and post-op measurements of mouth opening and complications were stated in the articles.

3.1.1 Inclusion criteria

The inclusion criteria based on the PICO (Miller & Forrest, 2001) format for the focused question are as below:

Focused question: Among all the patients with ankylosis, what are the most commonly used interpositional arthroplasty biomaterials that produce good long-term outcome and its complications?

Population: All patients with TMJ ankylosis who underwent interpositional arthroplasty

Intervention / Comparison: Individual application of biomaterial types

Outcomes: Changes in pre- and post-operative mouth opening (interincisal distance) and complications associated with interpositional arthroplasty biomaterials used.

3.1.2 Exclusion criteria

Articles were excluded if they were:

(i) case report, case series, expert opinions and review articles

(ii) animal / cadaveric studies

(iii) cases with gap arthroplasty only / involved ramus-joint reconstruction / total joint replacement cases / Mathew device placement / patient specific implant placement / distraction osteogenesis performed

(iv) discectomy in internal joint derangement cases

(v) TMJ osteoarthritis cases

(vi) TMJ rheumatoid arthritis cases

3.2 Search strategy and information sources

A thorough electronic search was conducted using four online databases which were Pubmed, Medline, EBSCO and Web of Science. To avoid missing out relevant articles, hand search was conducted via two journal online databases namely British Journal of Oral and Maxillofacial Surgery AND International Journal of Oral and Maxillofacial Surgery; as well as through reference lists of retrieved articles.

The following terms were used as keywords / combination of keywords and Medical Subject Headings (MeSH) terms to identify the suitable papers:

Table 3.1: Keywords / combination of keywords to identify suitable papers

K1	temporomandibular joint ankylosis OR temporomandibular joint ankylosis surgery OR temporomandibular ankylosis OR treatment TMJ ankylosis OR surgical options treatment TMJ ankylosis OR temporomandibular joint re-ankylosis OR biomaterials interpositional arthroplasty OR TMJ interpositional arthroplasty OR interposition arthroplasty OR condylectomy OR autograft interpositional arthroplasty OR allograft interpositional arthroplasty OR xenograft interpositional arthroplasty OR synthetic interpositional arthroplasty OR re-ankylosis interpositional arthroplasty OR materials comparison interpositional arthroplasty OR interpositional arthroplasty complications OR outcomes interpositional arthroplasty OR correction TMJ ankylosis OR surgical management TMJ ankylosis OR unilateral TMJ ankylosis OR bilateral TMJ ankylosis OR traumatic TMJ ankylosis treatment
K2	unilateral bilateral TMJ ankylosis OR TMJ ankylosis interpositional arthroplasty OR TMJ ankylosis autograft OR TMJ ankylosis allograft OR TMJ ankylosis xenograft OR TMJ ankylosis alloplastic OR TMJ ankylosis graft OR TMJ ankylosis biomaterials
K3	surgical treatment modalities TMJ ankylosis OR graft flap interpositional arthroplasty OR trauma infection TMJ joint ankylosis surgical management
Any keywords of each category were searched in such a manner [(K1)] OR [(K2)] OR [(K3)] OR [(K1) AND (K2)] AND (K3) to identify as many relevant published studies as possible. There were no time period restrictions during the search and papers retrieved involved all dates of coverage.	

EndNote X9, Clarivate was used for the management of the electronic titles and removal of duplicates.

3.3 Selection process

During the papers search procedures, 2 reviewers (W.L.V and D.L.K.H) would independently assess the eligibility of the papers searched by looking at the titles and abstracts of the papers; articles involving human clinical trials with a minimum participation of 5 patients, and review $\geq$ 6 months; patients diagnosed with either unilateral or bilateral condylar ankylosis; detailed description of types of biomaterials used in the study; pre- and post-operative clinical examination findings and measurement are stated in articles; and English language articles. Disagreements were resolved via discussion among the reviewers. If unable to reach final consensus, a third-party reviewer (M.Y.P.M.Y) was consulted. Reasons for rejection of articles were recorded.

3.4 Data collection

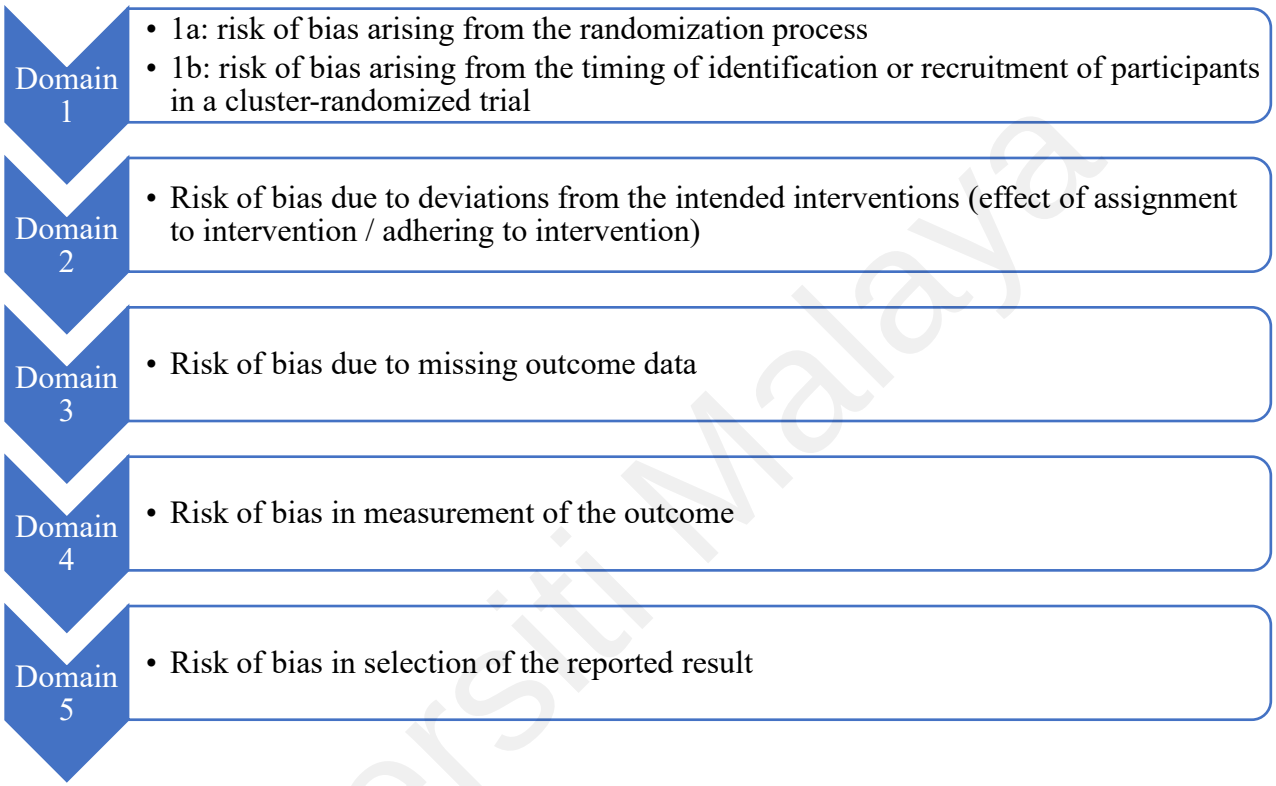
Data was then extracted by single reviewer (W.L.V) from each study with a standardized Excel form modified from Cochrane Collaboration (2014) data collection form for intervention review, inclusive of RCTs and non-RCTs. Data extracted was: year of the papers were published, authors involved, total patients recruited, age of patients (range / mean / median), gender, follow up duration, etiology of ankylosis, new / recurrent cases, duration of ankylosis, classification of ankylosis used in the paper, uni- / bilateral TMJ ankylosis, procedure performed on patients, approach for procedures, imaging pre- and / or post-op done (types, findings), biomaterials used, mouth opening in millimetres (pre-operative, post-operative), complications post-op and patients' compliance to post-operative physiotherapy.

3.5 Risk of bias

Included studies were analysed for risk of bias using Revised Cochrane risk-of-bias tool for cluster-randomized trials (RoB 2 CRT) and Risk of Bias in Non-randomized

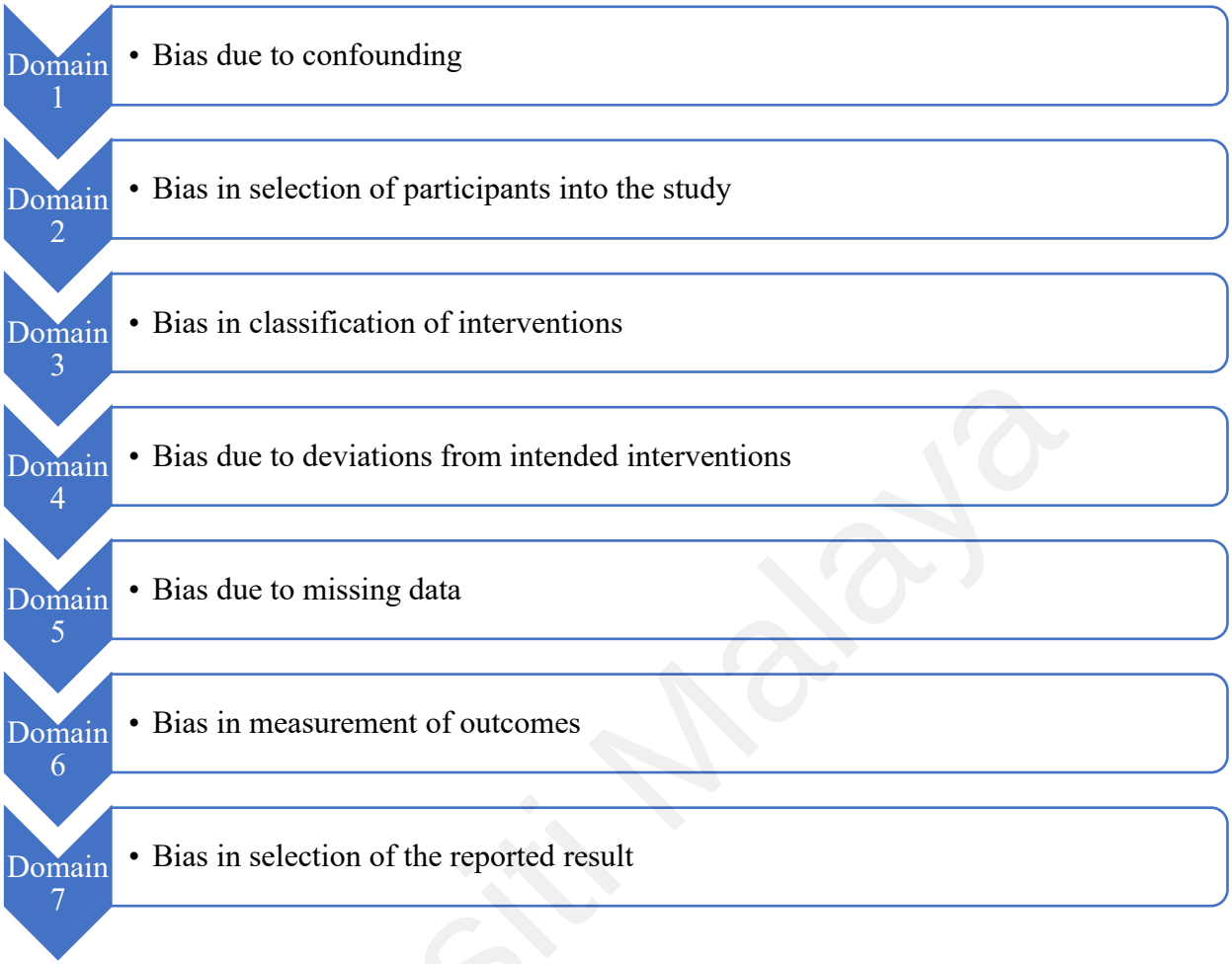
Studies of Interventions (ROBINS-I) for randomised controlled trial (RCT) and non-RCT articles respectively. This assessment was carried independently by 2 reviewers (W.L.V and D.L.K.H).

When using RoB2 RCT, 5 domains were assessed, namely:



The overall risk-of-bias judgement would categorise a paper to be low risk of bias if it had low risk of bias for all domains; some concerns if at least one domain raise some concerns yet not to be at high risk of bias for any domain; or high risk of bias if the study had at least one high risk of bias in at least one domain or it had multiple domains with some concerns in a way that substantially lowers confidence in result.

While for ROBINS-I, 7 domains for non-RCT papers were assessed, namely:



The overall bias risk would then categorise the papers into low risk of bias group if the study has low risk of bias for all domains; moderate risk of bias if the study had low or moderate risk of bias for all domains; serious risk of bias if at least 1 domain was at serious risk of bias but not at critical risk of bias in any domain; critical risk of bias group if at least 1 domain was critical risk of bias; or no information if there is no clear indication that the study is at serious or critical risk of bias and there is a lack of information in one or more key domains of bias.

CHAPTER 4: RESULTS

4.1 Study selection

The electronic search of databases retrieved 2256 papers, while hand search / websites / citation search identified 14 papers, which yielded a total of 2270 papers. Among the 2256 papers, 1396 papers with duplication and 200 unqualified records (eg: joint interpositional arthroplasty other than temporomandibular joint regions, animal studies, papers reported other than English language, case reports / case series / review articles, papers which were irrelevant to TMJ interpositional arthroplasty at all) were removed and left 660 papers. After screening and assessment for eligibility, further elimination of 569 papers was done as that research were about procedures performed for gap arthroplasty only, ramus-joint reconstruction, distraction osteogenesis and Mathew device / patient specific implants placement. With the remaining 91 papers, further scrutinization excluded 60 papers as those papers reported cases with post-op review interval < 6 months, no detail description of pre- and post-op maximal incisal opening for all subjects recruited and cases with TMJ osteoarthritis / internal joint derangement cases. For the 14 papers that were identified through hand search / websites / citation search, all were disqualified due to duplication of records or non-retrievable records. The final total number of 31 studies were included in this research, which consisted of 26 non-RCT papers and 5 RCT papers. (Figure 4.1)

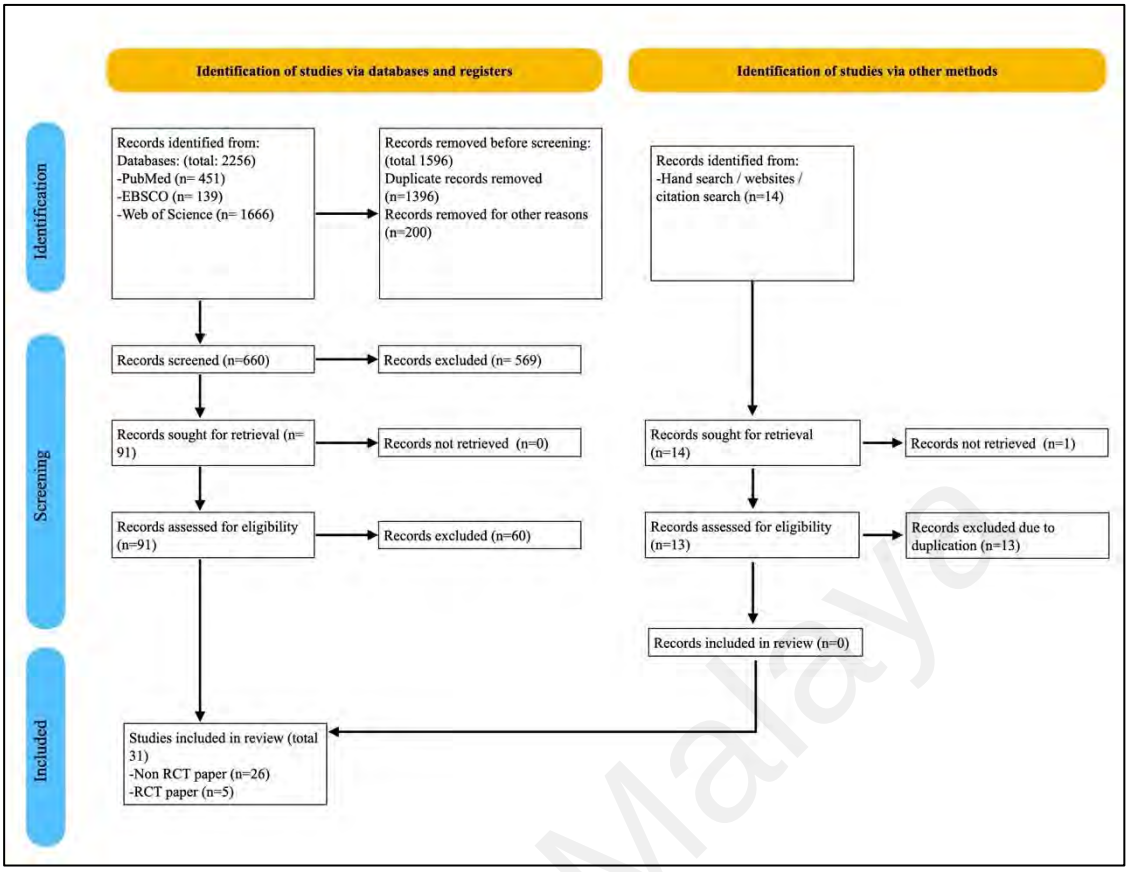


Figure 4.1: Flowchart showing selection process of studies

4.2 Study characteristics

4.2.1 Non-randomised controlled studies

Temporalis fascia / Temporalis muscle / Temporalis myofascial flap

Lin et al. (2019) included 11 patients (3 male, 6 female and 2 non-mentioned) in their retrospective study which included patients with Type III TMJ ankylosis. Their patients' age ranged from 16 to 32 years old. Temporalis myofascial flap was used in these patients. Trauma (n=9), which included five cases of fall, two cases of impact, one case of motor vehicle accident, and one case of violence, was the main cause of ankylosis in this group of patients. Causes of ankylosis in another two patients were unknown. Ipsilateral coronoidectomy was performed to increase the mouth opening to more than 30mm.

In their retrospective study, Rajurkar et al. (2017) included 15 patients (6 male, 9 female) with unilateral TMJ ankylosis. Patients' age ranged from 5 to 30 years old. They performed interpositional arthroplasty with temporalis fascia flap in all the patients. Trauma (n=13) was the most common cause of ankylosis in this group followed by premature delivery and post ear infection, one each. Recontouring of glenoid fossa was performed during the surgery.

Singh et al. (2014) recruited 4 patients who had temporalis myofascial flap as interpositional material in their retrospective study. These patients' age ranged from 14 to 17 years old. All the cases were of Sawhney Type III ankylosis were due to trauma. Coronoidectomy was performed to increase intra-operative mouth opening.

Maqsood et al. (2015) conducted a prospective study in 2015 and they managed to recruit 50 patients. Patients' age ranged from 4 to 35 years old. Only patient with true TMJ ankylosis with mouth opening less than 10mm were included. Cases of pseudoankylosis or fibrous ankylosis were excluded. Of these patients, 42 were unilateral and 8 were bilateral TMJ ankylosis. The authors used temporalis muscle flap as interpositional material in all the cases. Etiology of the TMJ ankylosis were trauma (46 cases), chronic infection (3 cases) and TMJ dislocation (1 case). These patients had TMJ ankylosis for a mean duration of 6.5 years prior to surgery.

