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Squamous Inclusion Cyst in the Palatine Tonsil Mimicking a Tumor

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Abstract

Squamous inclusion cyst is a rare benign cystic lesion most commonly affecting the floor of mouth in the oral cavity. Its presence in the palatine tonsil of the oropharynx is an extremely rare occurrence. We highlight a case of an elderly female who was histopathologically diagnosed as squamous inclusion cyst of the palatine tonsil. We shall discuss the presentation, diagnosis, management and postoperative follow-up of the case.

Keywords

Squamous Inclusion Cyst, Palatine Tonsil, Benign

1. Introduction

Squamous inclusion cysts are benign lesions which can be developmental or acquired. Developmentally in the fetal period they are formed from abnormal squamous epithelial components of ectodermal tissue. They can also be acquired from trauma or surgery related implanted epithelium [1]. Squamous inclusion cysts have an incidence of 1.6% - 7% in the head and neck region [2]. It can be congenital or acquired. Squamous inclusion cysts are synonymous with epidermoid cysts, epithelial cyst, keratinous cyst, sebaceous cyst, epidermal cyst, milia, epidermal inclusion cyst or the infundibular cyst [3]. Roser first gave the term epidermoid cyst in 1859 [4].

They commonly arise in the sublingual, submental, submandibular region, labial/lingual or buccal mucosa [2]. Involvement of the palatine tonsil is a rare occurrence. Histopathological examination is of utmost importance in every resected tonsil to differentiate benign squamous inclusion cysts from tonsillar squamous cell carcinomas. The objective of this case report is to throw light on a

simple case of squamous inclusion cyst of the palatine tonsil and how it can mimic a tumor.

2. Case Report

A 59 years old female presented to our ENT outpatient department with history of noticing a mass on the left tonsil along with foreign body sensation in the throat since 1 month, which was insidious in onset and gradually progressive. She also had dry cough for a month. There was no associated pain or difficulty in swallowing. On examination bilateral tonsils were enlarged left side was grade 2 and right was grade 1 in size and not congested. There was a round yellowish cyst on the superior pole of the left palatine tonsil (**Figure 1**). It was smooth, soft to firm in consistency and did not bleed on touch. Neck examination revealed bilateral jugulo-digastric lymphadenitis, left more than right. Rest of the examination was unremarkable.

A working diagnosis of a tumoral mass on left tonsil under investigation was made. Blood investigations were normal. Patient was offered treatment in the form of an excisional biopsy of the tonsillar mass by undergoing a bilateral tonsillectomy.

Tonsillectomy was done along with excision of the left tonsillar tumor mass (**Figure 2**).

Specimen was sent for histopathological examination. Patient recovered well post operatively with no complications. Sections from histopathology revealed an epithelial squamous inclusion cyst along with chronic non-specific inflammation of the tonsil, suggestive of chronic tonsillitis (**Figure 3**).

Patient recovered well post operatively. She was followed up for 6 months and was symptom free with no recurrences. Overall prognosis was good. Patients consent was taken to publish this case report.

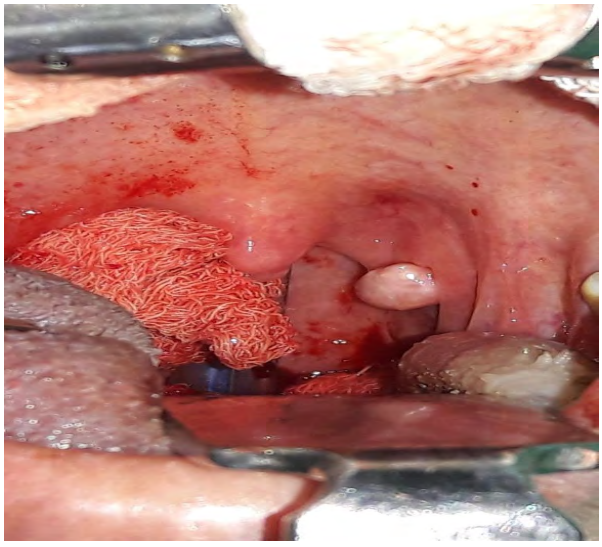

Figure 1. Clinical photograph showing a tumoral mass on the superior pole of the left palatine tonsil.

Figure 2. Clinical photograph of the post tonsillectomy specimen, the left tonsil with the tumor mass on its superior pole and the right tonsil.

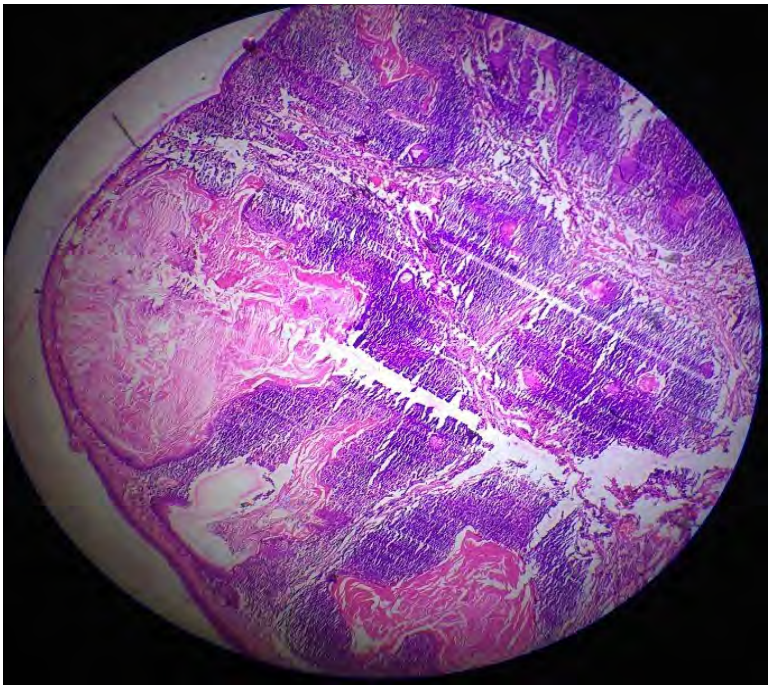

Figure 3. Photomicrograph showing a cyst lined by stratified squamous epithelium with keratinous material in the center. Lymphoid follicles with germinal centers were present in the wall of the cyst, suggestive of chronic tonsillitis (H & E, 100×).

