Vascularised versus Non Vascularised Autogenous Bone Grafts for Immediate Reconstruction of Segmental Mandibular Defects: A Systematic Review

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Abstract

Introduction: This systematic review was performed to address the focus question " what is the various success rates and complications of both vascularised and non vascularised bone grafts for immediate segmental mandibular reconstruction" in addition, this paper reviews various forms, recent advances and possible complications of autogenously vascularised and non vascularised bone grafts for mandibular reconstruction that were previously discussed in the literature.

Methodology: A thorough Medline database search performed on related terms yielded 389 titles. 202 studies were excluded after title screening. Out of 187 abstracts selected, 180 full text articles were obtained for further evaluation. Results showed that a total of 51 studies followed the inclusion criteria included in this systematic review. A primary analysis of the included studies showed that the majority were case series studies (37 articles) and only 5 Randomized controlled trials and 12 case reports were identified with most not providing objective outcomes of their results. Therefore quantitative data analysis and subsequent meta-analysis could not be performed. Results showed variable success rates and complications of different immediate autogenously graft forms.

Conclusion: both vascularised & non vascularised bone grafts could be used with different range of satisfactory results depending on many factors such as the size and site of the defect, patient age, histopathology of the lesion, fixation methods and radiotherapy.

***Key Words**: Vascularised, Non vascularised, Autogenous bone grafts*

Introduction

The mandible is very important for facial aesthetics and is also responsible for mastication and speech. Resection of the mandible is often indicated in the treatment of some infections, odontogenic tumors, severe trauma and oral cancer that represent a great challenge for surgeons because of the complexity and unique anatomy of the mandible. The main target of reconstruction of discontinuity defects of the mandible is to restore cosmetics, maximize function, mastication and preserve appearance and quality of life.

Treatment of segmental mandibular defects is considered a complex process. Various techniques of reconstruction, ranging from simple bridging plates to composite free flaps have been adopted; each has its advantages and disadvantages. Till now, autogenous bone grafts is still considered to be the gold Standard and the most preferred method in reconstruction of such defects.

There are various forms of the autogenous bone grafts either vascularised, non vascularised or pedicled flaps depending on the type of the defect required to be reconstructed, the most popular donor sites for free non vascularised grafts are the iliac crest; either anterior or posterior; and costochondral (rib grafts). Mandible reconstruction was revolutionized by the introduction of micro-vascular surgery, and the subsequent development of vascularised bone grafts. The evolution began with the initial development of vascularised iliac crest graft, later followed by vascularised fibula, radial forearm, and scapula grafts. These types of grafts led to the high success rate and significantly improved functional outcome seen in mandible reconstruction today.

The use of pedicled myocutaneous flaps is considered an available option for successful transfer of well-vascularised tissue into the defect. Osteomyocutaneous flaps, such as temporalis with parietal bone, sternocleidomastoid with clavicle, trapezius with scapula, pectoralis major with an associated rib, were used for mandible reconstruction with marginal success. Less resorption was found compared to nonvascular zed bone grafts, but functional results were generally poor due to the less than optimal quality of the transferred bone.

The objective of the review was to identify and compare the advantages and complications of autogenous bone grafts; vascularised and non vascularised; for immediate reconstruction of mandibular segmental defects as confirmed by the literature so as to influence the selection of an ideal grafting technique based on clinically relevant recommendations that finally will affect patients' quality of life.

Materials and Methods

Focus question

The focus question to be addressed was "what are the various success rates and complications of both vascularised and non vascularised bone grafts for immediate segmental mandibular reconstruction?"

Search strategy

A search in the MEDLINE (Pubmed) database was performed on 1/7/2014 using the following search query:

- #1: mandible OR mandibular (Mesh Terms)
- #2 (A): resection OR osteotomy OR discontinuity OR mandibulectomy OR mandibulotomy.
  (B): rehabilitation OR reconstruction.
  (C): immediate OR simultaneous.
- #4: Success rates OR successful (Mesh Terms)

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A hand search of journals was additionally undertaken to maximize the likelihood of capturing all relevant publications *Table 1*. Reporting of this review was based upon PRISMA guidelines.

Study selection

The result of this search yielded 389 titles that were independently screened by two reviewers (M.M. & A.A.).

Out of the 389 titles identified via Pubmed and hand search, both reviewers agreed to exclude 202 articles after screening titles and 187 articles were included to the second level of the search.

After subsequent screening and out of the 187 articles, 8 were excluded after screening abstracts and 128 were also excluded after subsequent screening of their full texts by the same reviewers.

At each level, any disagreements were discussed until a consensus was reached. Finally, 51 full text articles were relevant to the inclusion and exclusion criteria of this review and also related to the answer of our PICO question formulated previously *(Figure 1)*.

Excluded studies: *Table 2*

After full text screening, the 129 articles were excluded from final analysis due to the following reasons:

- Review articles
- Languages other than English language
- Animal studies
- Articles utilized non grafting procedures for reconstruction of the defects e.g Distraction osteogenesis
- Grafts other than autogenous bone

Quality assessment and data extraction

A Standardized descriptive tables was used to record data for each article within the inclusion and exclusion criteria. Two reviewers evaluated the descriptive tables independently and any disagreement was resolved through open discussion *(Tables 3-4)*.

From the included articles the following data were extracted *(Table 5)*:

Table 1. Systematic search strategy.