Babu et al. (2013) used temporal fascia as interpositional material in 15 TMJ ankylosis patients (10 male, 5 female) that they included in their prospective study. Twelve of them were of Sawhney Type II ankylosis while another 3 were of Type III. In this group, TMJ ankyloses were due to trauma (12 cases), infection (2 cases) and congenital (1 case). Unilateral coronoidectomy was performed in 11 cases and bilateral coronoidectomy was performed in the remaining 4 cases.

Bulgannawar et al. (2011) recruited a group of 8 patients with TMJ ankylosis in a retrospective study. The patients age ranged from 6 to 28 years old. Temporalis fascia

was used in all the patients during interpositional arthroplasty. All of them had unilateral TMJ ankylosis which was caused by trauma (7 cases) and infection (1 case). Instead of using Sawhney classification, the authors used a classification system that was according to anatomic borders and extension. TMJ ankylosis was classified as Class I when it was limited to condylar process and articular fossa, Class 2 when it extended out of fossa involving medial aspect of skull base up to carotid and jugular vessels, Class 3 when it extended and penetrated into middle cranial fossa and lastly Class IV was the combination of Class 2 and Class 3. In this cohort, there were 6 patients with Class I ankylosis and 2 with Class 2 ankylosis. Coronoidectomies were performed in 2 patients.

Guruprasad et al. (2010) reported a retrospective study on the use of temporalis muscle and fascia flap in interpositional arthroplasty. This flap was used in all the 9 patients included in this study. The age of patients ranged from 21 to 32 years old. Seven of the patients developed TMJ ankylosis as a result of trauma while the remaining 2 is due to infection. Intraoperatively, unilateral coronoidectomy was performed in 7 patients and another 2 patients required bilateral coronoidectomy.

Bayat et al. (2009) studied the use of temporalis muscle flap in interpositional arthroplasty in 33 patients whose age ranged from 3 to 47 years old. Twenty three of them suffered from unilateral TMJ ankylosis while the other 10 had bilateral ankylosis. The etiologies for TMJ ankylosis in these patients were trauma (30 patients), ear infection (2 cases) and osteochondroma (1 case). All the patients had bony TMJ ankylosis which they have been living with for a duration ranged from 8 to 240 months. Unilateral coronoidectomies were performed in 8 patients. Another 16 patients had bilateral coronoidectomy since the authors were unable to achieve adequate mouth opening intra-operatively. No additional procedures were performed on the remaining nine patients.

In a prospective study by Danda et al. (2009), 16 patients whose age ranged from 5 to 21 years old with TMJ ankylosis were recruited. However, only 8 of them had

interpositional arthroplasty with temporalis myofascial flap. Of these 8 patients, 7 were unilateral TMJ ankylosis and the remaining 1 was a bilateral case. TMJ ankyloses in 13 patients were due to trauma, 2 patients were due to infection and in another patient was idiopathic. No additional surgical procedures such as coronoidectomy were performed in this study.

Qudah et al. (2005) included 22 patients in their retrospective study for the treatment of TMJ ankylosis. Among those 22 patients, only 8 had interpositional arthroplasty with temporalis muscle while the other 16 patients had joint reconstruction with costochondral graft. The patients age ranged from 8 to 11 years old. Generally, ankylosis in the patients were due to trauma. All the 8 patients were of Sawhney Type III ankylosis. Coronoidectomy was performed in 2 patients during the surgery.

In a retrospective study by Balaji (2003), 31 patients with TMJ ankylosis were enrolled. Twenty-two of them were treated with interpositional arthroplasty with temporalis muscle. This group of patients made up 15 male and 6 female with their age ranged from 19 to 37 years old. However, 1 patient with arthritis was excluded from this study group resulting in remaining 15 unilateral TMJ ankylosis cases and 6 bilateral TMJ ankylosis cases. All these were recurrence cases. Most bilaterally ankylosed cases had coronoidectomy done; while in unilateral TMJ ankylosis cases, intraoral approach coronoidectomy on the contralateral side was done to facilitate good mouth opening.

A group of 7 patients with unilateral TMJ ankylosis were included in the retrospective study by Su-Gwan (2001). These patients' age ranged from 21 to 47 years old. In this study, temporalis muscle and fascia flaps were used in all the patients who underwent interpositional arthroplasty. Ankylosis occurred in these patients as a result of trauma (6 cases) and infection (1 case). All patients had coronoidectomy with 2 of them had it done on both sides.

Chossegros et al. (1997) conducted a retrospective study that included 5 patients (2 male, 3 female) with TMJ ankylosis and used temporalis myofascial flap as the biomaterial during interpositional arthroplasty. This group of patients age between 14 to 60 years old. There were 3 patients with bilateral TMJ ankylosis and 2 with unilateral ankylosis. The only cause of ankylosis in this group of patients was fracture. One of the patients with bilateral ankylosis had coronoidectomy performed.

Abdominal fat and groin fat

Hegab (2015) recruited 14 patients (3 male, 11 female) with their age ranged from 12 to 38 years old in his prospective study. Among these patients, 9 were unilateral and 5 were bilateral TMJ ankylosis cases which amounted to 19 ankylosed TMJ. Of this 19 TMJs, 2 were of Sawhney Type II ankylosis, 9 were Type III and 8 were Type IV. Hegab used abdominal dermis fat as interpositional material after arthroplasty. Ipsilateral coronoidectomies were performed while contralateral coronoidectomies were only performed if adequate interincisal opening was not achieved during surgery.

In a retrospective study reported by Thangavelu et al. (2011), they studied the use of full thickness skin-subcutaneous fat graft from lower abdomen in interpositional arthroplasty. Seven patients were recruited, with one of them being bilateral TMJ ankylosis. Their age ranged from 14 to 39 years old. Six cases were due to trauma and one due to forcep delivery. The authors utilised Topazian classification to grade severity of the cases. Two cases were Grade 1, 4 were Grade 2 and 1 Grade 3 case. Ipsilateral coronoidectomies were performed for all the 7 cases.

A retrospective study by Dimitroulis (2004) included 11 patients with true osseous or fibro-osseous TMJ ankylosis. Those with fibrous ankylosis were excluded from the study. Nine of them had interpositional arthroplasty with autogenous dermis fat from groin and the other two had reconstruction with costochondral graft overlaid with dermis fat graft.

Among the 9 patients who had interpositional arthroplasty, 6 cases were associated with iatrogenic causes while another 3 cases were related to trauma. Their age ranged from 18 to 55 years old. Four of them had osseous ankylosis and 5 had fibro-osseous ankylosis. Ipsilateral coronoidectomy was performed only in 2 patients.

Buccal fat pad

Malhotra et al. (2019) reported a retrospective study which included 10 patients. They used buccal fat pad as interpositional material following arthroplasty. The age of patients ranged from 7 to 16 years old. There were equal number of male and female patients in this study. TMJ ankylosis in all patients were attributed to trauma. All included patients had Sawhney Type III TMJ ankylosis. Ipsilateral coronoidectomy was performed in 2 patients while the remaining 8 patients had bilateral coronoidectomy.

Another retrospective study by Singh et al. (2011) used buccal fat pad in 10 patients that were recruited. Among this group, 9 were unilateral and 1 was bilateral TMJ ankylosis. Trauma was the cause of ankylosis in 7 patients while infection accounted for another 3 patients. Four of the patients were male and 6 were female. Their age ranged from 8 to 35 years old. These patients suffered from TMJ ankylosis for a duration that ranged from 2 to 15 years prior to surgery. Ipsilateral coronoidectomy was performed in 6 cases, while bilateral coronoidectomy was performed in 4 cases.

Native articular disc

In their retrospective study, Lin et al. (2019) included 23 patients (10 male, 11 female, 2 non-mentioned), in whom they used original articular disc as the interpositional material. All of them had Type III TMJ ankylosis. The patients' age ranged from 7 to 25 years old. Ankylosis in this group of patients were mainly due to trauma (5 cases of fall, 5 cases of impact, 4 cases of violence and 3 cases of motor vehicle accident). However, there were

four cases of unknown causes. It was reported that ipsilateral coronoidectomy was performed intra-operative when the maximal mouth opening was less than 30mm.

Singh et al. (2014) recruited 11 patients who had native articular disc as interpositional material in their retrospective study comparing to temporalis myofascial flap. These patients' age ranged from 8 to 18 years old. All the cases were of Sawhney Type III ankylosis. Ankylosis in these patients were attributed to trauma. Coronoidectomy was performed to increase intra-operative mouth opening.

Skin graft

Chossegros et al. (1999) reported a retrospective study that included 31 patients. Out of these, only 20 patients who had been followed up for more than 6 months. Their age ranged from 2 to 50 years old. All the patients had interpositional arthroplasty with full thickness skin graft. Ankylosis in these patients were attributed to trauma (12 cases), infection (5 cases) and idiopathic (3 cases). Among the 20 patients, 15 had unilateral TMJ ankylosis and another 5 had bilateral TMJ ankylosis. This amounted to 25 ankylosed joints.

In another retrospective study, Chossegros et al. (1997) placed full thickness retroauricular skin graft following interpositional arthroplasty in 12 patients (5 male, 7 female). Their age ranged from 2 to 38 years old. Eight patients had ankylosis as a result of fracture while the remaining four were due to infection. Among these patients, only one had bilateral TMJ ankylosis, the rest were unilateral. One of the patients with unilateral TMJ ankylosis had coronoidectomy done.

Costal cartilage

In their retrospective study, Huang et al. (2007) included 10 patients (6 male, 4 female) whose age ranged from 18 to 56 years old. They studied the use of autogenous costal cartilage graft for interpositional arthroplasty. Only 1 case involved bilateral TMJ ankylosis while the rest were unilateral cases. All these patients had history of trauma either motor vehicle accidents or falls. These patients suffered for between 1 to 21 years before getting treated. Since they were able to achieve more than 25mm of interincisal opening intra-operatively, all the patients had only unilateral coronoidectomy.

Chossegros et al. (1997) used costal cartilage as interpositional biomaterial in two of their patients (1 male, 1 female). Their age ranged from 22 to 25 years old. In both patients, ankylosis was due to fracture. The male patient had Type II bilateral TMJ ankylosis while the female patient had unilateral ankylosis. No coronoidectomy was performed in these patients.

Fascia lata

In their retrospective study, Chossegros et al. (1997) only managed to use fascia lata as interpositional biomaterial in one 50-year-old patient. TMJ ankylosis in this patient was due to tumour. No coronoidectomy was performed.

Silicone block and sheet

In contrary to other authors who used silicone sheet, Agarwal et al. (2021) used a 2cm silicone block as the interpositional material. They conducted a retrospective study which included 20 patients with TMJ ankylosis; 13 patients had unilateral while another 7 had bilateral TMJ ankylosis. Of the total 27 ankylotic TMJ, 2 were Type II, 12 were Type III and 13 were Type IV (Sawhney classification). Within this cohort, 8 were male while the remaining 12 were female. Most of the cases (15 patients) were due to trauma and another

5 patients had history of otitis media infection. Their age ranged from 3 to 35 years old. To improve mouth opening intra-operatively, coronoidectomy were performed. Coronoidectomy was performed on the side of ankylosis.

Aggarwal et al. (2015) recruited 10 patients with unilateral TMJ ankylosis in a prospective study on interpositional arthroplasty with ultrathin silicone sheet of 0.2mm. Six of them were male, while 4 were female. The patients' age ranged from 4 to 15 years old. All the patients had history of trauma. Authors performed recontouring of glenoid fossa during the surgery.

Kalra and Kakkar (2011) managed to recruit 80 patients in their retrospective study on the use of ultrathin silicone sheet as interpositional material. Among the 80 patients, 67 of them had only interpositional arthroplasty while the other 13 had reconstruction with costochondral graft. Their patients' age ranged from 5 to 45 years old. All the patients developed TMJ ankylosis as a sequela of trauma. Sixty-one patients were unilateral ankylosis while remaining 19 patients had bilateral TMJ ankylosis.

Manganello-Souza and Mariani (2003) conducted a retrospective study which included 14 patients for the treatment of TMJ ankylosis using silicone sheet. In 5 patients, interpositional arthroplasty with silicone sheet was performed while another 5 patients had constochondral graft with temporalis muscle flap and remaining 4 patients had costochondral grafts and silicone sheets insertion. The interpositional arthroplasty group made up of 3 males and 2 females, with their age range of 17 to 65 years old. Among them, 3 had history of trauma while another 1 had infection before. However, the cause of ankylosis in 1 patient was unknown. They had TMJ ankylosis for a duration between 5 and 20 years before receiving surgery. It was not mentioned whether additional procedure such as coronoidectomy was performed.

Bone wax and porcine acellular dermal matrix

Zhu et al. (2021) conducted a retrospective study involving 12 patients (7 male, 5 female). They used bone wax and porcine acellular dermal matrix as interpositional materials. Their patients age ranged from 20 to 59 years old. Patients included were TMJ ankylosis cases confirmed by computed tomography (CT) scan and clinical examination who were above 18 years old. Patients who required distraction osteogenesis or costochondral graft, were re-ankylosis case and unwilling to comply with post op therapy and review were excluded from this study. Patients with history of bone metabolism drug application, osteoporosis, osteoarthritis, autoimmune diseases and chemoradiotherapy in oral and maxillofacial region as well as those contraindicated for general anesthesia were also not recruited. All the 12 cases of ankylosis were attributed to trauma. Among these patients, 6 had unilateral interpositional arthroplasty while another 6 had surgery on bilateral TMJ.

Acrylic marbles

Erdem and Alkan (2001) conducted a retrospective study that recruited 46 patients with osseous or fibro-osseous TMJ ankylosis. Their age ranged from 7 to 48 years old. Forty-two of them were unilateral TMJ ankylosis and 4 were bilateral TMJ ankylosis. Apart from the 3 recurrent cases, the rest were all new cases. Generally, trauma were the cause of ankylosis in 40 patients, infection in 5 patients and 1 idiopathic case.

Table 4.1: Characteristics of included non-RCT studies

No.	Author (Year) Country Level of evidence Study design	Total patients Gender Age range (years old)	Inclusion criteria Exclusion criteria	Biomaterial used	Etiology New / recurrent cases Classification of ankylosis Duration of ankylosis	Ankylosis of joints	Approach Additional procedures
1	Zhu et al. (2021) China III Retrospective study	Total 12 patients Gender: 7 males, 5 females Age range (years old): 20-59	Inclusion criteria: -Primary traumatic TMJ ankylosis patients age > 18 years Exclusion criteria: -Cases that need distraction osteogenesis or costochondral graft -Uncooperative with post-op therapy / review -History of bone metabolism drug application, osteoporosis, osteoarthritis, autoimmune diseases chemoradiotherapy in oral and maxillofacial region -Re-ankylosis cases -General anaesthesia contraindications	Bone wax and porcine acellular dermal matrix in all 12 patients	Etiology: All 12 trauma cases New / recurrent cases: All 12 new cases Classification ankylosis: No info Duration ankylosis: No info	6 unilateral (all right sided) 6 bilateral joints Total 18 joints	Approach: Preauricular Additional procedures: No additional procedures done

Table 4.1 (Continued)

No.	Author (Year) Country Level of evidence Study design	Total patients Gender Age range (years old)	Inclusion criteria Exclusion criteria	Biomaterial used	Etiology New / recurrent cases Classification of ankylosis Duration of ankylosis	Ankylosis of joints	Approach Additional procedures
2	Agarwal et al. (2021) India III Retrospective study	Total 20 patients Gender: 8 males, 12 females Age range (years old): 3-35	Inclusion criteria: -Patients with TMJ ankylosis Exclusion criteria: -Patients with other causes of trismus (eg: subumucous fibrosis)	Silicone block in all 20 patients	Etiology: -15 post trauma -5 post infection otitis media New / recurrent cases: All 20 new cases Classification ankylosis: Sawhney: Type II: 2 joints Type III: 12 joints Type IV: 13 joints Duration ankylosis: No info	13 unilateral (6 left, 7 right) 7 bilateral joints Total 27 joints	Approach: Preauricular Additional procedures: -In unilateral TMJ ankylosis, ipsilateral coronoidectomy was done if inadequate mouth opening was achieved -For bilateral TMJ ankylosis, same procedure was repeated on contralateral side. No exact number of each procedure given

Table 4.1 (Continued)

No.	Author (Year) Country Level of evidence Study design	Total patients Gender Age range (years old)	Inclusion criteria Exclusion criteria	Biomaterial used	Etiology New / recurrent cases Classification of ankylosis Duration of ankylosis	Ankylosis of joints	Approach Additional procedures
3	Lin et al. (2019) China III Retrospective study	Total 32 patients Gender: -Temporalis myofascial flap (TMF): 3 males, 6 females -Original articular disc: 10 males, 11 females -2 patients: left side use TMF, right side use original disc Age range (years old): -Overall: 7-32 -TMF: 16-32 -Original articular disc: 7-25	Inclusion criteria: -Patients with Type III TMJ ankylosis Exclusion criteria: -Cases that involved other types of TMJ ankylosis or recurrence	Among 44 joints) -original disc: 33 joints -TMF: 11 joints 2 patients: left side TMF, right side original disc	Etiology: -TMF: 1 motor vehicle accident, 5 fall; 2 impact; 2 unknown; 1 violence -Original disc: 3 motor vehicle accident; 5 fall; 5 impact; 6 unknown; 4 violence New / recurrent cases: -TMF: 9 new, 1 recurrence (done open surgery), 1 unknown -Disc: 16 new, 5 recurrence (4 conservative management, 1 done open surgery), 2 details missing Classification ankylosis: Sawhney: All 32 patients Type III TMJ ankylosis Duration ankylosis: 2-12 years duration of ankylosis	20 unilateral (11 left, 9 right) 12 bilateral joints Total 44 joints	Approach: Preauricular Additional procedures: Ipsilateral coronoidectomy was done in 4 cases as maximal incisal opening after surgery <30 mm

Table 4.1 (Continued)

No.	Author (Year) Country Level of evidence Study design	Total patients Gender Age range (years old)	Inclusion criteria Exclusion criteria	Biomaterial used	Etiology New / recurrent cases Classification of ankylosis Duration of ankylosis	Ankylosis of joints	Approach Additional procedures
4	Malhotra et al. (2019) India III Retrospective study	Total 10 patients Gender: 5 males, 5 females Age range (years old): 7-16	Inclusion criteria: -Patients with Sawhney Type III TMJ ankylosis Exclusion criteria: -History of previous TMJ surgery	All 10 patients were treated with lateral arthroplasty and buccal fat pad interposition	Etiology: All 10 cases trauma: -9 fall from height -1 fall of heavy object (door) on face New / recurrent cases: All 10 new cases Classification ankylosis: Sawhney: all 10 patients Type III TMJ ankylosis Duration ankylosis: 2-10 years	7 unilateral (3 left, 4 right) 3 bilateral joints Total 13 joints	Approach: No info Additional procedures: -2 cases ipsilateral coronoidectomy -8 bilateral coronoidectomy