3. Discussion

The palatine tonsil is a lymphoid tissue present in the pharynx with an external lining of stratified squamous mucosa [5]. The cysts in oral cavity can be epidermoid, dermoid, teratoid [6]. Epidermoid cysts are enclosed and lined by stratified squamous epithelium only. Dermoid cysts contain skin, adnexal structures and teratoid cysts contain ecto, endo or mesodermal structures like muscle, bone, cartilage or fat. The treatment of choice is surgical excision. Recurrence

after surgery is rare and malignant transformation into squamous cell carcinoma is reported but not common [7]. Squamous inclusion cyst is lined by simple squamous epithelium and its wall does not contain skin adnexal structures or fibrous elements [6]. Their etiology is varied, including hormonal influence during puberty to abnormal inclusion of cells during surgery/trauma or development from the epithelial remnants isolated during the closure of first and second branchial arches in the midline [8]. The male to female ratio with diagnosis of squamous inclusion cyst is 1:4 with majority in the age group of 10-35 years [6]. Our patient was a 59 year old female who presented with a mass in the left palatine tonsil. They usually present as an asymptomatic painless slow growing mass [9].

These cysts can be associated with certain hereditary syndromes like Gardner syndrome, basal cell nevus syndrome and pachyonychia congenita [8].

Diagnosis can be confirmed by fine needle aspiration (FNAC) or excisional biopsy [10]. The differential diagnosis of a squamous inclusion cyst are varied from benign lesions like dermoid cysts, lymphoepithelial cysts, hydatid cysts and squamous papilloma to tonsillar carcinoma [6]. Histopathologically we can easily differentiate these entities, hence gross and microscopic examination of every resected tonsillar mass is of utmost importance. Histopathology is the gold standard to rule out malignancy and to confirm the benign nature of tonsillar squamous inclusion cyst. Complications of squamous inclusion cysts are rare, but they include infection, scarring from removal and recurrence. Malignancies are very rare.

4. Conclusion

The importance of this rare case report is to highlight the rarity of squamous inclusion cyst of the palatine tonsil and the need for histopathological examination in each and every case of tonsillectomy, so as to differentiate between benign and malignant tumors.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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An Overview and Comparative Evaluation of Head and Neck Cancer Risk Factors in India and Australia

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Abstract

Aim: An overview and comparative evaluation of head and neck cancer risk factors in India and Australia. **Method:** In this review we included articles with information on head and neck cancer risk factors and its association based on: smoking tobacco, alcohol, smokeless tobacco, betel nut and areca nut chewing, viral infection like HPV, dental hygiene, diet, family history, socioeconomic status, other heavy metals and systemic conditions. Articles with clinical features, diagnosis, treatment and prognosis were excluded. **Results:** Head and neck cancer in India has different demographic, risk factors, dietary habits, personal and family history. Oral cancer is more common amongst all head and neck squamous cell cancers in males. This is mainly attributed with consumption of a variety of smokeless tobacco, smoking, alcohol, poverty, illiteracy, cultural, advanced stage at presentation; lack of good treatment infrastructure creates main challenge to India as compared to Australia. **Conclusion:** The knowledge about risk factors for HNC in public health education for general population supports health promotion and tobacco prevention, which is the main aim of the programs started by the government, as head and neck cancers are potentially preventable.

Keywords

Head and Neck Cancer, Oral Cavity, Oropharynx Smoking and Smokeless Tobacco, Alcohol, HPV, Oral Hygiene, Other Risk Factors

1. Introduction

Worldwide, the head and neck cancer (HNC) is the 6th most common cancer; as

it is considered a lethal disease affecting the upper aero-digestive tract and near about 0.9 million new cases have been diagnosed each year [1] [2]. With 0.47 million cases diagnosed per year in India alone, HNCs are the second most common cancers in the Indian population by National Institute of Cancer Prevention and Research [3]. India contributes up to more than 8% of the global cancer burden and deaths [4]. Developed countries like Australia present with a maximum 40% of patients with advanced disease whereas prevalence in developing countries like India is >60% of these patients [5].

The incidence of HNC seems to be 12.3 per 100,000 in Australia and 22 per 100,000 population in India, also accounts for about 30% of all types of Indian cancers [6] [7]. HNC is the most common cancer of males in India and the fifth most common in females [8]. Great difference in mean age of presentation lies in the 5th-6th decade for the Indian population as compared to 7th-8th decade among the Australian population, also more frequently diagnosed in males than females [9]. In India, 90% - 95%, whereas, in Australia more than 90% of HNC originates from the mucosal lining of the mouth and oropharynx, hypopharynx, larynx, sinonasal tract, and nasopharynx [10].

Most of the HNC cases and deaths are due to the cigarette smoking and alcohol consumption in the global population, which are the major risk factors, along that it has synergistic effect in increasing oral cancer risk whereas smokeless tobacco (SLT), betel nut, and human papilloma virus are etiological agents responsible for it in the Indian population [11] [12]. The various forms in which SLT is used in developing countries include khaini, mava, paan (betel quid), zarda, snuff, mashiri, etc. [13]. The prevalence of HNC in India has different demographic profiles, risk factors, dietary habits, socioeconomic conditions, lifestyles and family history [14]. High incidence of the oral and oropharyngeal cancer is observed among native Australians [15]. Many epidemiological evidences strongly report that many risk factors are not only causal but also associated with an increased risk of HNC occurrence [16].