Population	#1- mandible OR mandibular (Mesh Terms)
Intervention	#2- (A)-resection OR osteotomy OR discontinuity OR mandibulectomy OR mandibulotomy. (B)-rehabilitation OR reconstruction. (C)-immediate OR simultaneous. (D)- (A) AND (B) AND (C)
Comparison	N.A
Outcome	4#- Success rates OR successful (Mesh Terms)
Search combination	#1AND # 2 #1 AND #2 OR #4
Database Search	
Language	English
Electronic	Pubmed
Journals	Journal of Oral Maxillofacial Surgery ,Journal of Craniomaxillofacial Surgery, International Journal of Oral and Maxillofacial Surgery, Journal of Clinical Oncology, Oral Surgery Oral Medicine Oral Pathology Oral Radiology Endodontics.plastic reconstructive surgery, british journal of oral and maxillofacial surgery.

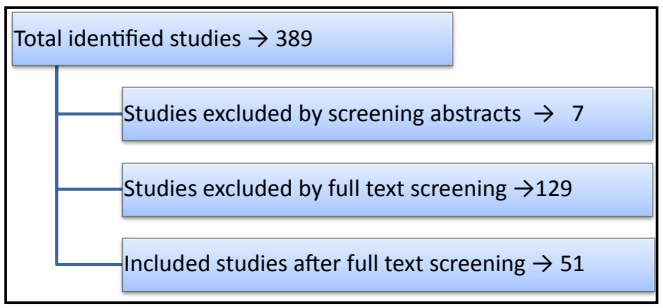

Figure 1. *Search strategy.*

Table 2. Selection criteria.

Inclusion criteria	English language Case series and R.C.T. Case reports Human studies only Computer guided mandibular segmental resection and recomstruction Vascularized and non vascularized bone graft.
Exclusion criteria	Languages other than English language Animal studies Articles utilized non grafting proceduresof the defects e.g Distraction osteogenesis Bone grafts other than autogenous bone

Table 3. Studies included for Data Extraction.

Type	Number	Studies
R.C.T.s	5	Lawson et al. [1], Kim and Donoff [2], Foster et al [3], Head et al [4], Zou et al. [5],
Case report	12	Schultze-Mosgau et al. [6], Montoro et al. [7], Hutchison et al. [8], Chen et al. [9], Cervelli et al. [10], Cuesta Gil et al. [11], Schepers et al. [12], Yoshimura et al. [13], Ziang et al. [14], Freudlsperger et al. [15], Khosla et al. [16], Pierse et al. [17].
Case series	34	Obwegeser and Saller [18], Barnes et al. [19], Sclaroff et al. [20], Shaha et al. [21], Hao et al. [22], Puxeddu et al. [23], Gerzenshtein et al. [24], Simon et al. [25], Vayvada et al. [26], Curi et al. [27], Shirani et al. [28], Warren et al. [29], Young et al. [30], Chana et al. [31], Chiapasco et al. [32], Hanasono et al. [33], Nocini et al. [34], Yi-qun et al. [35], Tosco et al. [36], Boffano et al. [37], Zhou et al. [38], Broer et al. [39], Ferri et al. [40], Fujiki et al. [41], Sonmez et al. [42], Zheng et al. [43], Kim et al. [44], Bianchi et al. [45], Sandor et al. [46], Zheng et al. [47], Landes et al. [48], Levine et al. [49], Simon et al. [50], Zhang et al. [51].
Total	51	

- Author
- Year of publication
- Study design
- Number of patients
- Histopathology of the lesion
- Site of the affected mandible
- Timing of grafting procedure
- Type of bone graft
- Method of fixation
- Prosthetic rehabilitation
- Follow-up
- Results

Statistical analysis

A preliminary analysis of the included studies showed that

Table 4. *Critical Appraisal: Risk of bias of randomized clinical trial according to Cochrane collaboration tool.*

Study	Adequate Sequence Generation?	Allocation Concealment?	Blinding of Participan?	Incomplete Outcome Data Addressed?	Free of selective Outcome Reporting?	Other Sources Of Bias?
Lawson et al.	yes	N.I	yes	N.I	yes	no
Kim and Donoff	yes	No	N.I	yes	N.I	no
Foster et al.	N.I	N.I	yes	N.I	N.I	no
Head et al.	no	Yes	N.I	N.I	no	no
Zou et al.	N.I	Yes	N.I	N.I	yes	no

N.I=Not Identified.

Table 5. *Data extracted from the articles.*

Author	Year	Study design	No of patients	Mean age	Histo-pathology	Site	Timing	Type of bone graft	Method of fixation	Prosthetic rehabilitation	Mean Follow up	Results
Lawson et al.	1981	R.C.T	54	N.I	ORN SCC Odontogenic tumers	Symphysis Body Angle condyle	GP1: immediate GP2: delayed	Vascularized and non-vascularized iliac –rib-clavicle	Titanium mesh tray	Removable denture	6mths-5yrs	90% Success Rate with Delayed-46% success rate with delayed
Kim and Donoff	1992	R.C.T	41	52± 18.1	28 cases were malignant	GPA: ant. Mand GPB: body GPC:Ramus + condyle	29 pts (delayed) 12 pts (immediate)	Rib ,iliac, Coronoid grafts	AO recons-truction plate	No dental implants	N.I	17.2% revised of delayed reconstruction 33% was revised of immediate reconstruction
Foster et al.	1999	R.C.T	75	49	Trauma, ORN Benign Malignant	NI	IMMEDIATE For both groups	Vascularized (fibula) & non Vascularized bone Grafts	NI	Dental implants	NI	Graft union : 69%(NON VASC. BONE GRAFTS) 96% in Vasc. Bone grafts
Head et al.	2001	R.C.T	210	Oral cancer Benign lesions Trauma ORN	GP 1: 151 ptsvasc. Grafts GP:59 pts rec-onst. Plates With soft Tissue flaps	Lateral Antero lateral Mandibular defects	immediate	Vascularized (fibula Iliac crest Radial,Forearm Scapular **GP 2**:rectus Abdominis Radial fascio-cutaneous flaps	Reconst. Plates , Mini plates	NI	20 months	94 % success rate In group 1 92% success rate In group 2
Zhou et al.	2013	R.C.T	32	42.4	Amloblastoma SCC Okc Myxoma	Body,ramus symphysis	Immediate reconstruction	Vascularized Iliac crest Group 1: Immediate Implant Placement (55) Group 2: Delayed Placement (55)	Mini-plates	Fixed implant Supported prosthesis	8-12 years	Graft survival rate was 100% dehiscence occurred in 2 pts without graft loss
Shultze-Mosgau et al.	2005	Case report	1 patient	7 years	Ewing sarcoma	Body, ramus	Immediate Reconst.	Fibula flap	Reconst-ruction plates	NI	12 months	No signs of local or Systematic recurrence