Table 4.1 (Continued)

No.	Author (Year) Country Level of evidence Study design	Total patients Gender Age range (years old)	Inclusion criteria Exclusion criteria	Biomaterial used	Etiology New / recurrent cases Classification of ankylosis Duration of ankylosis	Ankylosis of joints	Approach Additional procedures
5	Rajurkar et al. (2017) India III Retrospective study	Total 17 patients Gender: 6 males, 9 females Age range (years old): 5-30	Inclusion criteria: -Patients with unilateral TMJ ankylosis Exclusion criteria: -No info	Pedicled deep temporalis fascia flap based on middle temporal branch of superficial temporal artery in all 17 patients	Etiology: -15 trauma -1 premature delivery -1 ear infection New / recurrent cases: No info Classification ankylosis: No info Duration ankylosis: No info	All 17 unilateral: 9 left, 8 right 0 bilateral joint Total 17 joints	Approach: Preauricular Additional procedures: Recontouring of the glenoid fossa

Table 4.1 (Continued)

No.	Author (Year) Country Level of evidence Study design	Total patients Gender Age range (years old)	Inclusion criteria Exclusion criteria	Biomaterial used	Etiology New / recurrent cases Classification of ankylosis Duration of ankylosis	Ankylosis of joints	Approach Additional procedures
6	Maqsood et al. (2015) Pakistan II Prospective study	Total 50 patients Gender: 23 males, 27 females Age range (years old): 4-35	Inclusion criteria: -Patients with unilateral or bilateral TMJ ankylosis with MIO < 10 mm Exclusion criteria: -Patients with pseudoankylosis -Patients with fibrous ankylosis whose MIO improved after mouth stretching	Temporalis muscle flap in all 50 cases	Etiology: -46 trauma -3 chronic infection -1 TMJ dislocation New / recurrent cases: No info Classification ankylosis: No info Duration ankylosis: No info (mean 6.5 years)	42 unilateral joint (no info of left or right) 8 bilateral joints Total 58 joints	Approach: Preauricular Additional procedures: No additional surgical procedures

Table 4.1 (Continued)

No.	Author (Year) Country Level of evidence Study design	Total patients Gender Age range (years old)	Inclusion criteria Exclusion criteria	Biomaterial used	Etiology New / recurrent cases Classification of ankylosis Duration of ankylosis	Ankylosis of joints	Approach Additional procedures
7	Hegab (2015) Egypt II Prospective study	Total 14 patients Gender: 3 males, 11 females Age range (years old): 12-38	Inclusion criteria: -Patients with TMJ ankylosis that began in childhood Exclusion criteria: -Patients with systematic disease that might affect bone healing	Abdominal dermis fat graft in all 14 patients	Etiology: -12 trauma -2 fall New / recurrent cases: No info Classification ankylosis: Sawhney: (of 19 joints) Type II: 2 joints Type III: 9 joints Type IV: 8 joints Duration ankylosis: No info	9 unilateral joint (no info of left or right) 5 bilateral joints Total 19 joints	Approach: Preauricular Additional procedures: Ipsilateral intraoral coronoidectomy and (if required) contralateral coronoidectomy were performed no exact number given)

Table 4.1 (Continued)

No.	Author (Year) Country Level of evidence Study design	Total patients Gender Age range (years old)	Inclusion criteria Exclusion criteria	Biomaterials used	Etiology New / recurrent cases Classification of ankylosis Duration of ankylosis	Ankylosis of joints	Approach Additional procedures
8	Aggarwal et al. (2015) India II Prospective study	Total 10 patients Gender: 6 males, 4 females Age range (years old): 4-15	Inclusion criteria: -Severe trismus after traumatic injury Exclusion criteria: -No info	Ultrathin silicon sheet (0.2mm) in all 10 patients	Etiology: All 10 trauma cases New / recurrent cases: No info Classification ankylosis: No info Duration ankylosis: No info	10 unilateral (3 left, 7 right) 0 bilateral joints Total 10 joints	Approach: Preauricular Additional procedures: Recontoured glenoid fossa done, no further details described

Table 4.1 (Continued)

No.	Author (Year) Country Level of evidence Study design	Total patients Gender Age range (years old)	Inclusion criteria Exclusion criteria	Biomaterial used	Etiology New / recurrent cases Classification of ankylosis Duration of ankylosis	Ankylosis of joints	Approach Additional procedures
9	Singh et al. (2014) India III Retrospective study	Total 15 patients Gender: -Temporalis myofascial flap (TMF): 2 males, 2 females -Native disc: 7 males, 4 females Age range (years old) -Overall: 8-18 -TMF: 14-17 -Native disc: 8-18	Inclusion criteria: -Patients with Type III TMJ ankylosis Exclusion criteria: -History of previous TMJ surgery	-4 patients with TMF -11 patients with native articular disc	Etiology: All 15 cases trauma New / recurrent cases: All 15 new cases Classification ankylosis: Sawhney: 15 cases all in Type III ankylosis Duration ankylosis: No info	TMF: 1 left, 3 right Disc: 2 bilateral, 6 left, 3 right Total 17 joints	Approach: No info Additional procedures: -13 cases ipsilateral coronoidectomy, -2 bilateral coronoidectomy as mouth opening <35mm through intraoral approach

Table 4.1 (Continued)

No.	Author (Year) Country Level of evidence Study design	Total patients Gender Age range (years old)	Inclusion criteria Exclusion criteria	Biomaterial used	Etiology New / recurrent cases Classification of ankylosis Duration of ankylosis	Ankylosis of joints	Approach Additional procedures
10	Babu et al. (2013) India II Prospective study	Total 15 patients Gender: 10 males, 5 females Age range (years old): 7-29	Inclusion criteria: -Patients with TMJ ankylosis Exclusion criteria: -No info	Temporal fascia in all 15 patients	Etiology: -12 trauma -1 congenital -2 infection New / recurrent cases: No info Classification ankylosis: Sawhney: Type 2: 12 cases Type 3: 3 cases Duration ankylosis: No info	12 unilateral joint (no info of left or right) 3 bilateral joints Total 18 joints	Approach: Preauricular Additional procedures: -11 unilateral coronoidectomy -4 bilateral coronoidectomy

Table 4.1 (Continued)

No.	Author (Year) Country Level of evidence Study design	Total patients Gender Age range (years old)	Inclusion criteria Exclusion criteria	Biomaterial used	Etiology New / recurrent cases Classification of ankylosis Duration of ankylosis	Ankylosis of joints	Approach Additional procedures
11	Bulgannawar et al. (2011) India III Retrospective study	Total 8 patients Gender: 2 males, 6 females Age range (years old): 6-28	Inclusion criteria: -Patients with unilateral TMJ ankylosis Exclusion criteria: -No info	Temporalis fascia flap in all 8 patients	Etiology: -7 trauma -1 infection New / recurrent cases: No info Classification ankylosis: Other classification: Class 1, ankylotic bone at condylar process, articular fossa; Class 2, bone mass extend to fossa, medial aspect of skull base up to carotid, jugular vessels; Class 3, extend and penetrate into middle cranial fossa; Class 4, combination of Class 2 and 3 Overall: 6 cases Class 1; 2 cases Class 2 Duration ankylosis: No info	8 patients unilateral ankylosis (4 left, 4 right) 0 bilateral joints Total 8 joints	Approach: Preauricular Additional procedures: -2 had both temporalis fascia flap and coronoidectomy (6 only had interpositional arthroplasty with temporalis fascia flap)

Table 4.1 (Continued)

No.	Author (Year) Country Level of evidence Study design	Total patients Gender Age range (years old)	Inclusion criteria Exclusion criteria	Biomaterial used	Etiology New / recurrent cases Classification of ankylosis Duration of ankylosis	Ankylosis of joints	Approach Additional procedures
12	Kalra & Kakkar (2011) India III Retrospective study	Total 80 patients Gender: 59 males, 21 females Age range (years old): 5-45	Inclusion criteria: -Patients with TMJ ankylosis Exclusion criteria: -No info	Ultrathin silicone sheet in all 80 patients	Etiology: -43 fall -34 motor vehivle accident -3 condylar fracture New / recurrent cases: -68 new -12 recurrent Classification ankylosis: No info Duration ankylosis: No info	61 unilateral joint (no info of left or right) 19 bilateral joints Total 99 joints	Approach: Preauricular Additional procedures: -9 had costochondral graft post large ankylosed segment removal -4 had costocondral graft and coronoidectomy -67 had interpositional arthrpoplasty only with ultrathin silicone sheet

Table 4.1 (Continued)

No.	Author (Year) Country Level of evidence Study design	Total patients Gender Age range (years old)	Inclusion criteria Exclusion criteria	Biomaterial used	Etiology New / recurrent cases Classification of ankylosis Duration of ankylosis	Ankylosis of joints	Approach Additional procedures
13	Singh et al. (2011) India III Retrospective study	Total 10 patients Gender: 4 males, 6 females Age range (years old): 8-35	Inclusion criteria: -Patients with TMJ ankylosis Exclusion criteria: -No info	Buccal fat pad in all 10 cases	Etiology: -7 trauma -3 infection New / recurrent cases: All 10 new cases Classification ankylosis: No info Duration ankylosis: 2-15 years	9 unilateral cases (left 6, 3 right) 1 bilateral joints Total 11 joints	Approach: Preauricular Additional procedures: -Glenoid fossa was recontoured as necessary -6 had ipsilateral coronoidectomy -4 bilateral coronoidectomy

Table 4.1 (Continued)

No.	Author (Year) Country Level of evidence Study design	Total patients Gender Age range (years old)	Inclusion criteria Exclusion criteria	Biomaterial used	Etiology New / recurrent cases Classification of ankylosis Duration of ankylosis	Ankylosis of joints	Approach Additional procedures
14	Thangavelu et al. (2011) India III Retrospective study	Total 7 patients Gender: 3 males, 4 females Age range (years old): 14-39	Inclusion criteria: -Patients with TMJ ankylosis Exclusion criteria: -No info	Full thickness skin-subcutaneous fat grafts harvested from lower abdomen used in all 7 patients	Etiology: -6 trauma -1 forcep delivery New / recurrent cases: -3 new -4 recurrent Classification ankylosis: Topazian: Grade 1: 2 Grade 2: 4 Grade 3: 1 Duration ankylosis: No info	6 unilateral (all 6 left) 1 bilateral joint Total 8 joints	Approach: -6 preauricular approach -1 submandibular approach Additional procedures: All 7 had ipsilateral coronoidectomy

Table 4.1 (Continued)

No.	Author (Year) Country Level of evidence Study design	Total patients Gender Age range (years old)	Inclusion criteria Exclusion criteria	Biomaterial used	Etiology New / recurrent cases Classification of ankylosis Duration of ankylosis	Ankylosis of joints	Approach Additional procedures
15	Guruprasad et al. (2010) India III Retrospective study	Total 9 patients Gender: 7 males, 2 females Age range (years old): 21-32	Inclusion criteria: -Patients with unilateral TMJ ankylosis Exclusion criteria: -No info	Temporalis muscle and fascia flap in all 9 patients	Etiology: -7 trauma -2 infection New / recurrent cases: No info Classification ankylosis: No info Duration ankylosis: No info	No info	Approach: All 9 preauricular approach (2 had intraoral approach for contralateral coronoidectomy) Additional procedures: -7 had ipsilateral coronoidectomy -2 had bilateral coronoidectomy

Table 4.1 (Continued)

No.	Author (Year) Country Level of evidence Study design	Total patients Gender Age range (years old)	Inclusion criteria Exclusion criteria	Biomaterial used	Etiology New / recurrent cases Classification of ankylosis Duration of ankylosis	Ankylosis of joints	Approach Additional procedures
16	Bayat et al. (2009) Iran III Retrospective study	Total 33 patients Gender: 21 males, 12 females Age range (years old): 3-47	Inclusion criteria: -Patients with TMJ ankylosis Exclusion criteria: -No info	Temporalis muscle flap in all 34 patients	Etiology: -30 trauma -1 osteochondroma condyle -2 ear infection New / recurrent cases: No info Classification ankylosis: Other classification: All 34 patients had bony TMJ ankylosis Duration ankylosis: 8-240 months	10 bilateral Left 12 Right 11 Total 43 joints	Approach: Preauricular (Contralateral coronoidectomy from intraoral) Additional procedures: -8 had unilateral coronoidectomy -16 had bilateral coronoidectomy -9 had no coronoidectomy performed

Table 4.1 (Continued)

No.	Author (Year) Country Level of evidence Study design	Total patients Gender Age range (years old)	Inclusion criteria Exclusion criteria	Biomaterial used	Etiology New / recurrent cases Classification of ankylosis Duration of ankylosis	Ankylosis of joints	Approach Additional procedures
17	Danda et al. (2009) India II Prospective study	Among 16 patients, 8 patients had interpositional arthroplasty done Gender: 5 males, 3 females Age range (years old): 5-21	Inclusion criteria: -Patients with TMJ ankylosis Exclusion criteria: -No info	Group I: gap arthroplasty alone Group II: gap arthroplasty and interpositional arthroplasty with temporalis myofascial flap: 8 patients	Etiology: -13 trauma -2 infection -1 unknown New / recurrent cases: No info Classification ankylosis: Other classification: -Group II: all bony ankylosis Duration ankylosis: No info	Group II interpositional arthroplasty group: 7 unilateral 1 bilateral ankylosis Total 9 joints	Approach: Preauricular Additional procedures: No additional procedures done

Table 4.1 (Continued)

No.	Author (Year) Country Level of evidence Study design	Total patients Gender Age range (years old)	Inclusion criteria Exclusion criteria	Biomaterial used	Etiology New / recurrent cases Classification of ankylosis Duration of ankylosis	Ankylosis of joints	Approach Additional procedures
18	Huang et al. (2007) Taiwan III Retrospective study	Total 10 patients Gender: 6 males, 4 females Age range (years old): 18-56	Inclusion criteria: -Adult patients with TMJ ankylosis Exclusion criteria: -No info	Autogenous costal cartilage grafts in all 11 patients	Etiology: -8 motor vehicle accidents -2 falls New / recurrent cases: -9 new -1 recurrent Classification ankylosis: Other classification: -No info Duration ankylosis: 1-21 years	9 unilateral cases (left 7, 2 right) 1 bilateral joints Total 11 joints	Approach: -1 joint preauricular -10 joints intraoral approach Additional procedures: -10 ipsilateral coronoidectomy (No case with contralateral coronoidcetomy done)

Table 4.1 (Continued)

No.	Author (Year) Country Level of evidence Study design	Total patients Gender Age range (years old)	Inclusion criteria Exclusion criteria	Biomaterial used	Etiology New / recurrent cases Classification of ankylosis Duration of ankylosis	Ankylosis of joints	Approach Additional procedures
19	Qudah et al. (2005) Jordan III Retrospective study	Among 22 patients, 8 patients had interpositional arthroplasty done Gender: 6 males, 2 females Age range (years old): 8-11	Inclusion criteria: -Children with TMJ ankylosis treated in a dental teaching centre between 1993 and 2001 Exclusion criteria: -No info	Temporalis muscle interpositional arthroplasty in 8 joints (Others: Costochondral graft reconstruction in 16 joints)	Etiology: -2 falls -5 motor vehicle accidents -1 horse kick New / recurrent cases: No info Classification ankylosis: Sawhney: Type 3: 8 patients (8 joints) – the IA group Duration ankylosis: No info	3 left, 5 right Total 8 joints	Approach: Preauricular Additional procedures: 2 had coronoidectomy done (6 had no coronoidectomy)

Table 4.1 (Continued)

No.	Author (Year) Country Level of evidence Study design	Total patients Gender Age range (years old)	Inclusion criteria Exclusion criteria	Biomaterial used	Etiology New / recurrent cases Classification of ankylosis Duration of ankylosis	Ankylosis of joints	Approach Additional procedures
20	Dimitroulis (2004) Australia III Retrospective study	Among 11 patients, 9 patients had interpositional arthroplasty alone Gender: 9 females Age range (years old): 18-55	Inclusion criteria: -Patients with true osseous or fibro-osseous TMJ ankylosis directly involving the intracapsular structures of the TMJ Exclusion criteria: -Patients with fibrous TMJ ankylosis	Autogenous dermis-fat graft from groin n all 11 patients (2 B/L ankylosis patients with costochondral graft too)	Etiology: -6 iatrogenic -1 assault -2 motor vehicle accidents New / recurrent cases: No info Classification ankylosis: Other classification: Among 11 patients: -4 patients osseous ankylosis -5 patients fibro-osseous ankylosis Duration ankylosis: No info	6 left, 3 right Total 9 joints	Approach: Preauricular Additional procedures: -2 had ipsilateral coronoidectomy

Table 4.1 (Continued)

No.	Author (Year) Country Level of evidence Study design	Total patients Gender Age range (years old)	Inclusion criteria Exclusion criteria	Biomaterial used	Etiology New / recurrent cases Classification of ankylosis Duration of ankylosis	Ankylosis of joints	Approach Additional procedures
21	Balaji (2003) India III Retrospective study	Among 31 patients, 22 patients had interpositional arthroplasty done (1 arthritis patient excluded, hence remaining 21 patients) Gender: 15 males, 6 females Age range (years old): 19-37	Inclusion criteria: -Patients with TMJ re-ankylosis cases that previously operated with gap arthroplasty technique Exclusion criteria: -No info	Temporalis muscle in all 21 patients	Etiology: -13 trauma -1 idiopathic -5 infection -1 at birth -1 surgery New / recurrent cases: All recurrent / reankylosis Classification ankylosis: No info Duration ankylosis: No info	15 unilateral (8 left, 7 right) 6 bilateral joints Total 27 joints	Approach: Preauricular Additional procedures: -20 had uni- and contralateral coronoidectomy -11 had unilateral coronoidectomy

Table 4.1 (Continued)

No.	Author (Year) Country Level of evidence Study design	Total patients Gender Age range (years old)	Inclusion criteria Exclusion criteria	Biomaterial used	Etiology New / recurrent cases Classification of ankylosis Duration of ankylosis	Ankylosis of joints	Approach Additional procedures
22	Manganello-Souza & Mariani (2003) Brazil III Retrospective study	Among 14 patients, 5 patients had interpositional arthroplasty Gender: 3 males, 2 females Age range (years old): 17-65	Inclusion criteria: -Patients with TMJ ankylosis cases treated between March 1992 and February 1997 Exclusion criteria: -No info	Silicone sheet in 5 patients (Others: Costochondral graft + temporalis muscle flap: 5 patients -coctochondral graft + silicone sheet: 4 patients)	Etiology: -3 fracture / motor vehicle accident -1 infection -1 unknown New / recurrent cases: -1 new -4 recurrent Classification ankylosis: No info Duration ankylosis: 5-20 years	3 left, 2 right Total 5 joints	Approach: Preauricular Additional procedures: No info

Table 4.1 (Continued)