In India, nearly two-thirds of patients present with advanced stages [17]. Despite advances in treatment methods for HNC, the present treatments improve the quality of life of head and neck cancer patients but the overall survival rate of 5 years has not improved in the past decades [18].

Major aim of this article is comparative evaluation of published data about the prevalence of risk factors for head and neck cancer in India and Australia.

2. Methods

We collected data from published literature by carried out a organized search using key words with risk factors, tobacco, alcohol, betel nut chewing, human papilloma virus, environmental factors and other risk factors for HNC from Medline, Pubmed and Google Scholar using a combination of subject headings and keywords.

In this review we included articles with information on head and neck cancer

risk factors and its association based on; smoking tobacco, alcohol, smokeless tobacco, betel nut and areca nut chewing, viral infection like HPV, dental hygiene, diet, family history, socioeconomic status, other heavy metals and systemic conditions.

We selected the articles carefully after reading abstract and titles to determine whether, they were completely fitted the inclusion criteria for the review. In addition to this, we also studied the references of related articles to find more literature. Articles with clinical features, diagnosis, treatment and prognosis were excluded. Figure 1 shows the flowchart for selection of the articles.

	Inclusion Criteria
1)	Web-based search from Medline, Pubmed and Google Scholar
2)	Carefully review of titles and abstract of selected articles are available in English and limited to human research
3)	Articles reporting data on association between HNC, HNSCC and risk factors: (about smoking tobacco, alcohol, smokeless tobacco, betel nut and areca nut chewing, viral infection like HPV, dental hygiene, diet, family history, socioeconomic status, other heavy metals and systemic conditions, HNC, HNSCC) completing inclusion criteria
4)	Selected relevant studies for this review article
	Exclusion Criteria
1)	Articles with clinical features, diagnosis, treatment, prognosis, and case reports were excluded.

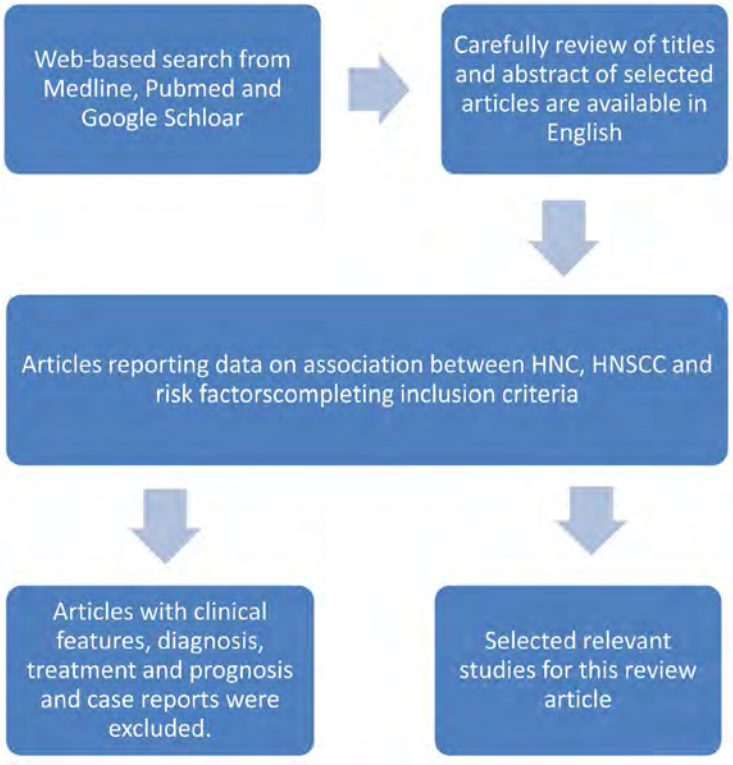

Figure 1. Flowchart for selection of the literature.

3. Risk Factors

3.1. Tobacco Use

Tobacco is deadly in any form and its use already has become responsible for more than 6 million deaths worldwide each year. According to the World Health Organization (WHO) estimates, globally, there were 100 million premature deaths due to tobacco in the 20th century, and if the current trends of tobacco use continue, this number is expected to rise to 1 billion in the 21st century [19]. Jha *et al.* have estimated that around 1 million deaths a year in India will be attributable to smoking by the early 2010s [20]. India's tobacco problem is very complex, with a large use of a variety of smoking forms and an array of SLT products are the most common cause of HNSCC [21].

In India tobacco smoking in the form of cigarettes, bidis, cigars/chutta/cheroot, dhumti (Goa), the water pipes/hookah (north India), reverse chutta smoking (in coastal regions in Andhra Pradesh and Orissa), hookli (Gujarat) and chillum (northeastern parts of India). Estimates indicate 57% of men and 11% of women between 15 - 49 years of age use some form of tobacco and an estimate of the Global Adult Tobacco Survey (GATS) conducted during 2009-10 indicate that 34.6% of the adults (47.9% males and 20.3% females) are current tobacco users. 14% of the adult smoke (24.3% males and 2.9% females) and similar number of students, whereas in Australia daily smoking rate for smokes is 17% in 2007 and around 70% of laryngeal cancers are attributed fully or in part to tobacco smoking [22] [23]. In Australia, the rate of smoking is approximately 15.1%, whereas in the Northern Territory is considered the highest smoking rate near 50% as compared to any state or territory in Australia [24].