Montoro et al.	2008	Case report	1	47	ameloblastoma		immediate	Non vascularised iliac crest	Mini plates Recon-struction plates	Implant supported prosthesis	8 months	Excellent graft consolodation
Hutchi-son et al.	2009	Case report	1	69	osteosarcoma	Mandibular ramus	immediate	Vascularized Scapular flap	Reconst-ruction Plates pre-Bended on Stereo-model	Dental Implants (cantilevered prosthesis)	30 mnths	Successful Immediate rehabilitation
Chen et al.	2010	Case report	1	14	Fibrous displasia	Symphesis , body, ramus, condyle	Immediate Reconst.	Non vuscularized Double Costo-chondral graft	Reconst-ruction plates mini-plates	Removable Partial denture	3 yrs	Successful Immediate reconstruction
Cervelli et al.	2012	Case report	1	13	Desmoplasti-cameloblas-toma	From angle to angle	immediate	Vascularized fibular graft	Reconst-ruction plates	Dental implants	N.I	successful Free fibular graft without reccurance
Cuesta Gil et al.	2012	Case report	1	33	Uni-cystic ameloblastoma	From Canine to second molar	immediate	Vascularized iliac crest	Reconst-ruction plates	Immediate implant placement	10 yrs	Successful graft and Implants
Schepers et al.	2012	Case report	1	68	ORN	Mandibular body	immediate	Vascularized fibular graft Guided by occlusion	Reconst-ruction plates	Computer Guided immediate Implant placement	N.I	Successful graft and implants
Yo-shimura et al.	2013	Case report	1	35	Ossifying fibroma	Body, condyle	immediate	Non Vascularized iliac crest	Mini-plates	Dental implants	10 yrs	Successful, no recurrence
Ziang et al.	2013	Case report	1	19	Aneurismal bone Cyst	condyle	immediate	Costo-chondral graft	Reconstru Ction plates	N.I	6 mths	No evidence of Recurrence
Freudls-perger et al.	2014	Case report	1	56	SCC	Floor of mouth	immediate	Free Vasclarized Fabular graft	2.4 AO plates	Dental Implants BAR supported prosth		Successful Mandibular reconstruction with immediate Prosthesis
khosla et al.	2014	Case report	1	12	Chondromyx-oid fibroma	Ramus, angle Body,condyle	immediate	Vascularized 7th rib (EVE PROCE-DURE)	Reconst-ruction plates	N.I	3 yrs	Normal growth Pattern. Normal growth pattern.
Pierse et al.	2014	Case report	1	15	Gngilio neuroma	Hemi-mandible	immediate	Free Fibula micro vascular flap	Reconst-ruction plates	N.I	1yr	Graft success Without complicationst
Obwegeser and Saller	1978	Case series	10	50	Ameloblastoma carcinomas	Body, ramus, condyle	immediate	Non vascularized Iliac crest, costochondral	Direct bone wiring	No implants	N.I	7 successful 3 failure
Barnes et al.	1981	Case series	5	57.4	carcinomas	Body , symphsis	4 Immediate 1 delayed	Sternocleido-Mastoid Musculo-Clavicular graft	External pin Fixator device	N.I	1-3 yrs	All grafts are vital
Sclaroff et al.	1994	Case series	22	N.I	SCC, osteomylitis	Ant and lateral Mandibular defects	immediate	Vascularized Iliac & fibular Flap	Reconst-ruction plates	Dental implants	N.I	4 died due to Metastasis 2 lost implants
Shaha et al.	1997	Case series	6	47-60	osteradione-crosis	Angle, Symphysis body	immediate	Free fibular Flap	Mini-plates	Implants in 1 pt	Mean= 33 mnthss	All pts healed Primarily