No.	Author (Year) Country Level of evidence Study design	Total patients Gender Age range (years old)	Inclusion criteria Exclusion criteria	Biomaterial used	Etiology New / recurrent cases Classification of ankylosis Duration of ankylosis	Ankylosis of joints	Approach Additional procedures
23	Erdem & Alkan (2001) Turkey III Retrospective study	Total 46 patients Gender: 21 males, 25 females Age range (years old): 7-48	Inclusion criteria: -Patients with osseous or fibro-osseous temporomandibular joint ankylosis cases treated between 1981 and 1998 Exclusion criteria: -No info	Acrylic marbles in all 46 cases	Etiology: -40 trauma -5 infection -1 unknwon New / recurrent cases: -43 new -3 recurrent Classification ankylosis: Other classification: -fibro-osseous ankylosis 9 patients -no info of other cases Duration ankylosis: No info	4 bilateral 42 unilateral Total 50 joints	Approach: Preauricular Additional procedures: No info

Table 4.1 (Continued)

No.	Author (Year) Country Level of evidence Study design	Total patients Gender Age range (years old)	Inclusion criteria Exclusion criteria	Biomaterial used	Etiology New / recurrent cases Classification of ankylosis Duration of ankylosis	Ankylosis of joints	Approach Additional procedures
24	Su-Gwan (2001) Korea III Retrospective study	Total 7 patients Gender: 4 males, 3 females Age range (years old): 21-47	Inclusion criteria: -Adult patients with unilateral TMJ ankylosis Exclusion criteria: -No info	Temporalis muscle and fascia flap in all 7 cases	Etiology: -6 trauma -1 infection New / recurrent cases: No info Classification ankylosis: No info Duration ankylosis: No info	All 7 unilateral 0 bilateral joints Total 7 joints	Approach: Preauricular Additional procedures: -7 patients coronoidectomy (with 2 patients among the 7 patients have bilateral coronoidectomy)

Table 4.1 (Continued)

No.	Author (Year) Country Level of evidence Study design	Total patients Gender Age range (years old)	Inclusion criteria Exclusion criteria	Biomaterial used	Etiology New / recurrent cases Classification of ankylosis Duration of ankylosis	Ankylosis of joints	Approach Additional procedures
25	Chossegros et al. (1999) France III Retrospective study	Among 31 patients, 20 patients recruited as only 20 patients had follow up > 6 months Gender: 11 males, 9 females Age range (years old): 2-50	Inclusion criteria: -Patients with TMJ ankylosis treated between year 1970 and 1994 Exclusion criteria: -No info	Full thickness skin graft autograft in all 31 patients	Etiology: -12 trauma -5 infection -3 unknown New / recurrent cases: All 20 new cases Classification ankylosis: Topazian classification: Complete ankylosis: -Grade 1: 8 joints -Grade 2: 10 joints Incomplete ankylosis: -post traumatic lateral bony ankylosis: 6 joints -fibrous ankylosis: 1 joint Duration ankylosis: 0-2 years	15 unilateral (left 6, right 9) 5 bilateral joints Total 25 joints	Approach: Preauricular Additional procedures: No additional procedures done

Table 4.1 (Continued)

No.	Author (Year) Country Level of evidence Study design	Total patients Gender Age range (years old)	Inclusion criteria Exclusion criteria	Biomaterial used	Etiology New / recurrent cases Classification of ankylosis Duration of ankylosis	Ankylosis of joints	Approach Additional procedures
26	Chossegros et al. (1997) France III Retrospective study	Total 22 patients Gender: 8 males (M), 14 females (F) (Skin: 5M, 7F; Temporalis: 2M, 3F; Cartilage: 1M, 1F; Fascia lata: 1F; Prosthesis: 2F) Age range (years old): 2-60 (Skin: 2-38; Temporalis: 14-60; Cartilage: 22-25; Fascia lata: 50; Prosthesis: 24-38)	Inclusion criteria: -Patients with TMJ ankylosis Exclusion criteria: -No info	-12 retroauricular skin graft -5 temporalis muscle fascia flap -2 human costal cartilage -1 autologous fascia lata -2 prosthesis	Etiology: -1 tumour -16 fracture -5 infection New / recurrent cases: No info Classification ankylosis: Topazian classification Duration ankylosis: 0-23 years (among 22 patients, 21 patients have 0-23 years of ankylosis duration; 1 tumour case had unknown age of onset of incident)	15 unilateral joints (no info of left or right) 7 bilateral joints Total 29 joints	Approach: Preauricular Additional procedures: -2 interpositional arthroplasty (with skin and temporalis each) and coronoidectomy (no info of ipsi- or contralateral coronoidectomy) 2 interpositional arthroplasty (both with temporalis) and disc repositioning

4.2.2 Randomised controlled studies.

Younis et al. (2021)

In this study, the authors recruited 30 patients with TMJ ankylosis (bony or fibrous) and randomised them into 2 groups i.e abdominal dermis fat graft (Group A) and temporalis muscle and fascia (Group B). Patients who were medically compromised, had history of previous TMJ surgery and not willing to participate in the study were excluded. Equal number of patients were allocated in each group. Group A comprised of 10 male and 5 female while Group B had 9 male and 6 female patients. Three patients were in their first decade of life in both groups, 9 patients from Group A and 10 patients from Group B were in their second decade while the remaining were in their third decade of life. Among the patients in Group A, 6 were unilateral and 9 were bilateral cases. On the other hand, Group B had 7 unilateral TMJ ankylosis and 8 bilaterally ankylosed TMJ. Ankylosis in most of the patients (27 patients) were attributed to trauma, 1 was due to otitis media and 2 others were of unknown causes. In term of severity of the joint ankylosis, Group A had 3 joints of Sawhney Type I, 8 joints of Type II, 9 joints of Type III and 4 joints with Type IV ankylosis. In Group B, 2 joints were Type I ankylosis, 7 joints were Type II, 11 joints were Type III and 3 joints were Type IV ankylosis. No additional procedures were performed during the surgery.

Roychoudhury et al. (2020)

This study enrolled 36 patients who were randomised into 2 different groups based on the biomaterials used for interpositional arthroplasty. Patients with TMJ ankylosis were included while those with metabolic fat disorders, other fat degeneration disorders, local abdominal or buccal mucosa pathology were excluded. The first group (Group A) was allocated to pedicled buccal fat pad while the second group (Group B) was allocated to

abdominal fat. There were equal number of patients in each group. Mean (±SD) age for patients in Group A was 12.6 (±8.5) years old while those in Group B was 14.3 (±8.2) years old. Causes of ankylosis in 20 patients were associated with trauma while 15 others were due to infection and 1 was of unknown cause. There were 15 new cases and 3 recurrent cases in Group A while in Group B, 11 were new cases and 7 were recurrent cases. Mean duration of ankylosis in Group A and B were 5.3 years and 5.2 years respectively. Pedicled buccal fat pad was used in 12 unilateral and 6 bilateral TMJ ankylosis cases. Meanwhile, equal number of unilateral and bilateral cases were recorded in abdominal fat group. During the surgery, ipsilateral coronoidectomy and stripping of temporalis tendon were performed when passive mouth opening was less than 25mm to 30mm. Contralateral coronoidectomy was only performed if maximum mouth opening was still less than 30mm despite ipsilateral coronoidectomy.

Andrade et al. (2020)

Andrade et al. (2020) recruited 22 patients in their study, however, 2 were excluded after they failed to attend follow up. These patients were assigned to a group of interpositional arthroplasty with autogenous dermis fat from subumbilical region and another group of only gap arthroplasty. There were equal number patients in both groups. Patients with TMJ ankylosis were included regardless of its type and sites. Patients with trismus not due to ankylosis or obstructive sleep apnea with severe micrognathia were excluded. It was only reported that patients in interpositional arthroplasty group had a mean ankylosis duration of 12.3 years. No additional procedures were performed during the surgeries.

Siddiqi et al. (2013)

In this randomised study, 30 patients were recruited to study the outcome of two different types of interpositional arthroplasty materials i.e silastic (Group A) and heat-cured acrylic (Group B). Equal number of patients were allocated to each group. This study included only patients with unilateral TMJ ankylosis. Patients, who had bilateral TMJ ankylosis, had TMJ operated before, required coronoidectomy during the surgery, were less than 16 years old and medically compromised, were excluded. Within this group of patients, ankylosis in 29 patients were attributed to trauma (motor-vehicle accident, fall and fight) and 1 were a complication of infection.

Mehrotra et al. (2008)

Mehrotra and his colleagues divided their study participants which consisted of 17 patients into 2 groups. Dermis fat graft group (Group A) were assigned 8 patients and temporalis muscle and fascia group were assigned 9 patients. Group A had 4 patients in age 0-5 years old, followed by 3 patients in 6-10 years old, and 1 patient in 11-15 years old. Meanwhile for group B, there were 4 patients each in age range group of 0-5 years old and 6-10 years old, and 1 patient in age range of 16-20 years old. Regarding aetiologies of TMJ ankylosis, group A had 1 recurrent and 7 new cases in which trauma had 4 cases (highest number), followed by unknown / idiopathic causes in 3 cases and 1 case post ear infection. Group B had 1 recurrent and 8 new cases, in which trauma also recorded highest number of 7 cases, followed by 1 case each due to birth trauma and ear infection. Patients had duration of ankylosis of 2-11 years prior further surgical intervention. No additional surgical procedures were performed intra-operatively.

Table 4.2: Characteristics of included RCT studies

No.	Author (Year) Country Level of evidence Study design	Total patients Gender Age range (years old)	Inclusion criteria Exclusion criteria	Biomaterial used	Etiology New / recurrent cases Classification of ankylosis Duration of ankylosis	Ankylosis of joints	Approach Additional procedures
1	Younis et al. (2021) India I RCT	Total 30 patients Gender: Group A: 10 males (66.7%), 5 females (33.3.%) Group B: 9 males (60%), 6 females (40%) Age range (years old): Group A: 1-10: 3 patients (20%) 11-20: 9 patients (60%) 21-30: 3 patients (20%) Group B: 1-10: 3 patients (20%) 11-20: 10 patients (67%), 21-30: 2 patients (13%)	Inclusion criteria: Patients with TMJ ankylosis (bony or fibrous, unilateral or bilateral) Exclusion criteria: Medically compromised patients, patients with history of previous TMJ surgeries and those not willing to participate in the study	BOTH GROUPS WERE AUTOGRAFT: -Group A: abdominal dermis fat graft: 15 patients -Group B: temporalis fascia and muscle: 15 patients	Etiology: -27 trauma (90%) -1 otitis media (3.3%) -2 unknown (6.7%) New / recurrent cases: All 30 new cases Classification ankylosis: Sawhney's classification Group A: Type I: 3 (12.5%) Type II: 8 (33.3%) Type III: 9 (37.5%) Type IV: 4 (16.7%) Group B: Type I: 2 (8.7%) Type II: 7 (30.4%) Type III: 11 (47.8%) Type IV: 3 (13.1%) Duration ankylosis: No info	Group A: Unilateral: 6 cases (40%) Bilateral: 9 cases (60%) Group B: Unilateral: 7 cases (46.7%) Bilateral: 8 cases (53.3%)	Approach: Preauricular Additional procedures: No additional procedures done

Table 4.2 (Continued)

No.	Author (Year) Country Level of evidence Study design	Total patients Gender Age range (years old)	Inclusion criteria Exclusion criteria	Biomaterial used	Etiology New / recurrent cases Classification of ankylosis Duration of ankylosis	Ankylosis of joints	Approach Additional procedures
2	Roychoudhury et al. (2020) India I RCT	Total 36 patients Gender: 15 males, 21 females Group A: 6 males (33.3%), 12 females (66.6%) Group B: 9 males (50%), 9 females (50%) Age range (years old): No info AGE: (mean $\pm$ SD) Group A: 12.6 $\pm$ 8.5 Group B: 14.3 $\pm$ 8.2	Inclusion criteria: Patients with TMJ ankylosis (irrespective of age, gender, or history of failed arthroplasty) Exclusion criteria: Patients with metabolic fat disorders or other fat degeneration disorders or with local abdominal or buccal mucosa pathology	BOTH GROUPS WERE AUTOGRAFT -Group A: pedicled buccal fat pad, 18 patients -Group B: abdominal fat, 18 patients	Etiology: -20 (55.56%) post trauma -15 (41.7%) post infection -1 (2.7%) unknown New / recurrent cases: Group A: 15 new, 3 recurrent Group B: 11 new, 7 recurrent Classification ankylosis: No info Duration ankylosis: (Mean) Group A: 5.3 years Group B: 5.2 years	Group A: (18 patients) Unilateral - 12 patients (66.6%) Bilateral - 6 patients (33.3%) Group B: 18 patients) Unilateral - 9 patients (50%) Bilateral - 9 patients (50%)	Approach: Preauricular Additional procedures: -Ipsilateral coronoidectomy and stripping of temporalis tendon when passive mouth opening was <25-30mm -If ipsilateral coronoidectomy did not achieve 30mm mouth opening, contralateral coronoidectomy was performed via intraoral route

Table 4.2 (Continued)

No.	Author (Year) Country Level of evidence Study design	Total patients Gender Age range (years old)	Inclusion criteria Exclusion criteria	Biomaterial used	Etiology New / recurrent cases Classification of ankylosis Duration of ankylosis	Ankylosis of joints	Approach Additional procedures
3	Andrade et al. (2020) India I RCT	Among 22 patients, 20 were recruited (2 were excluded as failed to attend follow up Gender: 14 males, 6 females Age range (years old): AGE: (mean ± SD) Group A: 24.90 ± 12.55	Inclusion criteria: Patients with unilateral or bilateral ankylosis, new or reankylosis, and osseous or fibro-osseous ankylosis Exclusion criteria: Patients with reported trismus from other than ankylosis of the TMJ, fibrous ankylosis, or obstructive sleep apnoea with severe micrognathia (without correction)	-Group A is autograft (dermis fat harvested from subumblical region) – 10 patients -Group B is plain gap arthroplasty without any interpositional arthroplasty materials	Etiology: No details info New / recurrent cases: Combination new or re-ankylosis case Classification ankylosis: Sawhney's classification Duration ankylosis: (Mean) Group A: 12.3 years	No info	Approach: Preauricular Additional procedures: No additional procedures done

Table 4.2 (Continued)

No.	Author (Year) Country Level of evidence Study design	Total patients Gender Age range (years old)	Inclusion criteria Exclusion criteria	Biomaterial used	Etiology New / recurrent cases Classification of ankylosis Duration of ankylosis	Ankylosis of joints	Approach Additional procedures
4	Siddiqi et al. (2013) Pakistan I RCT	Total 30 patients Gender: -Group A: (Silastic group) (total 15 patients) 8 males (53.5%) 7 females (46.7%) -Group B: (Heat cured acrylic group) (total 15 patients) 9 males (60%) 6 females (40%) Age range (years old): The predominant age in this study was third decade of life	Inclusion criteria: Patients with unilateral TMJ ankylosis Exclusion criteria: Patients having bilateral TMJ ankylosis, age less than 16 years, coronoidectomy required during procedure, already operated cases and medically compromised patients	BOTH GROUPS WERE ALLOPLASTIC BIOMATERIALS: -Group A: silastic group – 15 patients -Group B: heat-cured acrylic – 15 patients	Etiology: -16 (54%) trauma (motor vehicle accidents) -12 (40%) trauma (fall, eg: during kite flying) -1 (3%) trauma (fight) -1 (3%) infection New / recurrent casese: All 30 new cases Classification ankylosis: No info Duration ankylosis: No info	Only unilateral TMJ ankylosis included in this study Among the 30 patients: -20 (66.7%) right sided ankylosis -10 (33.3%) left sided ankylosis	Approach: Preauricular Additional procedures: No additional procedures done done

Table 4.2 (Continued)

No.	Author (Year) Country Level of evidence Study design	Total patients Gender Age range (years old)	Inclusion criteria Exclusion criteria	Biomaterial used	Etiology New / recurrent cases Classification of ankylosis Duration of ankylosis	Ankylosis of joints	Approach Additional procedures
5	Mehrotra et al. (2008) India I RCT	Total 17 patients Gender: 8 males, 9 females Group A: 5 males, 3 females Group B: 3 males, 6 females Age range (years old): Group A: 0-5: 4 patients 6-10: 3 patients 11-15: 1 patient 16-20: 0 patient Group B: 0-5: 4 patients 6-10: 4 patients 11-15: 0 patient 16-20: 1 patient	Inclusion criteria: Patients with TMJ ankylosis who visited the Outpatient Department of Oral & Maxillofacial Surgery, CSM Medical University (formerly King George's Medical College), Luc- know between the period from 2002–2004 Exclusion criteria: No info	BOTH GROUPS ARE AUTOGRAFT -Group A: dermis fat graft interposition , 8 patients - 10 joints -Group B: temporalis fascia and muscle interposition, 9 patients - 10 joints	Etiology: -Group A: 0 birth trauma; 1 ear infection; 4 trauma; 3 unknown -Group B: 1 birth trauma; 1 ear infection; 7 trauma; 0 unknown New / recurrent cases: Group A: -7 new, 1 recurrent Group B: -8 new, 1 recurrent Classification ankylosis: No info Duration ankylosis: BOTH GROUPS: 2-11 years	No info	Approach: Preauricular Additional procedures: No additional procedures

4.3 Risk of bias of included studies

The risk of bias of non-RCT studies included in this review was analyzed using ROBINS-I tool. Among 26 papers included, 5 papers were categorized as high / serious risk of bias group, meanwhile the remaining 21 papers were in the group of moderate / unclear risk of bias. None of the studies were of low risk of bias (Figure 4.2).

The risk of bias of each RCT paper included in this review was analyzed using Rob-2 tool. Among 5 papers included, 3 papers were in low risk of bias group, 1 paper were of some concerns of bias and 1 paper was categorized as high risk of bias group (Figure 4.3).