Studies on bidi smoking, the most common form of tobacco smoking in India, provide a strong association of bidi smoking with risk of developing cancer is 5 - 9 times greater than for nonsmokers at various sites, such as oral cavity, pharynx, and larynx, which is further multiply about 17 times for heavy smokers of 80 or more per day [25]. Pednekar *et al.* in their Mumbai cohort found that the prevalence of oral cancers was 42% raised among bidi smokers as compared with cigarette smokers [26]. A study showed that cannabis smoke used in different Australian regions have a carcinogenic and mutagenic potential because it contains a higher level of carcinogens than cigarette smoke [27].

3.2. Smokeless Tobacco (SLT)

Many different forms of smokeless tobacco are used in India, which are very popular in large number of people. Among them, the use of betel quid chewing (pan) is extremely widespread in many regions of India. Along with this, gutka, khara, mawa, zarda, and khainni, are mixes by vendors and are all dry mixtures of areca nut flakes, lime, tobacco power [28]. It is also used as a moist snuff containing lime with tobacco, vegetable oil and water (Naswar/Nass), mainly according to local traditions and for the purpose of enhancing flavor and also in the form of dried tobacco powder applied on gums and teeth [29].

About 10% of the world's population chews betel quid regularly and most prevalent in Asia-Pacific region but use of betel quid is not quite relevant to Australia [30] [31]. Areca nut alone is a long-established carcinogen and causally connected with a premalignant condition known oral submucous fibrosis (OSMF) and oral cancer [32]. Areca nut use is very exceptional in the Western world due to its scarcity. In India alone, five million people (0.5% of the population of India) have OSMF [33]. In Australian native citizens are changing from alcohol to cannabis utilization since the restrictions on alcohol in remote communities; thus there is an epidemic of cannabis use in remote Indigenous communities in the Northern Territory [34].

Australian immigration statistics show that 30% of new arrivals in Australia (New South Wales) are from Indian subcontinent, China, and Taiwan, are more likely to be responsible for this tradition of tobacco chewing, as they are closely connected to sociocultural and religious activities long after they migrate to Australia [35]. Univariate analysis revealed that, in terms of oral dipping products, the risk was 7.3 for consumption of gutka, 5.3 for consumption of chewing tobacco and 4 for consumption of supari (pure areca nut) and the minor risk was found for mishiri [36].

3.3. Alcohol Consumption

Drinking alcohol on regular basis is an important risk factor for HNC and it is associated with an increased risk, which is dose-dependent. A regular consumption of 4 - 5 drinks daily, increase oral cancer risk by 2 - 3 folds than non-drinkers but, in case of heavy alcohol drinking risk increase up to 7% to 19% oral cavity cancer [37]. A prospective study in India has found that alcohol consumption increases the incidence by 49% among current users and 90% in past drinkers [38]. According to Ferlay, oral cavity cancer has its highest rates of incidence in Western Europe, India, South Africa and Australia. In 2008 the Australian Department of Health reported that Australia is 30th highest alcohol-consuming country of 180 countries worldwide [39] [40].

The consumption of alcohol was very high in India; in 2016 11.4 L per capita per year with age above 15 years old and among them 30% are regular and 11% moderate to heavy drinker. However, the consumption is very high in the Northern Territory: approximately 15 L and New South Wales 13 L of pure alcohol per year have been consumed by adults (≥15 years old) [41] [42].

3.4. Alcohol in Combination with Smoking

Taking alcohol in combination with tobacco in any form further enhances risk of oral cancer by 11 times [37]. A study conducted in northern India on oral cancer (buccal and labial mucosa) showed that alcohol alone had a nonsignificant odd ratio of 2.7, however there was a significant odd ratio seen with alcohol with bidi smoking (8.5), alcohol and pan tobacco chewing (20), and with alcohol, pan, and smoking altogether (31.4%) [29].

3.5. Human Papilloma Virus (HPV)

The human papilloma virus (HPV) has been identified as an etiological factor in HNC mainly oropharyngeal cancer [43]. The overall prevalence of HPV is about 50% globally and their incidence increased by 25% in last 20 years and is the third predominant risk factor for HNSCC with the highest prevalence in cancer of tonsil and base of tongue [44].

HPV-16 is the most common genotype, occurring in 90% of high risk HPV oropharyngeal carcinomas [45]. In India HPV incidence ranges from 33.6% in the Eastern region to 67% in South India and 15% in Western India. A study showed a rate of HPV infections of 56.3% in cancers of the mandible, 37.5% in cheek, and 38.6% in maxilla are reported in the advanced stages (III, IV) had higher infection rates as compared to earlier stage. Lesions of the tongue had the highest rate (9 of 11) of HPV infection [46].

Within Australia, 8844 cases of HPV-related oropharyngeal cancers were diagnosed between 1982 to 2005. This particular study reported that the incidence of HPV-related cancers significantly increased annually among both males (1.42% per annum) and females (1.04% per annum) P value < 0.01 [47].

Increase in incidence found with use of newer techniques that could be helpful for 45% (26 of 57) of tumors tested were positive for P16 in patients from the Northern Territory in Australia; however, 63% of those were Indigenous Australians [41] [48]. The prevalence of HPV-related HNC in Australia is currently increasing; this trend may be attributable to changes in sexual behaviors, particularly oral sex [47]. Synergistic association between HPV and other notable risk factors (alcohol consumption and smoking) remains controversial [49].

The vaccination of HPV has not been incorporated in the national immunization program of India. There is dispute about using the HPV vaccine in Australian men; it is currently indicated for use in young women. In Australia, the current HPV vaccination program for females aged 12 to 13 years was introduced in 2007 and may have an effect on the future incidence of these cancers [50].