Hao et al.	1998	Case series	3	23	Ameloblas-toma, Fibrous dysplasia	Ramus, body	immediate	Free fibular Flap	Reconst-ruction plates	Primary Implant placement	30 mnths	Free fibular Flap restored Function and Contour
Puxeddu et al.	2003	Case series	12	62.5	SCC	N.I	immediate	Free iliac crest flap	Reconst-ruction plates	N.I	21 mnths	10 pts showed complete flap integration, 2 pts died
Gerzen-shtein et al.	2006	Case series	3	40	ameloblastoma	Symphysis, Body, angle	immediate	Free fibular Graft	Reconst-ruction plates	No implants	3 yrs	Intact Reconstruction
Simon et al.	2006	Case series	11	27	ameloblasto-mas	Symphysis, body, angle	immediate	5 pts: autog-enous particu-late non vascularized bone graft + platelets rich plasma (PRP)	Two 2.4 plates	No pros-Thetic reha-bilitation	N.I	7 pts showed uneventful wound healing and failure oc-curredin 4 pts
Vayvada et al.	2006	Case series	11	25.4	ameloblastoma	Body, angle	immediate	Free fibular Flap, circum-Flex iliac Artery flap	Reconst-ruction plates, mini-plates	Dental implants in 3 pts	29.3 mnths	All flaps sur-vived totally, no recurrence
Curi et al.	2007	Case series	5	61	ORN	Symphsis, body, ramus	immediate	Composite fibular Flap	Reconst-ruction plates	N.I	25 months	4 success 1 failure
Shirani et al.	2007	Case series	7	13-46	Benign , locally aggressive le-sions	Body,ramus, condyle	immediate	Iliac crest block autog-enous graft (non vascularized) + refixation of condylar process of the resected segment	Recon-struction plates	N.I	Up to 5 years	All the pts showed excel-lent graft con-colidation& and uneventful wound healing
Warren et al.	2007	Case series	7	10.4	Mandibular Hypoplasia, fibrous Dysplasia, Osteomylitis, hemi facial microsomia	Ramus, con-dyle	immediate	Fibular, Scapular, parascapular free Flap	Mini-plates	Dental im-plants in 2 pts only	10.5 yrs	all flaps were Successful except 1 partial flap loss
Young et al.	2007	Case series	26	29.8	Locally aggressive pts	Varies areas of mandible	delayed	N.I	Reconst-ruction plates	Implant sup-ported pros-thesis in 7 pts	18 months	Males showed higher quality of life than females
Chana et al.	2008	Case series	13	32	Ameloblasto-mas	Body,angle, ramus	immediate	Free fibular Flap and sural Nerve grafts	Reconst ruction plates	Implants immediately placed	40.1 months	All grafts were Successful, no recurrence
Chi-apasco et al.	2008	Case series	29	35.7	Benign lesions	N.I	Immediate, delayed	,Non Vascularised iliac crest ,calvarial bone grafts	Recon-struction plates	16 pts received implant sup-ported pros-thesis	94 months	Successful graft concoli-dation in all pts except in 1 case that showed partial graft loss. Pts satisfaction was given a score.
Hanasono et al.	2008	Case series	39	N.I	SCC,Sarcoma, Adenoid cystic carcinoma	34 cases showed Affected mandibles	immediate	Rib,fibula and Iliac crest flapN.I	N.I	N.I	156 MONTHS	66.7% showed no Evidence of Disease

Nocini et al	2008	Case series	7	61	Biphosphonate-Related osteomylitis	Subtotal mandibule ctomy , 1 case including condyle	immediate	Fibular free Flap shaped by Stereo model	2mm, 2.4 mm locking plates, mini plates	No implants	23 months	All grafts survived
Yi-qun et al.	2008	Case series	29	47.1	Malignant and benign	14 pts with affected mandibles	Immediate 2 delayed	Fibular free flaps	Reconst Ruction plates	Immediate and delayed implant placement	47.8	All grafts survived 1 pt received addition bone grafts
Tosco et al.	2009	Case series	18	N.I	Central giant cell granuloma	12 cases Showed affected mandibles, 6 maxilla	immediate	All pts (non vasc. Iliac crest),1 pt receive fibula free flap	Mini plates Reconstruction plates	Implants were placed	65 months	All grafts Survived, no lost implants
Boffano et al.	2010	Case series	10	40.1	Odontogenic myxomas	8 of the pts affecting Mandible (body)	immediate	Non vascularised iliac crest	Reconstruction plates	N.I	67.3	Successful immediate grafts
Zhou et al.	2010	Case series	6	28.5	Benign tumors	Body,ramus, condyle	immediate	Non Vascularised Iliac crest	3D prefabricated individual l titanium prosthesis using Rreverse Engineering (RE),CAD CAM technique	Dental Implants in 1 patient only	50 months	Woun healing was uneventful. Except In one pt who developed Infection and fistula formation
Broer et al.	2012	Case series	38	32	ameloblastomas	18 mandibles 2 including condyle	immediate	Free fibula	Reconstruction plates (CAD CAM	Implants for 16 patients	N.I	7 cases develop Failures)
Ferri et al.	2012	CASE SERIES	2	Less Than 4 years	Desmoplastic fibromas	Hemi mandible	immediate	Rib grafts non vascularised	Mini plates	N.I	24-36 MONTHS	Uneventful healing in 2 pts 1 pt need extra grafting Procedure
Fujiki et al.	2012	Case sseries	56	60.2 ±11.1	Oral cancers	Segmental Mandibulectomy	immediate	Vascularised fibula and scapula	N.I	N.I	N.I	13 pts of fibula group showed skin graft loss
Sonmez et al.	2012	Case series	10	29.25 ±16.22	ameloblastomas	Body, angle ramus Condyle in 2 pts	immediate	Iliac crest flap	Mini plates	N.I	2 years	Successful iliac crest flaps
Zheng et al.	2012	Case series	9	37	Benign lesions ORN carcinoma	Body, ramus condyle in 2 cases	immediate	Fibula free Flap using a positiong Template	Prebended reconstruction plates	Immediate implant placement	15 months	All graftsand implants survived Using CAD/ CAM technology
Kim et al.	2013	Case series	3	19-23	Ameloblastoma Ossifying fibroma	Buccal bone resection	immediate	N0n Vascularised iliac crest	Mini plates	Dental Implant placement	3-8 years	Graft Consolidation, no Recurrence
Bianchi et al.	2013	Case series	31	50.9	ameloblastomas	Symphysis, angle Posterior body	Immediate in 14 cases	Free iliac Crest,fibula flap	Mini plates	Implants in 25 pts (immediate , delayed)	5.3 months	All flaps were transplanted succssefully
Sandor et al.	2013	One Case	1	55	ameloblastoma	Anterior mandible	immediate	Autogenous adipose stem cells, B tricalcium phosphates , BMP-2	Titanium mesh And reconstruction plates	Detnal implants	N.I	Adipose stem cells BMP-2, BTCP is a promising reconstruct For large defects