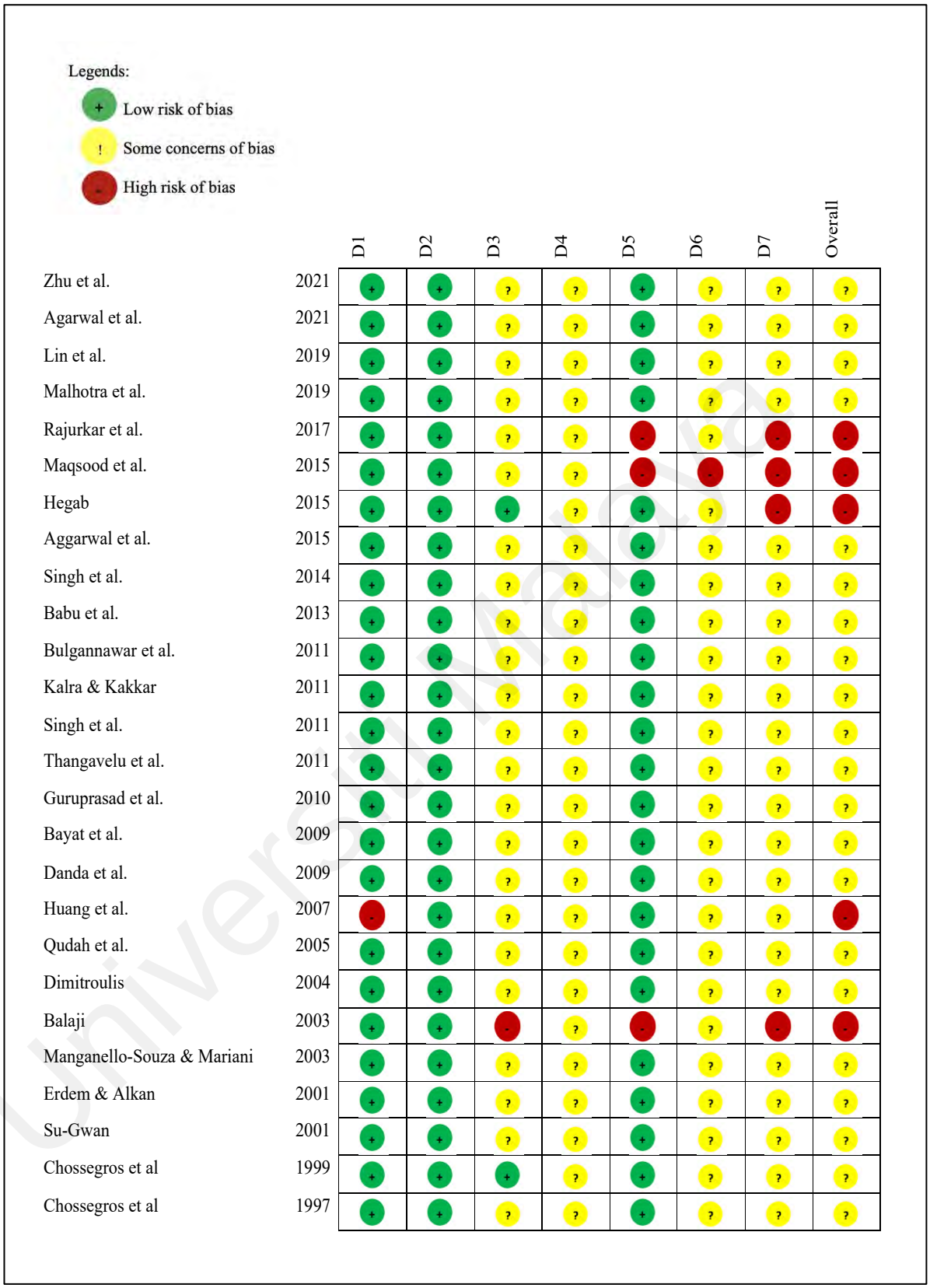


Figure 4.2: Risk of bias of non-RCT studies

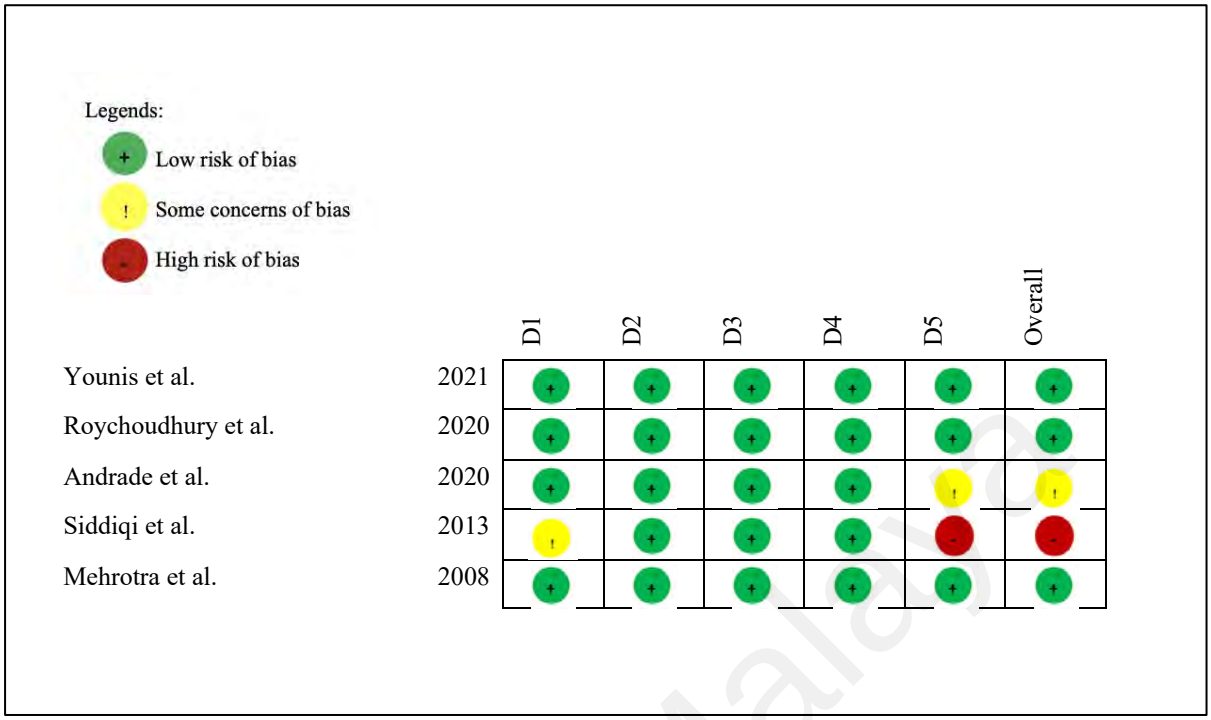


Figure 4.3: Risk of bias of RCT studies

4.4 Results of individual studies

4.4.1 Non-randomised controlled studies

Temporalis fascia / Temporalis muscle / Temporalis myofascial flap

Although Lin et al. (2019) took cone beam computed tomogram (CBCT) pre- and post-operatively, no details were provided on the pre-operative imaging. Post-operative CBCT showed that medially bent condyles and glenoid fossae formed new and functional joints. Maximum incisal opening increased from 9.67 ± 2.50mm to 35.22 ± 2.64mm following the use of temporalis myofascial flap in their patients. No details on lateral excursion, protrusion and pain score were provided. Jaw physiotherapy was initiated post-operatively but no details were reported. The mean follow-up period was 3 years. Within this period, there was 1 case of recurrence due to non-compliance to physiotherapy.

Prior to interpositional arthroplasty of TMJ ankylotic joints with temporalis fascia flap, Rajurkar et al. (2017) requested for orthopantomogram (OPG) and CT scan for radiological investigation and base line record for post-surgery comparison. Even though only OPGs were taken post-operatively, they showed that the intra-articular spaces were well maintained with most of the cases showed no signs of re-ankylosis. The maximum incisal opening gained from pre-op 4.00 ± 2.24mm to post-op 36.47 ± 5.35mm. Information on post-operative lateral excursion, protrusion range achieved and post-op and pain score among patients were not reported. Patients were taught on jaw exercise but no details on the device used and compliance level among patients were stated. The duration of follow up of patients was 1 to 6 years. For post-surgery complications, there was 1 confirmed case of re-ankylosis and all patients showed deviation to affected sides.

In this prospective study, Masqood et al. (2015) had OPG as pre-surgery radiological investigation prior interpositional arthroplasty with temporalis muscle flap. However, they did not elaborate further about the pre-operative imaging findings and types of post-op radiological imaging and findings in the paper. Pre-op maximum incisal opening recorded was 2.60 ± 1.40mm; and post-op maximal incisal opening was 31.26 ± 2.03mm. Other aspects not reported by authors were range of mandibular lateral excursion and protrusion and patients' pain score post-surgery. Mean follow-up of all patients was 1.5 years. During the review session, jaw physiotherapy was taught and patients were encouraged to use wooden spatulas during jaw exercise. Following surgery, there were 4 cases of temporary facial nerve palsy and 2 cases with anterior open bite.

In their temporalis myofascial flap group, Singh et al. (2014) reported improvement of mouth opening from 15.25 ± 0.96mm to 36.50 ± 3.11mm. This group was given mouth prop and spoon spatula as an aid for jaw physiotherapy. These patients were followed up between 1 to 4 years. In this study, ear infection occurred in 2 of the patients a week after surgery.

Babu et al. (2013) used temporalis fascia for interpositional arthroplasty in their patients. Following the surgery, their patients showed an increase of mean (± SD) maximum mouth opening from 3.87 ± 2.55mm to 34.20 ± 3.17mm. No details on lateral excursion, protrusion and pain score were stated. Wooden spatulas were used for jaw physiotherapy. Mean follow up duration was 3 years. No complications were reported during that period.

In their retrospective study, Bulgannawar et al. (2011) reported an increase of mean (± SD) maximum mouth opening from pre-operative 2.75 ± 2.44mm to post-operative 36.50 ± 2.18mm by using temporalis fascia for interpositional arthroplasty. Post-operative OPGs showed intra-articular space was well-maintained by the interposed biomaterial without sign of re-ankylosis. Although jaw physiotherapy was started after the surgery, no details in the physiotherapy were provided. All the 8 patients were followed up for 11 months to 6 years. Throughout this duration, it was reported that all the patients showed deviation to the affected side.

Bayat et al. (2009) reported the use of temporalis muscle flap in 33 patients following interpositional arthroplasty. The mean (±SD) maximum mouth opening of their patients was increased from 4.85 ± 3.46mm pre-operatively to 32.76 ± 5.56mm post-operatively. Therabite devices were used to assist in jaw physiotherapy. All patients were followed up for a duration of 6 to 44 months. During this time, 2 patients had re-ankylosis, 1 had surgical site infection and 12 facial nerve palsy of which 9 were temporary and 3 were permanent. Some of the 23 patients with unilateral TMJ ankylosis had jaw deviation to the affected side.

Study by Danda et al. (2009) reported that in patients that used temporalis myofascial flap, their mean (±SD) maximum mouth opening were increased from 3.50 ± 1.41mm to 31.44 ± 10.76mm. Although they also prescribed jaw physiotherapy, but no details were stated. Mean follow-up period in this study was 20.3 months. During the follow-up on

patients with temporalis myofascial flap, 1 had re-ankylosis, 2 had temporary facial nerve weakness and 1 had pre-auricular infection.

In their retrospective study, Qudah et al. (2005) utilized temporalis muscle for interpositional arthroplasty. Mean (±SD) maximum mouth opening prior to surgery was 6.63 ± 1.90mm and increased post-operatively to 31.00 ± 2.88mm. Jaw physiotherapy was performed using wooden spatulas. Patients were followed up for 10 to 42 months and 1 patient had re-ankylosis during this period.

Balaji (2003) reported that mean (±SD) maximum mouth opening could increase from 1.00 ± 1.52mm to 35.56 ± 2.34mm by performing interpositional arthroplasty with temporalis muscle flap. Post-operative CT scans showed no sign of fibrosis or re-ankylosis. During the follow-up period (mean = 6 years), 2 patients had wound infection, 1 had transient pre-auricular paraesthesia and 1 had Frey syndrome. All his patients were compliant with post-operative jaw physiotherapy.

Su-Gwan (2001) reported increment of mean (±SD) maximum mouth opening from pre-operative 15.00 ± 3.66mm to 36.10 ± 1.81mm following interpositional arthroplasty with temporalis muscle and fascia. Post-operative CT scans of 4 patients showed increased interarticular space with no signs of re-ankylosis while another 3 cases were undetermined. Mean VAS score was reduced from 5.3 pre-operatively to 1.9 post-operatively. Jaw physiotherapy was performed using stacked tongue depressors and bilateral rachet mouth props. All the patients were followed up for a duration of 13 to 30 months. No complications were recorded in this study.

In their retrospective study comparing multiple biomaterials, Chossegros et al. (1997) reported improvement of mouth opening from pre-operative 16.20 ± 8.50mm to post-operative 33.20 ± 4.32mm. Follow-up period in this study was between 3 years to 10 years. Although patients were taught on jaw physiotherapy but details of the device and compliance were not mentioned.

Abdominal fat and groin fat

In their prospective study, Hegab (2015) used abdominal dermis fat grafts for interpositional arthroplasty. Author mentioned of pre-op radiological investigation with OPG and CBCT but did not explain further on the imaging findings and types of post-op imaging. Pre-operative maximum incisal opening recorded as 2.07 ± 0.92mm; and post-op maximal incisal opening achieved was 43.50 ± 5.92mm. There were no details of post-op mandibular lateral excursion and protrusion achieved, as well as patients' pain score post-surgery. Patients were reviewed for 24 to 48 months, and throughout the follow-up sessions patients were encouraged to use wooden spatula during jaw physiotherapy. Throughout the follow-up, 9 unilateral TMJ ankylosis cases showed mandibular deviation to affected side at maximum mouth opening; some patients developed open bite but no specific numbers were stated; 2 patients had facial asymmetry; and 3 cases with bilateral TMJ ankylosis had temporary facial nerve paresis post-surgery.

Thangavelu et al. (2011) harvested full thickness skin-subcutaneous fat grafts from lower abdomen to be used as interpositional material. Following the surgeries, their patients achieved a mean (±SD) post operative maximum mouth opening of 31.71 ± 5.40mm compared to mean (±SD) pre-operative maximum mouth opening of 3.43 ± 3.16mm. No details on lateral excursion, protrusion and pain score were provided. Jaw physiotherapy was initiated after surgery. Throughout their follow-up period of 12 to 24 months, they reported 3 cases of transient facial nerve injury.

Autogenous dermis fat graft used by Dimitroulis (2004) in his patients provided an improvement of mean (±SD) maximum mouth opening from pre-operative 15.78 ± 3.96mm to post-operative 35.78 ± 3.35mm. No information of lateral excursion, protrusion and pain score were given. All patients had post-surgery jaw physiotherapy with Roccobado method. Follow-up period was between 24 to 72 months. During this

period, they noticed 1 case of re-ankylosis, 9 cases with unilateral TMJ ankylosis had some degree of mandibular deviation and 2 cases with donor site wound dehiscence.

Native disc

Lin et al (2019) in their retrospective study, found that mouth opening improved from pre-operative 10.05 ± 2.31mm to 34.38 ± 6.91mm post-operatively. Although post-operative jaw physiotherapy was emphasized, no information was mentioned about the device used and the compliance rate. In this study, the reported mean follow-up was 3 years and 1 patient had recurrence due to non-compliant to physiotherapy.

Similar to Lin et al (2019), Singh et al. (2014) also reported improvement in mouth opening following the use of native disc. Mouth opening increased from 12.72 ± 1.42mm to 35.18 ± 1.72mm. Post-operatively, patients underwent jaw physiotherapy which initially utilised mouth prop which was then followed by spoon spatula. Follow-up period was between 1 to 4 years. Two of the patients developed ear infection during post-operative period.

Buccal fat pad

In their retrospective study, Malhotra et al. (2019) reported that intra-articular spaces were well-maintained with buccal fat pad when viewing post-operative CBCT. Their patients showed an increase in the maximum incisal opening from 5.00 ± 4.86mm to 34.70 ± 2.49mm post-operatively. All patients were emphasized on the need of jaw physiotherapy after the surgery. Heister's mouth opener was used to aid in mouth opening exercise. Follow-up duration in this study was from 6 months to 2 years and 7 months. Post-operatively, only 1 patient developed temporary facial nerve weakness.

Following interpositional arthroplasty with buccal fat pad, Singh et al. (2011) reported an improvement in patients' mean (± SD) mouth opening from 2.80 ± 1.54mm to 35.10

± 3.05mm. Post-operative OPGs showed intra-articular spaces were well maintained by the interpositional biomaterial with no signs of relapse. Post surgery jaw physiotherapy was prescribed to all patients. They started off with mouth props before changing to tongue depressors. All patients were followed up for a duration between 6 months to 2 years. One patient has ear infection post operatively. While the authors also reported patients had jaw deviation to the affected side when opening mouth, no exact number were stated.

Skin graft

Chossegros et al. (1999) reported improvement of mean (±SD) maximum mouth opening from 16.40 ± 6.00mm to 37.60 ± 6.33mm following interpositional arthroplasty with full thickness skin graft. Post-operatively, patients were instructed to do jaw physiotherapy. Patients were followed up for a duration of 1 to 20 years. Throughout the post-operative period, there were 4 cases of transient facial paralysis and 1 case of epidemoid cyst with cutaneous fistula.

Another earlier study by Chossegros et al. (1997) reported improvement of mouth opening from pre-operative 16.08 ± 7.12mm to post-operative 38.58 ± 3.66mm following the use of retroauricular skin graft. Although patients were taught on jaw physiotherapy, no information of the device used, and patients' compliance were stated.

Costal cartilage

With the use of costal cartilage as interpositional material, Huang et al. (2007) showed an increase of mean (±SD) maximum mouth opening from pre-operative 11.20 ± 8.64mm to post-operative 37.40 ± 5.95mm. Post-operative jaw physiotherapy was emphasized, although no details provided. All their patients were followed up for a minimum of 25

months and maximum 107 months. Only 1 patient developed permanent numb lip following the surgery.

Chossegros et al. (1997) reported the use of costal cartilage can improve mouth opening following interpositional arthroplasty. Mouth opening improved from 9.50 ± 2.12mm to 23.50 ± 13.44mm post-operatively. All patients were subjected to jaw physiotherapy but no further details on this were given. Patients were followed up for 3 to 10 years. One of their patients developed graft overgrowth.

Fascia lata

Chossegros et al. (1997) mentioned that the mouth opening in their patient improved from pre-operative 15mm to post-operative 40mm. Jaw physiotherapy was emphasised, and patient was compliant. This patient was followed up for 3 years and no complications were reported.

Silicone block and sheet

Agarwal et al. (2021) studied interpositional arthroplasty with silicone block and reported an increased in maximum incisal opening from pre-operative 7.15 ± 2.03mm to post-operative 43.50 ± 2.62mm. Post-operative lateral excursion, mandibular protrusion and pain score were not reported. Despite mentioning that patients were instructed to do jaw physiotherapy, details were not provided. All the 20 patients were followed up from a range of 6 months to 5 years. Throughout the follow-up period, 1 patient had infection and another 1 experienced implant extrusion.

Apart from mentioning pre-operative CT scans being taken, no additional details on imaging findings pre- and post-operative were stated in the report by Aggarwal et al. (2015). Following interpositional arthroplasty with ultrathin silicone sheet, there was an increase in the maximum mouth opening from 3.10 ± 1.22mm to 31.00 ± 1.34mm.

Custom-made acrylic jaw exercises / dynamic jaw openers were used for jaw physiotherapy. All patients were followed up for a duration of 2 to 3 years. No complications were reported throughout this period.

In their retrospective study, Kalra and Kakkar (2011) reported a mean (± SD) pre-operative maximum mouth opening was 7.81 ± 1.96mm for the 80 patients recruited for interpositional arthroplasty with ultra-thin silicone sheet. Following surgery, mean (± SD) mouth opening improved to 34.30 ± 3.97mm. No details on lateral excursion, protrusion or pain score in this paper. Jaw physiotherapy was commenced after surgery but no details were provided. All patients were followed up from 1 year to 9 years. No complications were reported in these patients during the duration of follow-up.