3.6. Oral Hygiene

Poor oral hygiene also causes oral cancer. In one study, more than 85% of oral cancer patients had poor oral hygiene [7]. Poor oral hygiene related attributable risk is around 32% for men and 64% for women in India. Patients wearing poorly fitting or defective complete dentures for more than 15 years and not visiting a dentist regularly were highly associated with oral cancer but, least has occurred in Australian population who has received dental care [51] [52]. Periodontal disease has been found in connection with OSCC [53].

However, In India oral precancerous conditions are also prevalent which are helpful in diagnosing majority of oral cancer cases and exclusively present in tobacco users.

Oral lesions that have been identified clinically as having potential for malignant conversion include leukoplakia, erythroplakia, lichen planus, and submuc-

ous fibrosis. Reported rates of malignant transformation of leukoplakia range from less than 1% to 18% [54]. Erythroplakias are the most severe and carry a much greater risk of malignancy transformation followed by leukoplakia with 0.13% to 10% whereas in Australia malignant transformation rate of leukoplakia is approximately 1% but OSMF has highest transformation about 17% considered as important factor in the raising incidences of oral cancer in people 35 years and below in India [29].

3.7. UV Radiation

Ultraviolet (UV) light exposure may cause HNC, particularly lip cancer, is mainly caused by UVB (290 - 320 nm) irradiation due to increased exposure of the mucosal linning of the lips to the sun and cancer in the lower lip occurs in around 90% of all cases [55] [56]. A high incidence of lip cancer has been reported among whites and is about 3 times higher in men than in the women, which may be due to more outdoor occupations, smoking, and sun exposure among men. The variations in the incidence of lip cancer in the Australian states are probably attributable to differences in the rural and urban populations with respect to exposure to UV as a risk factor [55] [57].

In Australia, more than 50% of HNC in white people are located on the lip. [58]. However, HNC of the lip is not very common in nonwhite populations, in particular Indigenous Australians [59]. The reported incidence of skin cancer of HNC in India is less than 1% of all the cancers. BCC is the commonest skin cancer worldwide, but in India SCC as the most prevalent skin malignancy [60]. The incidence shows an inverse relation with the degree of pigmentation, presumably due to protective effect of eumelanin on ultraviolet light (UV)-induced damage [61].

In Western Australia annual incidence of lip cancer was 8.9 in 100,000 and 2.7 in 100,000 for males and females, respectively, from 1982 to 2006 [62].

3.8. Nutrition and Socioeconomic Status

Different studies in last few years showed diet has come into view as a risk factor of HNC along with tobacco smoking, alcohol intake and HPV [50]. A study in India showed that regular consumption of fruits and green leafy vegetables reduces risk by 2 folds as compare to butter and pulses for HNC [63]. Taking daily diet rich carbohydrates, vegetable oil, fish, fruits, vegetables and lean meat decrease risk of oral cancer by 50%, on the other side, too much meat consumption was considered to be a risk factor for many HNC [64].

According to the UN report published in 2017, India is home to 190.7 million underfed people, 51% women are anemic and more than 50% of elderly people of India are suffering from malnutrition but there is hardly any published quantitative data on the nutritional status of Indigenous Australians. Prevalence of malnutrition in Australia was reported at 2.5% in 2015, on average, daily smoking rate 3 times more in the lower socioeconomic group then higher [65] [66].

India is classified as a lower-middle-income group country by the World Bank. 90% of the oral cancer patients in rural areas belong to the lower or lower-middle socio-economic class, and 3.6% are below the poverty line based on Pareek's classification [67]. Around 80% of patients with cancers present with advance-stage incurable disease and hence increased mortality. Big reason for delayed diagnosis is the lack of easy access to healthcare, respectively further reasons included poor socio-economic status of the patient, cost of care, and high rate of illiteracy [68].

Brookes reported a significant difference between the survival of undernourished HNC patients (7.5% at 2 years) and the survival of adequately nourished patients (57.5% at 2 years) undergoing radiotherapy [69].

3.9. Family History and Genetic Susceptibility

Genetic susceptibility might play a role in the progression of cancer, but those that have revealed a high risk for HNC with respect to family history of cancer. A first-degree relative is a family member who shares about 50 per cent of their genes with a particular individual in a family beside this a higher risk of oral cavity cancer in males with a family history of smoking-related cancers than in females [70].

The prevalence of the p53 mutation is 81% in the Western world but rare in India. Multiple genetic abnormalities are common in head and cancers in India and Southeast Asia. These include a prevalence of Ha-ras mutations (35%), loss of heterozygosity of Ha-ras (30%), N-ras amplification (28%), and N-myc amplification (29%) [71].

4. Other Risk Factors

Environmental and occupational factors including asbestos, wood dust and leather dust can also contribute to some HNC, including in the larynx and pharynx [72].

In India large number of population dealing with Plummer-Vinson syndrome is associated with a high risk for development of carcinoma of oral cavity, oropharynx and esophagus [23].

Immunosuppressive conditions increase risk of developing oral cancers in a number of patient undergone kidney transplantation, lip cancer in patients suffering from AIDS oral carcinoma has been reported [73].

Australian diabetic patients consistently seemed to be more likely to have distant metastases of cancer at the time of diagnosis and it is involved as a risk factor not only for the development of HNC but also for oral premalignant lesions such as leukoplakia [74].

5. Conclusions

This review gives an idea that major risk factors are lifestyle, behavioral and environmental associated in developing various HNC in population of India and Australia.

In India, the illiteracy, lack of infrastructure and health care facilities, are major problems. Lack of awareness is more common in the lower socio-economic class about the side effects of tobacco, and prevalent cultural beliefs lead to delay in seeking treatment and result in advanced-stage presentation of disease. People in Australia more aware about symptoms and government provide better cancer treatment facilities and early diagnosis and treatment.