Zheng et al	2013	Case series	4	41	Benign,malignant ORN	Segmental mandibul-ectomy	immediate	Fibula free flap using CAD/CAM	Mini plates	N.I	14 months	No recurrence ,restoration of facial symmetry
Lands et al	2013	Case series	2	30	Oateosarcoma Unknown in-fection process	Body, ramus, condyle	immediate	Vascularized iliac crest, fibula	Total prosthetic joint Replace-ment, reconstruc-tion plates	Implants in 1 pt	45.5 months	Uneventful Healing
Levine et al	2013	Case series	4	25.7	3 of them mandibles Myxoma, ameloblastoma	Symphysis, body	immediate	Vascularised Fibula flap	N.I	Computer guided Implant and prosthesis placement	N.I	a successful single stage total reconstruction
Simon et al	2013	Case series	32	27.6	ameloblasto-mas	Body , symphsis	Immediate	Non vascular-Rised iliac crest + platlet rich plasma (prp)	2.4 plates	Removable partial Dentures for 13 pts only	6 months-7 years	Successful grafting proce-dures in 29 pts Recurrence in 1 pt & infec-tion in 2 pts
Zhang et al	2013	Case series	33	37.88	Benign lesions	N.I	28 Immediate And 5 delayed	Deep Circumflex Iliac artery flap	N.I	Dental implants in 25 pts	26 months	1 flap loss occurred, sur-vival rate was 96.97%

• N.I: not identified
• ORN: Osteoradionecrosis

the majority of studies were case series studies. Moreover only 5 randomized Clinical trials were identified. Therefore, quantitative data analysis and subsequent meta-analysis could not be performed.

Most of these studies did not give a numerical value for their results; they evaluated outcomes such as patient facial appearance, contour, mastication and speech in terms of patient satisfaction.

Results

The results of this search identified 51 full articles that were included in this systematic review of immediate autogenous bone grafting procedures for mandibular segmental defects. Of these articles, 5 studies were randomized controlled trials, 12 case reports and the remaining studies were case series *(Table 3)*. Since no meta- analysis was possible the review of these studies will be descriptive in nature.

Vascularised bone grafts

The search identified 35 articles addressing reconstruction of case series or Randomized Clinical Trials. The outcome of almost all the articles utilizing autogenous vascularised bone grafts depended on quality of life, patient satisfaction in terms of facial symmetry and function (such as swallowing and mastication) so no numerical data could be extracted from such results. Some authors depended on patient questionnaires to identify patients' opinion about the aesthetic outcome of the reconstruction procedure 26.

Microvascular free flaps are popular and become the most commonly used method of mandibular reconstruction. Vascularised bone grafts are widely recognized to be the most reliable method to achieve single stage, immediate reconstruction of the mandible, and therefore they represent the gold standard against which other methods should be compared [4]. The focus of these results relates to the use of osseous free flaps for mandible reconstruction. Although these vascularised bone allows for the replacement of living bone with living bone. Bone healing mainly resulting in a stable union between the flap and graft can be expected within 2–3 months in the majority of the cases in spite of preoperative or postoperative radiation therapy [52].

Careful donor site selection will allow for the use of a single flap to reconstruct the defect in most patients. The four osteocutaneous donor sites used most commonly for mandible reconstruction are the fibula, iliac crest, radial forearm, and scapula . Each donor site differs in the quality and quantity of available bone and soft tissue, the quality of the pedicle, donor site location permitting a two-team approach, and the potential for osseintegrated dental implants. The anatomic requirements of the defect coupled with donor site factors determine flap selection [53].

Several studies with a primary focus on the advantages and complications of each donor site, Since Hidalgo's initial report [54], the free fibula osseous or osseocutenous flaps has been considered the gold standard and the flap of choice for mandibular segmental reconstruction, this type of flaps provides many advantages Over previously described methods [55,56], many articles in this review reported on the advantages of the fibular flap [6,10,12,17,19,22,24]. First, it allow the surgeon to perform multiple osteotomies to shape the neomandible without divascularizing the flap due to segmental blood supply. Also, it has a Large and reliable vascular pedicle with sufficient caliber vessels. Furthermore, it could be harvested by another team simultaneous to the mandibular resection [57] that finally allow to decrease the overall operation time.

Some studies discussed the success of the free fibula flap

in cases of condylar reconstruction (cases of disarticulation), they recommend such technique due to the presence of fibula growth centers at its epiphesis and mid way which did not restrict growth in children.