Manganello-Souza and Mariani (2003) showed that the use of silicone sheet for interpositional arthroplasty could help in achieving mean (±SD) maximum mouth opening of 33.00 ± 4.24mm from pre-operative measurement of 9.00 ± 5.48mm. Jaw physiotherapy were performed using tongue blades. Their patients were followed up for a period of 12 to 48 months. Post-operatively, some of the patients developed jaw deviation to the affected side when opening mouth, however exact number was not stated. Another 4 patients had facial nerve paresis, of which 3 were transient and 1 was permanent.

Bone wax and porcine acellular dermal matrix

By utilizing bone wax and porcine acellular dermal matrix in 12 patients, Zhu et al. (2021) reported an increased in the maximum incisal opening from 7.40 ± 5.30mm to 37.60 ± 3.90mm. Although post operative computed tomography (CT) scans were taken. No details were provided on the CT findings. Improvement in lateral excursion and protrusion were also not mentioned in the report. Pain score after the surgery, which was measured using Visual Analog Scale (VAS), was zero. To prevent re-ankylosis, patients

were instructed to do jaw physiotherapy. However, details on the therapy such as the device used and patients' compliance were not mentioned too. Patients were followed up for a duration of 1 to 4 years and no complications were reported during this duration.

Acrylic marbles

Following the use of acrylic marble for interpositional arthroplasty, Erdem and Alkan (2001) reported an improvement of mean (±SD) maximum mouth opening of 15.76 ± 5.29mm pre-operatively to 32.70 ± 5.01mm post-operatively. Wooden spatulas were provided for jaw physiotherapy. Their patients were followed up for a duration of 6 months to 17 years. During this period, it was reported 3 patients had reankylosis, 4 patients had transient facial nerve paresis and 1 patient had acrylic marble extrusion and displacement, respectively.

Table 4.3: Summary of results of included non-RCT studies

No.	Author (Year) Country Level of evidence Study design	Biomaterial used	Pre-op imaging and findings Post-op imaging and findings	Pre-op maximal incisal opening		Post-op maximal incisal opening		Excursion range post-op -lateral excursion -protrusion	Pain score range post-op Physiotherapy	Duration follow-up Complications
				Mean	SD	Mean	SD			
1	Zhu et al. (2021) China III Retrospective study	Bone wax and porcine acellular dermal matrix in all 12 patients	Pre-op: CT, KIV CBCT if trismus and unable to do dental cast No info of imaging findings Post-op: CT No info of imaging findings	7.40	5.30	37.60	3.90	Lateral excursion: No info of excursion range Protrusion: No info of protrusion range	Pain score: VAS 0 Physiotherapy: Physiotherapy taught No info of device used and compliance	Follow-up: 1-4 years Complications: No complication

Table 4.3 (Continued)

No.	Author (Year) Country Level of evidence Study design	Biomaterial used	Pre-op imaging and findings Post-op imaging and findings	Pre-op maximal incisal opening		Post-op maximal incisal opening		Excursion range post-op -lateral excursion -protrusion	Pain score range post-op Physiotherapy	Duration follow-up Complications
				Mean	SD	Mean	SD			
2	Agarwal et al. (2021) India III Retrospective study	Silicone block in all 20 patients	Pre-op: No info Post-op: No info	7.15	2.03	43.50	2.62	Lateral excursion: No info of excursion range Protrusion: No info of protrusion range	Pain score: No info of pain score Physiotherapy: Physiotherapy taught No info of device used and compliance	Follow-up: 6 months-5 years Complications: -1 infection -1 extrusion of implant

Table 4.3 (Continued)

No.	Author (Year) Country Level of evidence Study design	Biomaterial used	Pre-op imaging and findings Post-op imaging and findings	Pre-op maximal incisal opening		Post-op maximal incisal opening		Excursion range post-op -lateral excursion -protrusion	Pain score range post-op Physiotherapy	Duration follow-up Complications
				Mean	SD	Mean	SD			
3	Lin et al. (2019) China III Retrospective study	Among 44 joints: -original disc: 33 joints -temporalis myofascial flap (TMF): 11 joints	Pre-op: CBCT No info of imaging findings Post-op: CBCT Medially bending condyles and glenoid fossa form new and functional joints	9.87	2.39	34.50	5.75	Lateral excursion: No info of excursion range Protrusion: No info of protrusion range	Pain score: No info of pain score Physiotherapy: Physiotherapy taught No info of device used and compliance	Follow-up: (Mean) 3 years Complications: 1 recurrence (as patient not compliant to physiotherapy)

Table 4.3 (Continued)

No.	Author (Year) Country Level of evidence Study design	Biomaterial used	Pre-op imaging and findings Post-op imaging and findings	Pre-op maximal incisal opening		Post-op maximal incisal opening		Excursion range post-op -lateral excursion -protrusion	Pain score range post-op Physiotherapy	Duration follow-up Complications
				Mean	SD	Mean	SD			
4	Malhotra et al. (2019) India III Retrospective study	All 10 patients were treated with lateral arthroplasty and buccal fat pad interposition	Pre-op: CBCT No info of imaging findings Post-op: CBCT Well-maintained intra-articular space in all patients	5.00	4.86	34.70	2.49	Lateral excursion: No info of excursion range Protrusion: No info of protrusion range	Pain score: No info of pain score Physiotherapy: Physiotherapy taught Heister's mouth opener used No info of compliance	Follow-up: 6 months-2 years 7 months Complications: 1 patient with temporary facial nerve weakness

Table 4.3 (Continued)

No.	Author (Year) Country Level of evidence Study design	Biomaterial used	Pre-op imaging and findings Post-op imaging and findings	Pre-op maximal incisal opening		Post-op maximal incisal opening		Excursion range post-op -lateral excursion -protrusion	Pain score range post-op Physiotherapy	Duration follow-up Complications
				Mean	SD	Mean	SD			
5	Rajurkar et al. (2017) India III Retrospective study	Pedicled deep temporalis fascia flap based on middle temporal branch of superficial temporal artery in all 17 patients	Pre-op: OPG, CT No info of imaging findings Post-op: OPG 16 cases showed no signs of reankylosis; intra-articular space well maintained	4.00	2.24	36.47	5.35	Lateral excursion: No info of excursion range Protrusion: No info of protrusion range	Pain score: No info of pain score Physiotherapy: Physiotherapy taught No info of device used and compliance	Follow-up: 1-6 years Complications: -1 reankylosis -17 deviation to affected side

Table 4.3 (Continued)

No.	Author (Year) Country Level of evidence Study design	Biomaterial used	Pre-op imaging and findings Post-op imaging and findings	Pre-op maximal incisal opening		Post-op maximal incisal opening		Excursion range post-op -lateral excursion -protrusion	Pain score range post-op Physiotherapy	Duration follow-up Complications
				Mean	SD	Mean	SD			
6	Maqsood et al. (2015) Pakistan II Prospective study	Temporalis muscle flap in all 50 cases	Pre-op: OPG No info of imaging findings Post-op: No info	2.60	1.40	31.26	2.03	Lateral excursion: No info of excursion range Protrusion: No info of protrusion range	Pain score: No info of pain score Physiotherapy: Physiotherapy taught Wooden spatula used No info of compliance	Follow-up: (Mean) 1.5 years Complications: -4 temporary facial nerve palsy -2 anterior open bite

Table 4.3 (Continued)

No.	Author (Year) Country Level of evidence Study design	Biomaterial used	Pre-op imaging and findings Post-op imaging and findings	Pre-op maximal incisal opening		Post-op maximal incisal opening		Excursion range post-op -lateral excursion -protrusion	Pain score range post-op Physiotherapy	Duration follow-up Complications
				Mean	SD	Mean	SD			
7	Hegab (2015) Egypt II Prospective study	Abdominal dermis fat graft in all 14 patients	Pre-op: OPG, CT No info of imaging findings Post-op: No info	2.07	0.92	43.50	5.92	Lateral excursion: No info of excursion range Protrusion: No info of protrusion range	Pain score: No info of pain score Physiotherapy: Physiotherapy taught Wooden spatula used No info of compliance	Follow-up: 24-48 months Complications: -9 unilateral mandibular deviation to op site at maximum mouth opening -2 facial asymmetry -3 temporary facial nerve paresis (of bilateral ankylosis cases) -open bite: no specific number of patients mentioned

Table 4.3 (Continued)

No.	Author (Year) Country Level of evidence Study design	Biomaterial used	Pre-op imaging and findings Post-op imaging and findings	Pre-op maximal incisal opening		Post-op maximal incisal opening		Excursion range post-op -lateral excursion -protrusion	Pain score range post-op Physiotherapy	Duration follow-up Complications
				Mean	SD	Mean	SD			
8	Aggarwal et al. (2015) India II Prospective study	Ultrathin silicon sheet (0.2mm) in all 10 patients	Pre-op: 3D-CT No info of imaging findings Post-op: No info	3.10	1.22	31.00	1.34	Lateral excursion: No info of excursion range Protrusion: No info of protrusion range	Pain score: No info of pain score Physiotherapy: Physiotherapy taught Custom made acrylic jaw exerciser / dynamic jaw opener used No info of compliance	Follow-up: 2-3 years Complications: No complication

Table 4.3 (Continued)

No.	Author (Year) Country Level of evidence Study design	Biomaterial used	Pre-op imaging and findings Post-op imaging and findings	Pre-op maximal incisal opening		Post-op maximal incisal opening		Excursion range post-op -lateral excursion -protrusion	Pain score range post-op Physiotherapy	Duration follow-up Complications
				Mean	SD	Mean	SD			
9	Singh et al. (2014) India III Retrospective study	-4 patients with temporalis myofascial flap -11 patients with native articular disc	Pre-op: OPG, CT No info of imaging findings Post-op: OPG, CT Well maintained intra-articular space	Disc: 12.72 Temporalis: 15.25	1.42 0.96	35.18 36.50	1.72 3.11	Lateral excursion: -To affected side: range 4.0-7.0mm -Towards normal side: range 2.0-4.0mm Protrusion: -Pre-op: range 0.5-1.5mm -Post-op: range 3.0-5.5mm	Pain score: (Mean 2) VAS 1-4 Physiotherapy: Physiotherapy taught Mouth prop used, then continued at home with spoon spatulas. No info of compliance	Follow-up: 1-4 years Complications: 2 ear infection post-op 1 week

Table 4.3 (Continued)

No.	Author (Year) Country Level of evidence Study design	Biomaterial used	Pre-op imaging and findings Post-op imaging and findings	Pre-op maximal incisal opening		Post-op maximal incisal opening		Excursion range post-op -lateral excursion -protrusion	Pain score range post-op Physiotherapy	Duration follow-up Complications
				Mean	SD	Mean	SD			
10	Babu et al. (2013) India II Prospective study	Temporal fascia in all 15 patients	Pre-op: OPG, CT No info of imaging findings Post-op: No info	3.87	2.55	34.20	3.17	Lateral excursion: No info of excursion range Protrusion: No info of protrusion range	Pain score: No info of pain score Physiotherapy: Physiotherapy taught Wooden spatula used No info of compliance	Follow-up: (Mean) 3 years Complications: No complication

Table 4.3 (Continued)

No.	Author (Year) Country Level of evidence Study design	Biomaterial used	Pre-op imaging and findings Post-op imaging and findings	Pre-op maximal incisal opening		Post-op maximal incisal opening		Excursion range post-op -lateral excursion -protrusion	Pain score range post-op Physiotherapy	Duration follow-up Complications
				Mean	SD	Mean	SD			
11	Bulgannawar et al. (2011) India III Retrospective study	Temporalis fascia flap in all 8 patients	Pre-op: CT No info of imaging findings Post-op: OPG Intra-articular space was well maintained without signs of relapse / reankylosis	2.75	2.44	36.50	2.18	Lateral excursion: No info of excursion range Protrusion: No info of protrusion range	Pain score: No info of pain score Physiotherapy: Physiotherapy taught No info of device used and compliance	Follow-up: 11 months-6 years Complications: 8 deviation to affected side

Table 4.3 (Continued)

No.	Author (Year) Country Level of evidence Study design	Biomaterial used	Pre-op imaging and findings Post-op imaging and findings	Pre-op maximal incisal opening		Post-op maximal incisal opening		Excursion range post-op -lateral excursion -protrusion	Pain score range post-op Physiotherapy	Duration follow-up Complications
				Mean	SD	Mean	SD			
12	Kalra & Kakkar (2011) India III Retrospective study	Ultrathin silicone sheet in all 80 patients	Pre-op: OPG, CT No info of imaging findings Post-op: No info	7.81	1.96	34.30	3.97	Lateral excursion: No info of excursion range Protrusion: No info of protrusion range	Pain score: No info of pain score Physiotherapy: Physiotherapy taught No info of device used and compliance	Follow-up: 1-9 years Complications: No complication

Table 4.3 (Continued)

No.	Author (Year) Country Level of evidence Study design	Biomaterial used	Pre-op imaging and findings Post-op imaging and findings	Pre-op maximal incisal opening		Post-op maximal incisal opening		Excursion range post-op -lateral excursion -protrusion	Pain score range post-op Physiotherapy	Duration follow-up Complications
				Mean	SD	Mean	SD			
13	Singh et al. (2011) India III Retrospective study	Buccal fat pad in all 10 cases	Pre-op: OPG, CT No info of imaging findings Post-op: OPG Well-maintained intra-articular space with no signs of relapse	2.80	1.54	35.10	3.05	Lateral excursion: No info of excursion range Protrusion: No info of protrusion range	Pain score: No info of pain score Physiotherapy: Physiotherapy taught Mouth prop used, then tongue depressors No info of compliance	Follow-up: 6 months-2 years Complications: -1 ear infection post-op -deviation to affected side upon opening: 0-4mm (mean 1.6mm)

Table 4.3 (Continued)

No.	Author (Year) Country Level of evidence Study design	Biomaterial used	Pre-op imaging and findings Post-op imaging and findings	Pre-op maximal incisal opening		Post-op maximal incisal opening		Excursion range post-op -lateral excursion -protrusion	Pain score range post-op Physiotherapy	Duration follow-up Complications
				Mean	SD	Mean	SD			
14	Thangavelu et al. (2011) India III Retrospective study	Full thickness skin-subcutaneous fat grafts harvested from lower abdomen used in all 7 patients	Pre-op: No info Post-op: No info	3.43	3.16	31.71	5.40	Lateral excursion: No info of excursion range Protrusion: No info of protrusion range	Pain score: No info of pain score Physiotherapy: Physiotherapy taught No info of device used and compliance	Follow-up: 12-24 months Complications: -3 transient injury facial nerve

Table 4.3 (Continued)

No.	Author (Year) Country Level of evidence Study design	Biomaterial used	Pre-op imaging and findings Post-op imaging and findings	Pre-op maximal incisal opening		Post-op maximal incisal opening		Excursion range post-op -lateral excursion -protrusion	Pain score range post-op Physiotherapy	Duration follow-up Complications
				Mean	SD	Mean	SD			
15	Guruprasad et al. (2010) India III Retrospective study	Temporalis muscle and fascia flap in all 9 patients	Pre-op: OPG, CT No info of imaging findings Post-op: OPG Increased interarticular space without signs of relapse or ankylosis.	11.70	3.61	38.30	1.63	Lateral excursion: No info of excursion range Protrusion: No info of protrusion range	Pain score: No info of pain score Physiotherapy: Physiotherapy taught Stacked tongue depressors and bilateral rachet mouth props used No info of compliance	Follow-up: 13-31 months Complications: -3 anterior open bite (resolved subsequently with physiotherapy)

Table 4.3 (Continued)

No.	Author (Year) Country Level of evidence Study design	Biomaterial used	Pre-op imaging and findings Post-op imaging and findings	Pre-op maximal incisal opening		Post-op maximal incisal opening		Excursion range post-op -lateral excursion -protrusion	Pain score range post-op Physiotherapy	Duration follow-up Complications
				Mean	SD	Mean	SD			
16	Bayat et al. (2009) Iran III Retrospective study	Temporalis muscle flap in all 33 patients	Pre-op: OPG, CT All 33 patients had bony TMJ ankylosis Post-op: OPG, KIV CT if need to reconfirm reankylosis post-op No info of imaging findings	4.85	3.46	32.76	5.56	Lateral excursion: No info of excursion range Protrusion: No info of protrusion range	Pain score: No info of pain score Physiotherapy: Physiotherapy taught Therabite device used No info of compliance	Follow-up: 6 months-44 months Complications: -2 reankylosis -1 surgical site infection -12 facial nerve palsy (9 temporary palsy, 3 permanent palsy after 3 month follow up) -all 23 patients of unilateral ankylosis: some mandibular deviation to op site upon mouth opening

Table 4.3 (Continued)

No.	Author (Year) Country Level of evidence Study design	Biomaterial used	Pre-op imaging and findings Post-op imaging and findings	Pre-op maximal incisal opening		Post-op maximal incisal opening		Excursion range post-op -lateral excursion -protrusion	Pain score range post-op Physiotherapy	Duration follow-up Complications
				Mean	SD	Mean	SD			
17	Danda et al. (2009) India II Prospective study	Group I: gap arthroplasty alone Group II: gap arthroplasty and interpositional arthroplasty with temporalis myofascial flap: 8 patients	Pre-op: PA skull, lateral cephalogram, OPG (3D CT: used on 1 patient) No info of imaging findings Post-op: No info	3.50	1.41	31.44	10.76	Lateral excursion: No info of excursion range Protrusion: No info of protrusion range	Pain score: No info of pain score Physiotherapy: Physiotherapy taught No info of device used and compliance	Follow-up: (Mean) Group I: gap arthroplasty only: 23.1 months Group II: gap arthroplasty and interpositional arthroplasty with temporalis myofascial flap: 20.3 months Complications: -reankylosis (unilateral): Group I: 1 Group II: 1 -temporary weakness facial nerve 1 patient Group I: 1 Group II: 2 -preauricular infection Group II: 1

Table 4.3 (Continued)

No.	Author (Year) Country Level of evidence Study design	Biomaterial used	Pre-op imaging and findings Post-op imaging and findings	Pre-op maximal incisal opening		Post-op maximal incisal opening		Excursion range post-op -lateral excursion -protrusion	Pain score range post-op Physiotherapy	Duration follow-up Complications
				Mean	SD	Mean	SD			
18	Huang et al. (2007) Taiwan III Retrospective study	Autogenous costal cartilage grafts in all 11 patients	Pre-op: No info Post-op: No info	11.20	8.64	37.40	5.95	Lateral excursion: No info of excursion range Protrusion: No info of protrusion range	Pain score: No info of pain score Physiotherapy: Physiotherapy taught No info of device used and compliance	Follow-up: 25-107 months Complications: -1 permanent numb lip

Table 4.3 (Continued)

No.	Author (Year) Country Level of evidence Study design	Biomaterial used	Pre-op imaging and findings Post-op imaging and findings	Pre-op maximal incisal opening		Post-op maximal incisal opening		Excursion range post-op -lateral excursion -protrusion	Pain score range post-op Physiotherapy	Duration follow-up Complications
				Mean	SD	Mean	SD			
19	Qudah et al. (2005) Jordan III Retrospective study	Temporalis muscle interpositional arthroplasty in 8 joints (Others: Costochondral graft reconstruction in 16 joints)	Pre-op: OPG, CT No info of imaging findings Post-op: No info	6.63	1.90	31.00	2.88	Lateral excursion: No info of excursion range Protrusion: No info of protrusion range	Pain score: No info of pain score Physiotherapy: Physiotherapy taught Wooden spatulae used No info of compliance	Follow-up: 10-42 months Complications: -2 recurrences / reankylosis (1 in costochondral graft, 1 in temporalis muscle) -2 overgrowth costochondral graft