The knowledge about risk factors for HNC in public health education for general population supports health promotion and tobacco prevention programs by the government, as HNC are potentially preventable.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Adipo Fascio Cutaneous Perforator Based, Shape Modified Radial Forearm Flap: Vascular Analysis of Perforators & Its Clinical Applications in Head & Neck Reconstruction

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Abstract

Resume of the study & Background: Radial forearm free flap with all its present day modifications is the workhorse of soft tissue reconstruction. Although there are several advantages, it requires sacrifice of a major artery of forearm. Several modifications are described in harvesting a forearm flap. In order to achieve a reliable, safe flap harvest & design one must have a very clear understanding of radial artery perforators, relative to its distribution, territory & flow. The purpose of this study is to determine the location, size & vascular territory of the radial artery cutaneous perforators & to demonstrate application of shape modification of radial forearm free flap based on its distal & proximal perforators in various head & neck defects. **Materials & Methods:** Anatomical Study: 12 fresh human cadavers & 24 cadaveric forearms were dissected to determine the number, location, size & vascular territory of radial artery perforator. The cutaneous territory of distally dominant perforators was analyzed using methylene blue injections & three-dimensional computed tomographic angiogram to determine the vascular network. Clinical Study: 15 patients with various head neck defects following oncological resections were reconstructed with shape modified adipo-fascio cutaneous free forearm flap. All these patients were prospectively followed for donor site healing, motor & sensory nerve deficit, function & quality of life questioner for donor site assessment. **Results:** 12 fresh human cadavers & 24 cadaveric forearms were dissected, and a total of 222 perforators were dissected for an average of 18.5 perforators per forearm. 118 were smaller than 0.5 mm in diameter (53.15%) & were not clinically significant. 104 perforators were

greater than 0.5 mm in diameter (46.84%) & were clinically significant. 127 perforators (57.20%) were radially distributed & 95 perforators (42.79%) had ulnar distribution. 90 perforators (40.54%) were identified on distal side (Radial styloid) & 132 perforators (59.45%) were identified on proximal side (Lateral epicondyle). Mean number of perforators, on radial side was 10.6 & 7.9 on ulnar side; comparison of both using student t paired test gives a P value of 0.006, which is significant. Comparison of mean number of perforators on the distal side was 7.5 & proximal side was 11.0; Student Paired t test gives a P value of 0.003, which was statistically significant. Comparison of mean diameter of perforators on Distal side (1.11) & Proximal side (0.86), side using Student Paired t test gives a P value of 0.01 which was statistically significant. A chi square test was done to compare mean diameter of perforators on distal side, which was more than 1 mm (80%) & less than 1 mm (20%) & on proximal side more than 1 mm (35.6%) & less than 1 mm (64.4%). Chi square value of 42.406 was obtained, degree of freedom value was 1 & P value of <0.001 was achieved which was found to be highly significant. Methylene blue injections demonstrated clusters both in proximal & distal forearm & also marked the cutaneous territory of flap. Three-dimensional computed tomographic angiography reveals a network of linking vessels found to communicate between adjacent perforators & running parallel to radial artery. A total of 15 patients were reconstructed with shape modified radial forearm flap following oncologic resections. Wound healing in all 15 patients was good, with scar assessment faring better than traditional radial forearm flap. There was no sensory or motor nerve deficit. Although pedicle length was comparatively shorter in shape-modified flap, there was no problem in anastomosing to neck vessels. **Conclusion:** Increase in knowledge of vascular territory of radial artery perforators with regards to numbers, size, location, & cutaneous territory can lead to expanded use of radial forearm flap based on either distal or proximal perforator alone. Shape modified technique for harvesting radial forearm flap allows primary closure of donor site. Donor site is better healed and shows a predicted pattern, which is functionally and aesthetically good.

Keywords

Vascular Anatomy, Angio Computed Tomography, Perforator Flap, Radial Artery, Reconstruction, Vascularization

1. Introduction

Knowledge of vascular anatomy has inevitably led to innovations in flap design & use in clinical arena. The evolution of random pattern flaps to facio-cutaneous flaps to myocutaneous flaps & finally to the perforator flaps has followed a linear progression, largely because of pioneering vascular anatomical studies. The information derived from such kind of work has fuelled an evolution in flap designs & its clinical applications.

The ultimate goal of reconstruction is to match optimal tissue replacement with minimum donor site morbidity while maintaining function. Perforator flaps meet these goals & are the result of over 30 yrs of evolution in flap refinement & design.

Since the original description of radial forearm flap in 1978 by Yang & Yuzhi [1] & Timmons anatomical description in 1986, this versatile flap has found numerous applications in plastic & reconstructive surgery [2]. Its value in head & neck reconstruction & upper & lower extremity reconstruction is well documented. Nevertheless, its application as both retrograde flow pedicled island flap & free flap has resulted in two major draw backs:

1) Donor site morbidity.

2) Sacrifice of radial artery.

A study detailing the location & vascular territory of the radial artery perforators therefore becomes necessary to facilitate operative planning & to allow safer flap harvest. A well described territorial outline of the consistently located, clinically significant perforators would be useful for operative decision making & forms the basis for shape modified radial forearm harvest.

2. Materials & Methods

Anatomical Study: To determine the location, size & vascular territory of radial artery adipo-facio cutaneous perforators involving 12 fresh human cadavers & 24 cadaveric forearms.

Need for the study: Anatomical studies defining the perforator vessel anatomy & distribution have been done before. However there are very few studies defining the location of perforator clusters or the cutaneous territory along the radial artery axis. A well defined territorial outline of the consistently located, clinically significant perforators would be useful for operative decision making of shape modified adipo-facio cutaneous radial artery perforator flap.