Difficulties of segmental reconstruction using fibular flaps were mentioned briefly in the literature; Ambulation is a major concern regarding the free vascularised fibula which is still controversial. In elderly patients, there is a delay in mobilization that may cause some complications as gait disturbance and venous thrombosis. Peirse *et al.* [17] reported that the length and width of the fibula allow either immediate or delayed dental implant placement due to sufficient bone volume with average cross sectional 90 mm^2 [17]. However, there is a height discrepancy between the native bone of the mandible and the graft that cause a great inter-arch space between the graft and the opposing arch causing aesthetic and functional problems. They suggested a double barrel technique to solve such problem. Vertical distraction osteogenesis using a distractor device is another solution that was performed by Yi-Qun *et al.* [35] as an alternative to the double barrel procedure for treatment of such problem.

The Results also showed that 9 descriptive publications [4,5,11,20,26,33,42,45,48] reported on the use of iliac crest free flaps for immediate reconstruction of mandibular defects. Unlike other free flaps, vascularised iliac crest flaps provides optimal bone quantity and quality and also height for implant placement.

Vayvada *et al.* [26] recommended the used of iliac free flaps for their natural curvature that already anatomically contoured for mandibular reconstructions and it also includes sufficient soft tissue component for composite defects. The donor site scar is superior to those of other choices. Conversely, the attached soft tissue is of extensive bulkness, higher blood loss and limited length of the harvested bone if compared with fibula is a major disadvantage of this flap.

From the limitations of this flap is the presence of short vascular pedicle, the skin island is thick and relatively unreliable and immobile and the donor site morbidity that may occur as hernia, numbness in hip region and gait disturbance. Scapular flaps were considered from the available donor sites that were used for immediate rehabilitation of mandibular segmental defects, 4 articles in this review describes the use of such flaps [4,8,29,41].

The scapula flap is based upon the circumflex scapula artery, Vessel length and diameter is good. Up to 14 cm of bone that is inferior in quality to the fibula and iliac crest can be harvested. An axial (parascapular flap) and/or transverse (scapular flap) skin island, and all could be based on the same pedicle. Moreover, the high reliability of soft tissue based on the subscapular system that gives a good seal of the oral mucosa without dead space. The main objection to the use of the scapular flap for mandibular reconstruction is the approximately longer operation than that of other donor sites due to the inconvience of changing the patient's position during the operation [58,59].

In a randomized clinical trial, Head *et al.* [4] utilized various donor sites, from them the radial forearm. Although up to 10 cm of bone could be obtained from the radius, the circulation is tenuous and also osteotomies is hazardous, furthermore, radial donor site closure and post donor fractures are problematic.

Khosla *et al.* [16] conducted a study on the use of vascularised 7th rib musculo-osseous flap with cartilage (EVE FLAP) for immediate segmental reconstruction of a chondromyxoid fibroma affecting the mandible of a 12 years old child. after 3 years follow up, results showed that there was normal bone union, excellent range of jaw opening, although the pattern of growth of such flap is unpredictable, but they considered this method feasible for reconstruction of adolescents.

Non vascularised bone grafts

The literature contains a number of studies evaluating the success and various complications associated with non vascularised bone grafts for reconstruction of mandibular defects. According to this search, 15 publications were identified evaluating the use of these type of grafts.3 randomized clinical trials [1-3], 3 case reports [7,9,13] and 9 case series [18,25,28,32,36-38,40,44,50]. The most popular extra oral donor sites for non vascularised bone grafts are the iliac crest(either anterior or posterior) and the costochondral grafts that mainly used for reconstruction of disarticulation cases.

Autogenous bone grafts harvested from the ileum were considered to be a very reliable method for the reconstruction of mandibular defects following ablation of mandibular tumours. The advantages of the non-vascularised iliac bone grafts were discussed by Kim *et al.* [44] as they claimed that this type of grafts characterized by large volume (ranges from 50 cc to 90 cc), shorter surgery and recovery time, no necessity for microvascular surgical expertise, a 2-team approach could be performed, minimal donor site morbidity, minimal recipient site scarring. Moreover, it has the advantage of that it could be harvested in various forms such as block and particulate either cortical or cortico- cancellous. Iliac bone has been associated with large degrees of resorption. Studies have demonstrated long-term mandibular reconstruction with free iliac bone graft and implant placement [60,61]. Iliac graft resorption has been attributed to its endochondral origin [62] and corticocancellous morphology.

In a case report conducted by Chen *et al.* [9] for immediate reconstruction of a hemi mandibular defect including the condyle, they recommended the use of double non vascularised costochondral grafts, one for reconstruction of the inferior border and the other for alveolar process reconstruction. The results were very promising in adolescents.

However, in spite of significant advances in bone-grafting techniques, internal splinting, and methods of fixation, reported failure rates of greater than 50% [63] and overall complication rates approaching 70% may occur using NVBGs. In addition, dental-implant success rates with NVBGs vary widely, from 60% to 90%.

Composite pedicled flaps

The popularity of the pedicled flaps containing bone increased in mandibular reconstruction due to maintenance of the blood supply to the graft that facilitates bone consolidation [64]. Variety of donor sites such as deltopectoral flap containing clavicle, oblique chest wall flap with rib,the posterior neck skin flap with scapula and sternomastoid muscle flap with clavicle.

According to our search, one study recommended

the composite pedicled flap for segmental mandibular reconstruction. Barens *et al.* [19] in a case series study postulated that pedicled osseto- musculocutaneous flaps were considered another available option for immediate reconstruction of mandibular segmental defects other than vascularised and non-vascularised bone grafts. They conducted a study on 5 patients suffering carcinomas of mandibular body and symphysis that were treated by immediate reconstruction using sternocleidomastoid musculoclavicular graft, the results showed that this is a reliable technique where all grafts were vital and successful.