Table 4.3 (Continued)

No.	Author (Year) Country Level of evidence Study design	Biomaterial used	Pre-op imaging and findings Post-op imaging and findings	Pre-op maximal incisal opening		Post-op maximal incisal opening		Excursion range post-op -lateral excursion -protrusion	Pain score range post-op Physiotherapy	Duration follow-up Complications
				Mean	SD	Mean	SD			
20	Dimitroulis (2004) Australia III Retrospective study	Autogenous dermis-fat graft from groin in all 11 patients (2 bilateral ankylosis patients with costochondral graft too)	Pre-op: CT No info of imaging findings Post-op: No info	15.78	3.96	35.78	3.35	Lateral excursion: No info of excursion range Protrusion: No info of protrusion range	Pain score: No info of pain score Physiotherapy: Physiotherapy taught Roccobado method used No info of compliance	Follow-up: 24-72 months Complications: -1 reankylosis -9 unilateral cases had some degree of mandibular deviation to op side on maximum mouth opening -2 with donor site wound dehiscence

Table 4.3 (Continued)

No.	Author (Year) Country Level of evidence Study design	Biomaterial used	Pre-op imaging and findings Post-op imaging and findings	Pre-op maximal incisal opening		Post-op maximal incisal opening		Excursion range post-op -lateral excursion -protrusion	Pain score range post-op Physiotherapy	Duration follow-up Complications
				Mean	SD	Mean	SD			
21	Balaji (2003) India III Retrospective study	Temporalis muscle in all 21 patients	Pre-op: OPG No info of imaging findings Post-op: CT CT analysis showed no dura exposure with increased joint space. No signs of fibrosis or re-ankylosis seen.	1.00	1.52	35.56 (missing 5 data during 6 years review)	2.34 (missing 5 data during 6 years review)	Lateral excursion: No info of excursion range Protrusion: No info of protrusion range	Pain score: No info of pain score Physiotherapy: Physiotherapy taught No info of device used All patients were compliant to physiotherapy	Follow-up: (Mean) 6 years Complications: -2 wound infection -1 transient preauricular paraesthesia -1 Frey syndrome -2 resorption (paediatric cases of costochondral graft which used together with temporalis muscle)

Table 4.3 (Continued)

No.	Author (Year) Country Level of evidence Study design	Biomaterial used	Pre-op imaging and findings Post-op imaging and findings	Pre-op maximal incisal opening		Post-op maximal incisal opening		Excursion range post-op -lateral excursion -protrusion	Pain score range post-op Physiotherapy	Duration follow-up Complications
				Mean	SD	Mean	SD			
22	Manganello-Souza & Mariani (2003) Brazil III Retrospective study	Silicone sheet in 5 patients (Others: -Costochondral graft and temporalis muscle flap: 5 patients -Coctochondral graft + silicone sheet: 4 patients)	Pre-op: OPG, CT No info of imaging findings Post-op: No info	9.00	5.48	33.00	4.24	Lateral excursion: No info of excursion range Protrusion: No info of protrusion range	Pain score: No info of pain score Physiotherapy: Physiotherapy taught Tongue blades used No info of compliance	Follow-up: 12-48 months Complications: Group 1: costochondral graft: -1 recurrence -2 temporary paresis of facial nerve Group 2: -mandibular deviation to affected side upon mouth opening (unsure patients number) -4 paresis facial nerve (among 4 patients, 1 patient presented with pre-op paresis; (1 permanent, 3 temporary)

Table 4.3 (Continued)

No.	Author (Year) Country Level of evidence Study design	Biomaterial used	Pre-op imaging and findings Post-op imaging and findings	Pre-op maximal incisal opening		Post-op maximal incisal opening		Excursion range post-op -lateral excursion -protrusion	Pain score range post-op Physiotherapy	Duration follow-up Complications
				Mean	SD	Mean	SD			
23	Erdem & Alkan (2001) Turkey III Retrospective study	Acrylic marbles in all 47 cases	Pre-op: OPG, cephalometry (CT if need to check for coronoid ankylosis) No info of imaging findings Post-op: No info	15.76	5.29	32.70	5.01	Lateral excursion: No info of excursion range Protrusion: No info of protrusion range	Pain score: No info of pain score Physiotherapy: Physiotherapy taught Wooden spatula used No info of compliance	Follow-up: 6 months-17 years Complications: -3 reankylosis -1 extrusion -1 displacement of acrylic marbles -4 transient facial nerve paresis

Table 4.3 (Continued)

No.	Author (Year) Country Level of evidence Study design	Biomaterial used	Pre-op imaging and findings Post-op imaging and findings	Pre-op maximal incisal opening		Post-op maximal incisal opening		Excursion range post-op -lateral excursion -protrusion	Pain score range post-op Physiotherapy	Duration follow-up Complications
				Mean	SD	Mean	SD			
24	Su-Gwan (2001) Korea III Retrospective study	Temporalis muscle and fascia flap in all 7 cases	Pre-op: OPG, CT No info of imaging findings Post-op: CT 4 cases with increased interarticular space without signs of relapse of joint / fibrosis / ankylosis / of degenerative joint disease; 3 cases not determined	15.00	3.66	36.10	1.81	Lateral excursion: No info of excursion range Protrusion: No info of protrusion range	Pain score: VAS: Pre-op: 4-7 Post-op: 0-4 (Mean: VAS: Pre-op: 5.3 Post-op: 1.9) Physiotherapy: Physiotherapy taught Stacked tongue depressors and bilateral rachet mouth props used No info of compliance	Follow-up: 13-30 months Complications: No complication

Table 4.3 (Continued)

No.	Author (Year) Country Level of evidence Study design	Biomaterial used	Pre-op imaging and findings Post-op imaging and findings	Pre-op maximal incisal opening		Post-op maximal incisal opening		Excursion range post-op -lateral excursion -protrusion	Pain score range post-op Physiotherapy	Duration follow-up Complications
				Mean	SD	Mean	SD			
25	Chossegros et al. (1999) France III Retrospective study	Full thickness skin graft autograft in all 31 patients	Pre-op: OPG, frontal, sagittal films for patients treated prior to 1985; axial and coronal CT treated after 1985. Cephalometric radiographs for facial deformities patients. No info of imaging findings Post-op: OPG, CT No info of imaging findings	16.40	6.00	37.60	6.33	Lateral excursion: No info of excursion range Protrusion: No info of protrusion range	Pain score: No info of pain score Physiotherapy: Physiotherapy taught No info of device used and compliance	Follow-up: 1-20 years Complications: -4 transient facial paralysis -1 epidermoid cyst with cutaneous fistula

Table 4.3 (Continued)

No.	Author (Year) Country Level of evidence Study design	Biomaterial used	Pre-op imaging and findings Post-op imaging and findings	Pre-op maximal incisal opening		Post-op maximal incisal opening		Excursion range post-op -lateral excursion -protrusion	Pain score range post-op Physiotherapy	Duration follow-up Complications
				Mean	SD	Mean	SD			
26	Chossegros et al. (1997) France III Retrospective study	Retroauricular skin graft: 12 cases Temporalis muscle fascia flap: 5 cases Human costal cartilage: 2 cases Autologous fascia lata: 1 case Prosthesis: 2 cases	Pre-op: OPG, frontal, axial views using tomography (before 1985), CT scan (after 1985) No info of imaging findings Post-op: No info	15.46 Skin: 16.08 Temporalis: 16.20 Cartilage: 9.50 Prosthesis: 16.00	6.91 7.12 8.50 2.12 8.49	35.64 38.58 33.20 23.50 34.00	6.64 3.66 4.32 13.44 8.49	Lateral excursion: No info of excursion range Protrusion: No info of protrusion range	Pain score: No info of pain score Physiotherapy: Physiotherapy taught No info of device used All patients are compliant to physiotherapy	Follow-up: 3-20 years Complications: -1 overgrowth costochondral graft

4.4.2 Randomised controlled studies

Younis et al. (2021)

OPG and CBCT were taken prior and after surgical intervention in both Group A (abdominal dermis fat graft) and Group B (temporalis fascia and muscle) patients. Group A showed mean increment of maximum mouth opening from pre-op 8.46mm to 38.20mm immediate post-op, and At 6 months follow-up a further increment to 39.93mm was recorded. Group B also showed improvement in mean maximum mouth opening, from pre-operative 9.67mm to 35.01mm immediate post-op and a further increase to 33.67mm 6 months later. The authors did not report the range of mandibular movement upon lateral excursion and protrusion. For post-op pain score of first day post-op, 40% of Group A patients reported no pain and 60% had mild pain; meanwhile 20% of Group B patients complaint of mild pain, 46.7% moderate pain and 33.3% of patients experienced severe pain. At post-operative 1 week, 93.3% of patients in Group A had no pain and the remaining 6.7% had only mild pain. For Group B patients, 33.3% still had moderate pain, 46.7% with mild pain and only 20% had no pain of surgical sites. Group A patients had mean follow up of 2.3 years and Group B 2.1 years. Small wooden spatulas were used to aid in jaw physiotherapy. Regarding post-operative complications, there was no re-ankylosis seen in both groups. Group A and B each had 1 case of donor site infection and 2 cases from Group A showed hypertrophic scar. Both groups had facial nerve injury. For Group A, 4 cases showed temporary facial nerve weakness, 2 cases each with Grade II mild dysfunction and Grade III moderate dysfunction. Group B had 5 cases with temporary facial nerve weakness, 2 cases with Grade II facial nerve injury and 3 patients reported to have Grade III facial nerve injury.

Roychoudhury et al. (2020)

Authors performed pre- and post-operative magnetic resonance imaging (MRI) to compare the mean volumetric changes in both Group A (pedicled buccal fat pad) and Group B (abdominal fat). Throughout the 1 year follow up, Group A with immediate post-operative fat volume of 4.3cm^3 reduced to 1.5cm^3, meanwhile Group B's immediate post-operative fat volume was 10.8cm^3 but reduced to 6.3cm^3 a year later. Group A had 32.4% fat retention and Group B showed 58.1% fat retention. Relative percentage of volumetric fat shrinkage of 67.5% and 41.9%for Group A & B respectively. For mean (±SD) maximum mouth opening, Group A showed an improvement from pre-op of 6.80 ± 4.40mm to post-op 30.60 ± 6.30mm; while Group B recorded 4.20 ± 1.20mm pre-operatively and 41.90 ± 4.00mm post-operatively. There was no detail about the range of mandibular post-op lateral excursion, protrusion, and post-op pain score. During jaw physiotherapy, a cone-shaped acrylic trismus screw was used to aid in jaw exercise. There were no complications reported in this study.

Andrade et al. (2020)

In this study, Group A had dermis fat harvested from subumbilical region and Group B undergone plain gap arthroplasty. Pre-operative OPG, lateral cephalogram, postero-anterior (PA) cephalogram and CT scan were done. Group A patients had mean (±SD) pre-operative maximum mouth opening of 4.00 ± 1.56mm which increased to post-op 41.40 ± 3.60mm. There was no information on the range of mandibular post-op lateral excursion and protrusion. The mean VAS pain score in Group A patients was 0.60. Patients were followed up for 3 years. Heister's jaw stretchers were used during jaw physiotherapy. Authors did not specify if there were any complications post-surgery but no re-ankylosis detected during review sessions.

Siddiqi et al. (2013)

In this study, Group A patients had silastic biomaterial and Group B patients were provided with heat-cured acrylic as interpositional arthroplasty biomaterials. Throughout the 1-year review, Group A patients had mean pre-operative maximum mouth opening of 3.87mm which increased to 38.27mm immediately post-op; reduced to 35.93mm at post-operative 1 week and further reduced to 34mm at post-operative 3 weeks. At post-operative 6 weeks and 3 months, the measurements remained the same at 34.13mm. Further reduction to 33.27mm and 32.73mm was recorded at 6 months and 1 year post-operative respectively. For Group B patients, mean pre-operative maximal mouth opening was recorded at 3.37mm. Immediately after surgery, the measurement was 38.33mm. Measurements recorded during post-operative 1-week, 3-week, 6-week, 3-month and 6-month were 34.73mm, 31.87mm, 31.60mm, 31.13mm and 30.33mm respectively. At 1 year follow-up, mean maximal mouth opening was 29.53mm. There was no record of range of mandibular range of lateral excursion and protrusion movement; also no post-op pain score described in text. For jaw physiotherapy, patients were started with passive physiotherapy with chewing gum before active physiotherapy with wooden spatulas. Post-surgery, authors noticed that 28 patients showed post-op swelling on first week of review sessions; transient facial nerve injury in 6 patients (2 patients of Group A, 4 patients of Group B); permanent facial nerve injury to temporal branch of facial nerve in 1 patient from Group B; infection in 4 patients (2 patients each from respective groups), in which 1 patient from Group A had antibiotics alone before infection subsided meanwhile the other patient from Group A and 2 patients from Group B need interpositional biomaterials removal before the infection resolved; graft removal in 1 patient from Group A and 2 patients from Group B due to infection and graft displacement; 1 patient from Group B showed recurrence with mouth opening 11mm post-surgery.

Mehrotra et al. (2008)

In this study, authors had utilized dermis fat graft in Group A patients and temporalis fascia and muscle in Group B patients. Pre- and post-op OPG and CT scan were done. The mean pre-operative maximum mouth opening for Group A was 3.90mm. Immediate post-operative mean maximum mouth opening increased to 33.80mm but at post-operative 6 months it reduced slightly 33.30mm. In Group B, the pre-operative mean maximum mouth opening was 2.00mm. This measurement increased to 27.60mm immediate post-surgery and at 6 months post-surgery it reduced further to 25.90mm. Four patients from Group A and 3 from Group B were able to perform lateral excursion post-operatively. Meanwhile, 1 patient from Group A and 3 from Group B were able to do protrusive movement. However, authors did not specify the range of mandibular movement for both excursion and protrusion that their patients managed to perform post-surgical intervention. VAS pain score for Group A patients was 2.5 during the immediate post-operative period, reduced to 1.4 during a week review, and was pain-free at 6 months. Immediately after surgery, Group B recorded a VAS pain score of 2.7. Their VAS was further reduced to 1.3 during the 1-week review and were also pain-free at the 6 months review. The mean follow-up duration for Group A and B was 24 months and 26 months, respectively. Overall, there was 1 infected case in Group A and 1 re-ankylosis from Group B.

Table 4.4: Summary of results of included RCT studies

No.	Author (Year) Country Level of evidence Study design	Biomaterial used	Pre-op imaging and findings Post-op imaging and findings	Pre-op maximal incisal opening Mean / SD	Post-op maximal incisal opening Mean / SD	Excursion range post-op -lateral excursion -protrusion	Pain score range post-op Physiotherapy	Duration follow-up Complications
1	Younis et al. (2021) India I RCT	BOTH GROUPS WERE AUTOGRAFT: -Group A: abdominal dermis fat graft: 15 patients -Group B: temporalis fascia and muscle: 15 patients	Pre-op: OPG, CBCT, lateral ceph No info of imaging findings Post-op: OPG, CBCT, lateral ceph No info of imaging findings	Maximal incisal opening value: Group A: Pre-op: 8.46 Group B: Pre-op: 9.67	Maximal incisal opening value: Group A: -Immediate post-op: 38.20 -6 months post-op: 39.93 Group B: -Immediate post-op: 35.01 -6 months post-op: 33.67	Lateral excursion: No info for excursion Protrusion: No info for protrusion	Pain score: VAS -First day post-op: :Group A: No pain: 40%, Mild: 60%, Moderate: 0, Severe: 0 :Group B: No pain: 0, Mild: 20%, Moderate: 46.7%, Severe: 33.3% -1 week postop: :Group A: No pain: 93.3%, Mild: 6.7%, Moderate: 0, Severe: 0 :Group B: No pain: 20%, Mild: 46.7%, Moderate: 33.3%, Severe: 0 Physiotherapy: Physiotherapy taught Small wooden spatulas used No info of compliance	Follow-up: (Mean) Group A: 2.3 years Group B: 2.1 years Complications: -Donor site infection: Group A: 1; Group B: 1 -Hypertrophic scar: Group A: 2; Group B: 0 -Facial nerve: Group A: Temporary weakness: 4 Grade II injury: 2 Grade III injury: 2 :Group B: Temporary weakness: 5 Grade II injury: 2 Grade III injury: 3

Table 4.4 (Continued)

No.	Author (Year) Country Level of evidence Study design	Biomaterial used	Pre-op imaging and findings Post-op imaging and findings	Pre-op maximal incisal opening		Post-op maximal incisal opening		Excursion range post-op -lateral excursion -protrusion	Pain score range post-op Physiotherapy	Duration follow-up Complications
				Mean (mm)	SD (mm)	Mean (mm)	SD (mm)			
2	Roychoudhury et al. (2020) India I RCT	BOTH GROUPS WERE AUTOGRAFT -Group A: pedicled buccal fat pad: 18 patients -Group B: abdominal fat: 18 patients	Pre-op: MRI No info of imaging findings Post-op: MRI MEAN VOLUMETRIC CHANGE: -Immediate post-op fat volume: (cm^3) - Group A: 4.3 Group B: 10.8 -1-year-post-op fat volume: (cm^3) - Group A: 1.5 Group B: 6.3 -% fat retention - Group A: 32.4 % Group B: 58.1% -Relative % of volumetric shrinkage - Group A: 67.5% Group B: 41.9%	Group A: 6.80 Group B: 4.20	Group A: 4.40 Group B: 1.20	1 year post-op: Group A: 30.60 Group B: 41.90	1 year post-op: Group A: 6.30 Group B: 4.00	Lateral excursion: No info for excursion Protrusion: No info for protrusion	Pain score: No info of pain score Physiotherapy: Physiotherapy taught Cone-shaped acrylic trismus screw used No info of compliance	Follow-up: 1 year Complications: No complication

Table 4.4 (Continued)

No.	Author (Year) Country Level of evidence Study design	Biomaterial used	Pre-op imaging and findings Post-op imaging and findings	Pre-op maximal incisal opening		Post-op maximal incisal opening		Excursion range post-op -lateral excursion -protrusion	Pain score range post-op Physiotherapy	Duration follow-up Complications
				Mean	SD	Mean	SD			
3	Andrade et al. (2020) India I RCT	Group A: autograft (dermis fat harvested from subumbilical region): 10 patients Group B: plain gap arthroplasty without any interpositional arthroplasty materials	Pre-op: OPG, lateral cephalogram, PA cephalogram, CT scan No info of imaging findings Post-op: No info	Group A: 4.00	Group A: 1.56	Group A: 41.40	Group A: 3.60	Lateral excursion: No info for excursion Protrusion: No info for protrusion	Pain score: VAS: (Mean) Group A: -3-year: 0.60 Physiotherapy: Physiotherapy taught Heister's jaw stretcher used No info of compliance	Follow-up: 3 years Complications: Not stated but no reankylosis seen