Inclusion criteria:

12 fresh human cadavers with normal radial artery anatomy were included in study.

Exclusion criteria:

1) Cadavers more than one month old.

2) Anomalies of radial artery.

Clinical study:

15 patients who underwent oncological resections were reconstructed with shape modified adipo-fascio cutaneous radial forearm free flap. All 15 patients were prospectively evaluated for donor site healing, scar, motor & sensory function & quality of life assessment.

Inclusion criteria:

1) Small to moderate defects requiring thin pliable flap for reconstruction.

Exclusion criteria:

1) Patients with systemic complications, who are not fit enough for a microvascular procedure.

2) Large defects.

3. Methodology

Anatomical study: 12 fresh human cadavers & 24 cadaveric forearms were dissected. All radial artery adipo-facio cutaneous perforators were analyzed for:

1) Number of perforators.

2) Orientation of perforators.

a) Radial distribution.

b) Ulnar distribution.

3) Size of perforators.

4) Cutaneous territory.

Upper extremity at the level of elbow & the brachial artery was cannulated & perfused with warm saline. This was continued until the backflow was clear. Subsequently the artery was injected with 20 cc of microfil red & the arm was stored in refrigerator at 0˚C for 24 hrs. A total of 24 flaps were dissected to access the size, numbers, & location of radial artery perforators. Two flaps were used for vascular injection studies using methylene blue & lead oxide. An incision is made on the palmar aspect of forearm, extending from wrist crease to elbow. All perforators originating from radial artery are identified & dissected. Parameters include; orientation of perforators, whether they arise on the radial side/lateral or on the ulnar side/medial, distance from radial styloid for distal perforators & from the lateral epicondyle for the proximal perforators, external diameter (Artery) using calipers, cutaneous cluster pattern with methylene blue injections.

In order to determine the vascular cutaneous territory of a distally based radial artery perforator flap, two forearm flaps were dissected based on distal most dominant perforator near the radial styloid. The artery was cannulated & injected with methylene blue dye to examine the territory of cutaneous staining. Injection of contrast material (Lead oxide) was then injected & the specimen subjected to three-dimensional CT Scan with volume rendering function in order to access the vascular territory & identify linking vessels communicating with adjacent perforators. The results were statistical analyzed with student T paired test & Chi-Square test (Software: SPSS 17-Chicago Inc., SPSS version 22, IBM. Corp.).

Clinical operative procedure:

Radial artery course is marked with the help of Doppler. Skin pinch test is done to mark the dimensions of skin paddle. Approximately 2 cm of skin width in distal forearm and 3 cm of skin width in proximal forearm can be harvested & closed primarily. This may slightly vary depending on the fat content in subcutaneous plain. Flap is harvested unto the origin of radial artery. Skin Island is marked and divided after visualizing the perforators to the skin. Suturing of these individual skin paddles together is done to give this flap the desired dimensions required to reconstruct the defect. After the harvest with its desired

dimension and achieving the required pedicle length, donor site is closed primarily without the need for a skin graft.

4. Results

12 fresh human cadavers & 24 forearm specimens, a total of 222 perforators were dissected for an average of 18.5 radial artery perforators per forearm (Table 1). Of the total 222 perforators dissected 118 were smaller than 0.5 mm in diameter (53.15%) these were not clinically significant. 104 perforators were greater than 0.5 mm in diameter (46.84%) these were clinically significant (Figure 1).

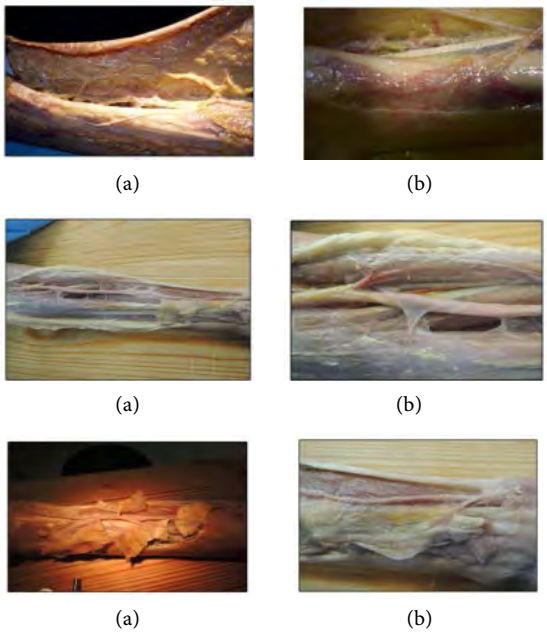


Figure 1. Radial artery perforators to skin.

Table 1. Master chart.

Cadavers	No of perforators	Radial side	Ulnar side	Distal side	Proximal side
1	19	10	9	8	11
2	21	12	9	11	10
3	20	11	9	7	13
4	18	11	7	7	11
5	12	10	2	7	5
6	18	10	8	7	11
7	20	13	7	6	14
8	16	9	7	5	11
9	19	10	9	10	9
10	20	11	9	7	13
11	21	9	12	9	12
12	18	11	7	6	12
	Total = 222	Total = 127	Total = 95	Total = 90	Total = 132

Of the 222 radial artery perforators dissected, 127 perforators (57.20%) were radially distributed & 95 perforators (42.79%) had ulnar distribution (Table 1). A total of 90 perforators (40.54%) were identified on distal side (Radial styloid) & 132 perforators (59.45%) were identified on proximal side (Lateral epicondyle) (Table 1). Mean number of perforators on radial side was 10.6 & 7.9 on ulnar side, a comparison of both using student t paired test gives a P value of 0.006, which was statistically significant (Table 2) (Figure 2). Comparison of mean number of perforators on the distal side was 7.5 & proximal side was 11.0, Student Paired t test gives a P value of 0.003, which was statistically significant (Table 3) (Figure 3). Comparison of mean Diameter of perforators between the Distal side (1.11) & Proximal side (0.86), side using Student Paired t test gives a P value of 0.01 which was statistically significant (Tables 4-6) (Figure 4).