Discussion

Several case series compared vascularised and non vascularised bone grafts for mandibular reconstruction. Although the nonvascular bone grafts decrease the overall operation time and hospital stay, vascular flaps have shown higher incidence of bony union, faster graft consolidation, fewer operations to achieve union, and minimal donor-site morbidity.

Mandibular reconstruction can be performed immediately, at the time of the resection, or delayed. Both vascularised bone flaps (VBFs) and non vascularised bone grafts (NVBGs) are generally accepted treatment modalities for mandibular reconstruction. Success could be defined as restoration of bone continuity and complete consolidation with absence of infection both clinically and radiographically. The reconstruction was considered complete if prosthetic rehabilitation was accomplished.

Many factors were discussed in the literature affecting success rates of various autogenous bone grafts for immediate segmental mandibular reconstruction. The most common factors are the type of bone graft used whether vascularised or none vascularised fixation methods, defect size & site, histopathology of the lesion, and finally radio and chemotherapy.

Fixation methods

Rigid fixation of the graft seems essential as healing is impaired by movements of the graft and infection with subsequent loss of the graft. Bony mandibular discontinuity defect can be restored using an alloplastic stabilization device with or without bone grafting. An alloplastic device could either be a Titanium mesh tray or one of various designs of mandibular reconstruction plates (MRP).

Mandibular reconstruction plates (MRP) come in various designs and shapes, the AO reconstruction plate, titanium hollow screw reconstruction plate (THORP) and the titanium functionally dynamic bridging plate system. MRPs are rigid enough to restore mandibular continuity while controlling the spatial orientation of the mandibular segments as well as allowing early function. Another advantage is that the bone graft can be directly secured to the plate by screws. However, stress shielding from the use of MRPs has often been stated to be a concern because bone may undergo resorption if it is not stimulated by a functional load following graft incorporation [68]. Several reports document the use of different types of MRPs and their complication rates [69-71].

Titanium mesh trays are easily adapted to the required contour to be then filled with a bone graft. It is said to have a modulus of elasticity similar to that of cortical bone. This, along with placement of the bone graft 10 to 15 mm above the titanium tray, allows bone graft function during the healing phase to reduce bone stress shielding. However, the patients are frequently put in maxilla-mandibular fixation for a period of 1-6 weeks postoperatively, or inter-arch elastics are used in dentate patients to maintain precise dental occlusal control [72].

Zhou *et al.* [38] introduced reverse engineering (RE), computer-aided design (CAD), and rapid prototyping (RP) technique to fabricate customized mandibular titanium trays to precisely restore the mandibular defects. They performed this study on 6 patients with benign lesions affecting the mandible, computer guided segmental resection and immediate reconstruction with 3D prefabricated custom made titanium prosthesis filled with autogenous bone grafts which was attached by extended arms to the residual bone stumps . Wound healing was uneventful in all patients with minimal operative time and excellent facial symmetry. Except in one patient where the titanium tray was removed due to infection and fistula formation due to stress shielding caused by its rigidity and finally replaced by free revascularised fibula flap.

Mini plates are considered available fixation method for the graft either free vascularised or non vascularised. Ferri *et al.* [40] and Fujiki *et al.* [41] used miniplates as a method of fixation between the transplanted autogenous bone grafts and the native mandibular bone stumps. They recommend such technique as there is no bone stress shielding and do not require hard ware removal on the long terms. Simon *et al.* [25,50] used two 2.4 mm plates one superior fixed to the proximal and distal stumps of the alveolar ridges while the other placed inferiorly fixed to the remaining bone segments of the inferior border ,they preferred to use particulate autogenous non vascularised bone grafts and Platlet Rich Plasma (PrP) that were placed into the defect taking support from the 2 plates.

The most common hardware related complications are plate exposure (extrusion), plate-induced infection, screw loosening, screw or plate fracture and temporomandibular joint pain. Plate exposure and infection are commonly related to either insufficient soft tissue closure especially in irradiated patients or excessive pressure on the overlying skin or mucosa by an improperly shaped or bent plate. Screw loosening may be due to an insufficient number of screws per segment, in the presence of excessive muscular load. Early plate fractures indicate an improperly adapted plate, while a late one, often is a sign of cortical bone resorption around the screws so that the plate is no longer adapted to the bone surface. Distraction of the condyle by an improperly adapted plate during screw tightening, results in significant temporomandibular joint (TMJ) pain.

Type of bone grafts, histopathology of the lesion ,radiation therapy

Despite the increasing use of free vascularised bone flaps, non-vascularised autogenous bone grafts still have great support. Carlson and Marx [65] advocated the use of autogenous non-vascularised grafts, particularly cancellous cellular bone (CCB). They pointed out the main advantages to be, being performed on a delayed basis thus respecting the nature of malignant lesions and radiation tissue injury, minimal donor

site morbidity, more anatomic mandibular reconstruction as regards alveolar height and symmetrical arch form, and providing better support for tissue borne or implant supported prosthetic appliances.

Vascularised bone-containing free flaps (VBFFs) are now the gold standard for reconstruction of post-oncologic segmental mandibular defects. According to Wells [66], a vascularised graft allows the possibility of immediate reconstruction especially in hypo-vascular irradiated tissue beds. Moreover, the abundant soft tissue in these flaps particularly suit those types of defects in which a large volume of both intra- and extra-oral soft tissues are resected. Having performed 210 VBFFs, Urken [67] reported an overall success rate of 96%, a flap ischemia rate of 8% that was salvageable in 50% of the cases, and an overall postoperative mortality of 1.5%. He placed a total of 360 implants into those patients with an overall success rate of 92%, decreasing to 86% when placed in post-operatively irradiated bone, and to 64% when placed in pre-operatively irradiated bone.