Table 4.4 (Continued)

No.	Author (Year) Country Level of evidence Study design	Biomaterial used	Pre-op imaging and findings Post-op imaging and findings	Pre-op maximal incisal opening		Post-op maximal incisal opening		Excursion range post-op -lateral excursion -protrusion	Pain score range post-op Physiotherapy	Duration follow-up Complications
				Mean	SD	Mean	SD			
4	Siddiqi et al. (2013) Pakistan I RCT	BOTH GROUPS WERE ALLOPLASTIC BIOMATERIALS: -Group A: silastic group: 15 patients -Group B: heat-cured acrylic: 15 patients	Pre-op: OPG,some patients done CT scan to assess extension of medio-lateral ankylotic mass No info of imaging findings Post-op: OPG, some patients done CT scan to assess extension of medio-lateral ankylotic mass No info of imaging findings	Maximal incisal opening (mean): Group A: -Pre-op: 3.87 Group B: -Pre-op: 3.37		Maximal incisal opening (mean): Group A: Immediately after op: 38.27; 1 week: 35.93; 3 weeks: 34.00; 6 weeks: 34.13; 3 months: 34.13; 6 months: 33.27; 1 year: 32.73; Net increase: 28.867 Group B: -Immediately after op: 38.33; 1 week: 34.73; 3 weeks: 31.87; 6 weeks: 31.60; 3 months: 31.13; 6 months: 30.33; 1 year: 29.53; Net increase: 26.17		Lateral excurion: No info for excursion Protrusion: No info for protrusion	Pain score: No info of pain score Physiotherapy: Physiotherapy taught: Passive physiotherapy with chewing gum Active physiotherapy with wooden spatula No info of compliance	Follow-up: 1 year Complications: -28 swelling -6 transient facial nerve injury (2 Group A, 4 Group B) -1 permanent injury to temporal branch of facial nerve (Group B) -4 infection :2 Group A :2 Group B -1 recurrence (Group B) -graft removal: 1 Group A, 2 Group B

Table 4.4 (Continued)

No.	Author (Year) Country Level of evidence Study design	Biomaterial used	Pre-op imaging and findings Post-op imaging and findings	Pre-op maximal incisal opening		Post-op maximal incisal opening		Excursion range post-op -lateral excursion -protrusion	Pain score range post-op Physiotherapy	Duration follow-up Complications
				Mean	SD	Mean	SD			
5	Mehrotra et al. (2008) India I RCT	BOTH GROUPS WERE AUTOGRAFT -Group A: dermis fat graft interposition: 8 patients (10 joints) -Group B: temporalis fascia and muscle interposition: 9 patients (10 joints)	Pre-op: OPG, CT scan No info of imaging findings Post-op: OPG, CT scan No info of imaging findings	Maximal incisal opening (mean): -Group A: Preop: 3.9 -Group B: Preop: 2.0		Maximal incisal opening (mean): -Group A: Immediate post-op: 33.8 6-month post-op: 33.3 -Group B: Immediate postop: 27.6 6-month post-op: 25.9		Lateral excursion: Group A: 4 Group B: 3 No data available for amount of excursion movement Protrusion: Group A: 1 Group B: 3 No data available for amount of protrusive movement	Pain score: VAS -Immediate postop: Group A: 2.5 Group B: 2.7 -1 week postop: Group A: 1.4 Group B: 1.3 -6 months postop: Group A: 0 Group B: 0 Physiotherapy: No info	Follow-up: (Mean) Group A: 24 months Group B: 26 months Complications: -re-ankylosis: Group A: 0 Group B: 1 -infection: Group A: 1 Group B: 0

CHAPTER 5: DISCUSSION

Among all the articles (RCT and non-RCT) included in this study, 83.8% were reported in Asian countries mainly India (54.8%). The remaining were reported in the Europe, South America and Australia. This finding concurred with the report by Gupta et al. (2012) that high prevalence of TMJ ankylosis is observed in Asian countries. They further reported that the prevalence of TMJ ankylosis in India was about 1 in every 2000 children (Gupta et al., 2012).

Most adult cases of TMJ ankylosis occurred as a result of trauma which includes motor-vehicle accidents, falls, violence and sport injuries, while for children, the commonest cause was ear infection or otitis media followed by trauma and forceps delivery. Motor-vehicle accidents in developed and developing countries override other causes due to reckless driving attitude with poor road transport safety awareness (example: no seatbelt and helmets wearing), poor road condition, vehicles without safety measures such as airbag, and poor local administrative without taking strict actions to those who violate the rules (Khan et al., 2015). When there are insults to TMJ regions post trauma, bleeding occurs and haematoma formation will then form and gradually ossification of these fibrous structures promote bony union and TMJ ankylosis (Roychoudhury et al., 1999). Meantime, joints infection cases due to underlying ear infection have reduced dramatically in the era of antibiotics, yet it is still disease of concern in developing and underdeveloped countries (Moorthy & Finch, 1983).

Since trauma is one of the main causes of TMJ ankylosis, it is not surprising to observe higher prevalence among male patients. In this study, male patients made up 53.9% of the total patients included in all the included studies (RCT and non-RCT). This phenomenon of males' predominance is due to inherent social behaviour, greater participation and exposure to risk factors such as vehicles driving, sports, machinery

control, high risks occupations and other active social activities (Al-Bokhamseen et al., 2019; Khan et al., 2022; Khan et al., 2015).

5.1 Biomaterials for interpositional arthroplasty

Temporalis muscle / temporalis fascia / temporalis myofascial flaps are the most utilized interpositional arthroplasty biomaterials post TMJ ankylosis mass resection (35.7%). The autogenous origin of this biomaterial, proximity to the TMJ ankylotic mass resection sites, pedicled with own blood supply, resilience, no additional donor incision / functional and cosmetic morbidity at donor sites, attachment at coronoid post-harvest that allow flaps movement, mimic the physiological action of articular disc with low degree of friction and positional stability, all these factors have made this biomaterial the most favored choice (Feinberg & Larsen, 1989). With good compliance of patients for jaw physiotherapy, most patients can maintain good maximal incisal opening post-surgery. However, re-ankylosis still occurs among patients using this autologous tissue. It has been suggested that the dissection of the myofascial flaps can lead to scar formation and scar contracture at adjacent donor sites which then causes muscle shrinkage and unavoidable fibrosed and leads to trismus (Mehrotra et al., 2008). Another concern about this biomaterial is regarding the bulky temporalis muscle flap when tunnel down into surgical site, and hence some surgeons preferred temporalis superficial fascia flap over the temporalis muscle flap (Zhi et al., 2009).

The next most used autograft are fat grafts namely pedicled buccal fat pad (18.3%) / abdominal fat grafts. These fat grafts can be packed into the post ankylotic mass resected site to obliterate dead space, ensure haemostasis at ankylotic joint cavities, and reduce blood clot formation and organization to form bone (Arnáiz-García et al., 2018). Whether to choose buccal fat pad or abdominal fat pad is always the surgeons' preference. Whichever site of fat harvested will eventually show ischemia and average resorption of

30-40% during early stage of transplantation (Roychoudhury et al., 2020). The pedicled buccal fat pad is just adjacent to the recipient sites which can be easily harvested and mobilized into surgical site without additional donor site morbidity. Compared to fat harvested from other donor sites, buccal fat pad has small fat lobules, limited volume available, lesser stem cells availability and easy to breakdown and fragmentize during harvesting and active joint loading (Broccaioli et al., 2013). As a result of these unfavourable features, abdominal fat grafts are harvested as an alternative. Abdominal fat harvest does not pose any significant functional and cosmetic morbidity, offers abundant volume for harvest with lower volumetric shrinkage compared to buccal fat pad, and is able to decrease the risk of heterotopic bone formation at recipient site (Roychoudhury et al., 2020).

For surgeons who are keen for autografts that can withstand continuous functional loading and pressure, skin grafts can be another option. These full-thickness skin grafts are autologous origin with no rejection risks, simple to be harvested from retroauricular region next to operative field with low risk of iatrogenic injury, resilient and able to withstand shearing and stretching forces, lesser scar formation at recipient site due to no immunologic risks of autografts and hence lesser risk of re-ankylosis with promising long-term surgical outcomes (Chossegros et al., 1999). Yet, opponents for skin grafts claimed that these biomaterials are not able to restore and maintain the ramus height if aggressive resection is done, and no one can predict how much threshold of force that the skin grafts can endured before perforation occurs (Chossegros et al., 1997).

Even though rarely performed now, autogenous cartilages from auricular and costal origin still merit for brief discussion. These cartilages with pliable texture are believed to work well in resected TMJ joints gap created. Although they are viable, but perforation of cartilage can occur, and it is more often in thinner auricular cartilage compared to the thicker costal cartilage (Yih et al., 1992). If the cartilage is harvested from rib, there will

be other concerns of donor sites morbidity, scarring and longer operative time that need to take into consideration as well.

A more conservative method but need proper case selection is the preservation of residual native disc. Lin et al has advocated that Sawhney Classification of Type III TMJ ankylosis can have the lateral TMJ ankylotic mass resected while maintain the medially displaced condyles and retain the native discs as well, provided that the discs are intact with no surface destruction noted (Lin et al., 2019). Lin et al believed that the condyles even medially displaced but still able to retain in place, preserve growth potential, avoid shortening of mandibular ramus and this will avoid post-surgery occlusal changes then. Also, there are no risks from graft surgery, neither from donor site morbidity nor recipient site complications.

Silicone and silastic materials have been once used extensively in post TMJ ankylotic mass resection cases. These alloplastic materials are users friendly, easily shape and adapt into place, biocompatible, easy to purchase, preformed in different shapes (rectangle, disc, block, sheet) and hence allows for shorter operating hours, no donor sites morbidities, and inexpensive (Latif et al., 2013). Long term review noted that these biomaterials cause fragmentation after prolonged functional loading, foreign body reaction, giant cell reaction, abrasion of implant, infection at surgical site and instability with possibility of migration, extrusion or dislodgement if not rigidly fixed in-situ (Chossegros et al., 1997; Maqsood et al., 2015). All these drawbacks will induce re-ankylosis at surgical sites.

The obsolete acrylic cylinders as interpositional arthroplasty biomaterials were used due to its low cost, easily available, biocompatible, easily to be shaped and applied at surgical sites, reduce operating hours and no donor site complications make it once the ideal biomaterials (Erdem & Alkan, 2001; Siddiqi et al., 2013). However, acrylics are not as soft and rubbery as silicone and silastic materials to allow compressibility during functional loading (Siddiqi et al., 2013). Similar to silicone and silastic materials, long

term issues and complications associated with their usage had led to this material being not favoured by surgeons.

Sometimes combination of different biomaterials can offer satisfactory outcome as well. Zhu et al has introduced the usage of bone wax and absorbable porcine acellular dermal matrix to form barrier and prevent future re-ankylosis at resected ankylotic mass region (Zhu et al., 2021). The xenogenic origin of porcine acellular dermal matrix offers no donor site complications, no obvious foreign body reaction as per other alloplastic materials and no overt surgical site post-op infection; meanwhile the bone wax of beeswax origin with Vaseline softening agent content allows easy adaptation to bleeding bone for haemostasis, form physical barrier with thin layer application, disrupting osteogenesis by minimizing new blood vessels formation and preclude osteoblasts into surgical site and prevent heterotopic calcification done (Papay et al., 1996; Wellisz et al., 2008). However, patients' religious and cultural aspects need to be respected as the porcine origin are not acceptable for some groups of patients.

5.2 Post-operative mouth opening and jaw physiotherapy

Good post-operative mouth opening was achieved in all the cases reported in the articles. In this systematic review, most patients were able to achieve mouth opening of between 30 to 40mm throughout their follow-up. Most articles did not report the post-operative range of jaw movement during protrusion and excursion. This measurement is necessary to understand the function of the jaw following interpositional arthroplasty. Due to the lack of data, comparison of range of movement during protrusion and excursion for different biomaterials was not able to be carried out.

Good compliance of patients for post-surgery jaw physiotherapy can aid in muscle stretching to original length to overcome pre-existing fibrous adhesion, muscle training to regain muscular strength and minimize re-ankylosis issue (Agarwal et al., 2021).

Intensive early jaw physiotherapy can ensure good long term surgical outcome. Surgeons can either recruit experienced physiotherapist on-board (Dimitroulis, 2004) or follow regimen as per surgeons' experience. Some centres recommended passive jaw exercise prior to active jaw physiotherapy, while others promote active jaw exercise to be commenced as soon as possible right after surgery.

For passive jaw exercise, surgeons encourage patients to chew on chewing gum (Siddiqi et al., 2013) during early post-operative period, or to move mandible vertically or horizontally with frequent soft diet chewing (Qudah et al., 2005) for few days to 1-week post-surgery to gradually increase joints mobility before switching to more intense active jaw physiotherapy. Rocabado exercise for good postural control can be alternative as well (Dimitroulis, 2004).

Different types of active jaw physiotherapy devices that are used to help patients in performing jaw exercise effectively are: elastic traction; Heister's mouth opener / modified Heister's jaw opener / mouth prop / bilateral rachet mouth prop / Fergusson mouth gag; wooden spatulas / tongue depressors; custom made acrylic jaw exerciser or mouth opener; mouth gag with expansion screw / cone-shaped acrylic trismus screw / silicone wedges; Therabite devices; and Spring-Bite devices

For regimen of jaw exercise, some surgeons will start jaw exercise first day right after surgery (Bulgannawar et al., 2011; Kalra & Kakkar, 2011; Singh et al., 2014; Singh et al., 2011), or second days after surgery (Aggarwal et al., 2015), or three days after surgery (Bayat et al., 2009), or 7 days after surgery (Dimitroulis, 2004). The principle is to start jaw physiotherapy as early as possible after surgery provided patients can tolerate it. However, pain at surgical site during early post-surgery can easily deter patients' motivation to follow the jaw exercise regimen. Therefore, good post-operative pain control is important. This can be achieved by giving analgesics (NSAIDs) (Su-Gwan, 2001), adjuncts with ultrasound at surgical site (Dimitroulis, 2004), concurrently with

steroids (prednisolone) (Guruprasad et al., 2010) and antibiotics. Intermaxillary fixation with arch bar temporarily is also an alternative to reduce pain, ensure satisfactory occlusion and promote healing of new resected joints (Qudah et al., 2005). Patients can perform the jaw exercise 6 to 8 times per day or every hourly (Malhotra et al., 2019); gradually increase in frequency or as frequent as possible with each series for seconds initially and increment to 5 minutes and later 15 minutes depends on regimen and types of devices used for jaw exercise, up to 6 months (Babu et al., 2013; Hegab, 2015; Roychoudhury et al., 2020; Younis et al., 2021). Zhang et al. (2018) even advocated jaw physiotherapy up to 2 years to prevent recurrence. Patients need to be reinforced and emphasized that compliance with jaw exercise is crucial to maintain good maximal incisal opening. It has been observed that the more severe the types of ankylosis (Sawhney Type IV), the higher chance of recurrence to occur. Hence more aggressive jaw physiotherapy is mandatory to ensure good maximal incisal opening (Mohamed, 2020).

5.3 Complications

Although not rare, re-ankylosis or recurrence is one of the most unwanted long-term complications following interpositional arthroplasty (n=14, 2.2%). This usually happened when patients were not compliant with post-operative jaw physiotherapy (Kaban et al., 1990).

One of the immediate post-operative complications that was reported is facial nerve paralysis. This complication is related to surgical access to the temporomandibular joint. Most surgeons utilized preauricular approach to gain access to the ankylotic joint. It has been reported that incidence of facial nerve injury can range from 1% to 25% (Moin et al., 2018). Of the 51 cases of facial nerve injury reported, 47 were transient and 4 were permanent. The possible causes of facial nerve injury during TMJ surgery are listed in Table 5.1.

None of the reported complications were directly related to the biomaterial itself.

Table 5.1 Possible causes of facial nerve injury (Weinberg & Kryshtalskyj, 1992)

1. Trauma from heat electrocoagulation
2. Deep ligatures or plication sutures
3. Crushing by forceps or clamps
4. Excessive retraction and traction
5. Nerve transection
6. Haemoatoma or edema in nerve sheath
7. Inflammation or infection
8. Distortion of normal anatomy by adhesions from previous TMJ surgery

5.4 Follow-up duration

For the interval of review, the included studies reported follow-up interval of 1-week post-op, 2 weeks post-op, 1-month post-op, 3 months post-op, 6 months post-op, 12 months post-op; and more frequent visits were advocated if there were post-surgery complications. Early review post discharge from ward can identify surgical sites and donor sites complications, such as infection that need to supplement with antibiotics, or wound dehiscence that may need further wound care management (Dimitroulis, 2004; Singh et al., 2011). Regular follow-up is also important to verify if patients are doing the jaw exercise correctly with any early signs of recurrence. Unless patients have defaulted on the review session, the review sessions can last up to 20 years as per articles included in this research (Chossegros et al., 1997). There is no definitive timeframe or end point of follow-up when patients can be discharged from the respective centers care. This is because signs of recurrence can be detectable from as early as 6 months to 1.5-year post-surgery, or only become prominent 3 years after surgery (Lin et al., 2019; Mehrotra et al.,

2008; Qudah et al., 2005). Based on these articles, it is suggested that a minimum of 3 years follow-up is recommended to ensure late occurrence of recurrence can be identified before condition worsens.

5.5 Limitations

During the conduct of this systematic review, a few limitations were identified. There were inadequate RCT studies that were conducted to compare various types of biomaterials for interpositional arthroplasty. As mentioned before, most of the studies were from Asian countries mainly India. This can skew the outcome of surgery as socio-economic status, patients awareness and pain threshold may affect the compliance to post-operative jaw physiotherapy and follow-up which can affect long term outcome of the surgery. None of the included non-RCT studies were of low risk of bias. Five (19.2%) of these were of high risk of bias while the remaining (80.8%) were of some concern of bias. Two of the RCT studies were of high and some concern of bias. This resulted in this study lacking high quality included studies. Some of the included studies did not record important information such as exclusion criteria, imaging findings and range of jaw movements during protrusion and excursion. This has led to incomplete data collection and comparisons cannot be made among the different biomaterials.

CHAPTER 6: CONCLUSIONS

Within the limitations of this study, the following conclusions can be made:

1. The most utilized biomaterials in interpositional arthroplasty are temporalis myofascial flap / temporalis fascia and fat grafts (buccal fat pad and abdominal fat).
2. All the studied biomaterials are able to produce good post operative mouth opening.
3. Reported complications are mostly related to surgical techniques and patients' compliance to jaw physiotherapy rather than the biomaterials itself.

Each biomaterials have its own pros and cons upon application clinically. Good pre-surgical planning with aid of radiographic imaging can reduce intra- and post-op complications. Compliance of patients to jaw physiotherapy can ensure long term success.

More high quality randomised controlled studies should be conducted to allow better comparison between different biomaterials for interpositional arthroplasty.

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