In a study conducted by Van Gemert *et al.* [73] only 5 (19%) of the 27 irradiated patients had a complication, which is low in comparison to 22 (47%) of the non irradiated patients. The low incidence of complications in irradiated patients in this study may be explained by the fact that almost all irradiated patients had a delayed reconstruction through an extraoral approach. All irradiated patients received HBO2 therapy and intravenous antibiotic therapy continued 10 days postoperatively. Lawson *et al.* [63] found that delayed mandibular reconstruction could be performed with 90% success following a full course of radiotherapy. Adamo and Szal [74] reported an 81% incidence of complications in previously irradiated patients, of which 63% were major. Moreover, Carlson and Marx65 described comparable success rates in irradiated and non irradiated patients.

Site and size of the defect

The site of the defect was important factor that affects the success of the grafting procedure. Segmental resection in the anterior mandible causes the muscles of the floor of the mouth and tongue to lose their insertion to the mandible [73]. Lesions crossing the midline involving the mandibular Symphysis together with an intraoral approach appeared significantly associated with failure and major recipient-site complications. The most common complication was intraoral wound dehiscence, often resulting in graft failure. It is very likely that intraoral wound dehiscence and graft failure are related to the intraoral approach and contamination of the wound with oral micro-organisms.

Concerning the size of the defect ,The results of our search showed that most of the articles recommended the use of vascularised bone grafts for reconstruction of large segmental mandibular defects (> 5cm) specially with adolescent or elder patients who cannot withstand several operations and in cases that suffers from impaired vascularity of the soft tissue bed specially after irradiation. Moreover, some publications recommended the use of the non vascularised bone grafts in large segmental defects specially in benign lesions where watertight closure of the intraoral wound is possible and in cases where the mucosa remains intact; but On the other hand, some authors recommended the use of non vascularised bone grafts for immediate reconstruction of large sized mandibular defects without any fear from failures [32].

Timing of reconstruction (Immediate versus Delayed)

The controversy of immediate versus delayed bone grafting of the post-resection defect, is still a subject of great debate. A graft loss rate of 20% after immediate grafting was reported by Kruger *et al.* [75]; this was much higher than a 3.2% for delayed grafting. Komisar *et al.* [76] lost 2 out of 7 (28.5%) immediate bone grafts in their group of patients. Lawson *et al.* [77], using various grafting techniques, reported success rates of delayed and immediate grafting to be 91% and 46% respectively. He attributed the poor results of immediate grafting to salivary contamination.

In a prospective study of nine consecutive patients undergoing reconstruction of segmental mandibular defects, no difference between immediate and delayed bone grafting was noted by Ardary WC [68] where both groups showed a graft incorporation rate of 100%. It should be noted that all but one of his patients did not suffer from significant soft tissue losses, having had their mandibles resected for benign tumors or trauma. Kim *et al.* [8] found no difference in the infection rates between immediate and delayed grafts (26.9 vs. 26.7%), and interestingly as well, they reported a lower revision rate for immediate grafts compared to delayed ones (19.2 vs. 26.7%).

Recent advances in immediate segmental mandibular reconstruction

Over the past 20 years, surgeons have adopted computer-aided surgical techniques to assist and guide complex surgical repairs. Computer-aided maxillofacial surgery can be divided into two main categories: computer-aided presurgical planning and image-guided navigational surgery. Presurgical planning software allows the surgeon to import two-dimensional computed tomography (CT) data and generate a precise three-dimensional virtual representation of the skull. The proposed surgical repair can then be performed in a virtual environment prior to the actual procedure. Stereolithographic (hard copy) models can be fabricated from the virtual model to assist with surgical planning and intraoperative repair. The virtual data can also be imported into an intraoperative navigation system which is used to guide the movement of bone segments and application of hardware.

Six publications [12,34,39,47,49,51] were identified reporting the use of computer assisted technology for immediate reconstruction of segmental mandibular defects . Levine *et al.* [49] used computer aided design and computer aided manufacturing (CAD/CAM) for fabrication of stereolithographic models, patient specific osteotomy guides, implants guides and dental prosthesis. First, implants were placed into the fibula then the graft was placed guided by implant supported dental prosthesis. They recommended this technique for single stage mandibular reconstruction.

In a case series study, Zheng *et al.* [47] conducted a successful immediate reconstruction using computer aided manufacturing of surgical templates that define the resection margins. Moreover, fibula cutting and positioning guides were constructed for accurate harvesting of the graft ,results of this study showed satisfactory surgical accuracy but they reported some difficulty in application of fibula cutting templates at the same position of the preoperative virtual planning due to the cylinder configuration of the fibula.

Again In 2013 Zheng and co-workers [43] utilized vascularised fibula flap by the aid of virtual planning including tumour resection, fibula reconstruction, virtual implant and abutment placement into the graft. For restoration of patient facial symmetry the reconstruction plates were pre-bended on reconstructed mandibular models. Finally, the graft was precisely placed in its ideal position guided by the occlusion using a positioning template moulded on stereo model and prefabricated dental prosthesis.

Conclusion

From this review We can concluded that both vascularised & non vascularised bone grafts could be used with different range of satisfactory results depending on many factors such as defect size,defect site,histopathology of the lesion, fixation methods and radiation therapy.

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