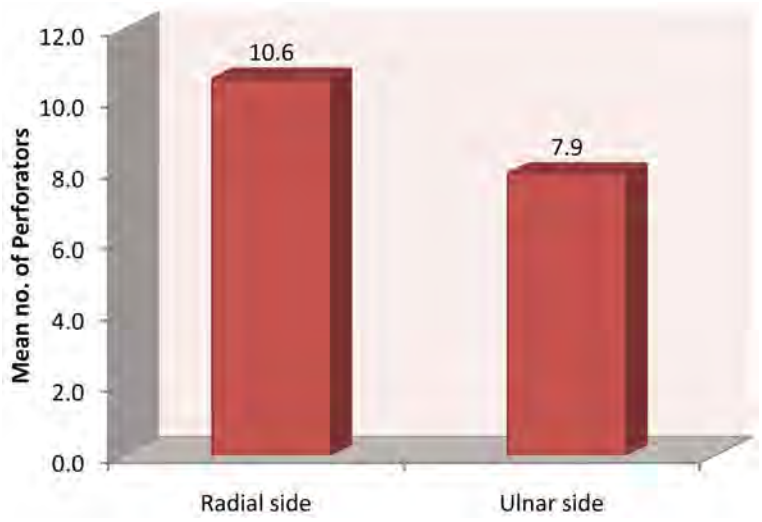


Figure 2. Comparison of mean number of perforators between radial and ulnar side.

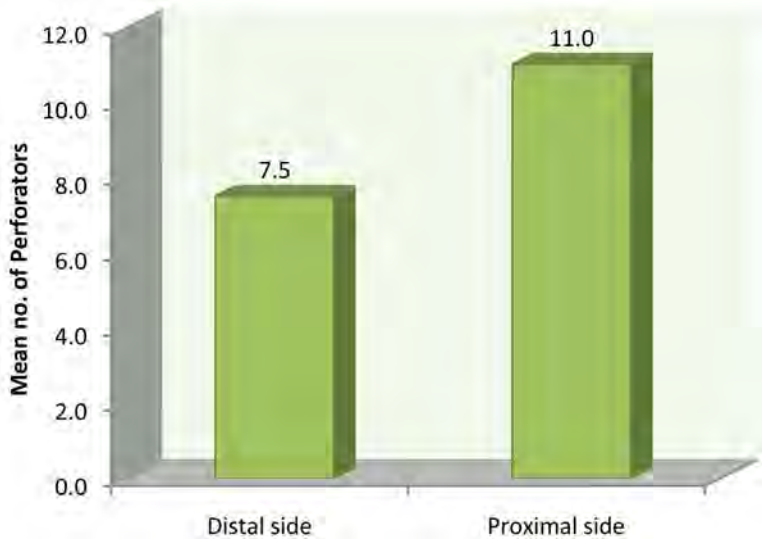


Figure 3. Comparison of mean number of perforators between the distal and proximal side.

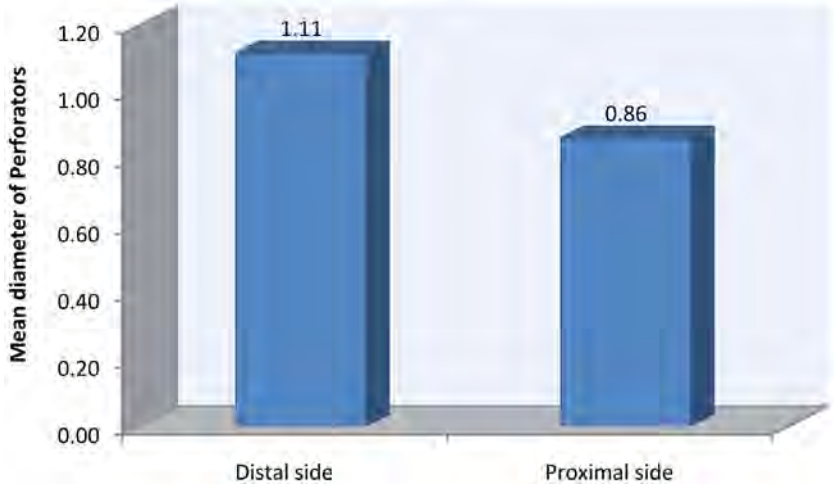


Figure 4. Comparison of mean diameters of perforators between the distal and proximal side.

Table 2. Comparison of mean number of perforators between the radial & ulnar side-using student paired t test.

Sides	N	Mean	SD	S.E.M	Mean Diff	95% CI of the Diff		t	P-Value
						Lower	Upper		
Radial side	12	10.6	1.2	0.3	2.7	0.9	4.4	3.370	0.006*
Ulnar side	12	7.9	2.4	0.7					

Table 3. Comparison of mean number of perforators between the distal & proximal side-using student paired t test.

Sides	N	Mean	SD	S.E.M	Mean Diff	95% CI of the Diff		t	P-Value
						Lower	Upper		
Distal side	12	7.5	1.7	0.5	−3.5	−5.6	−1.4	−3.718	0.003*
Proximal side	12	11.0	2.3	0.7					

Table 4. Mean diameter of perforators.

	Distal (Radial Styloid)	Proximal (Lateral Epicondyle)
1	1.23	0.54
2	1.01	1.00
3	1.23	0.64
4	0.92	0.63
5	1.20	0.83
6	1.17	0.92
7	0.98	1.20
8	0.87	1.00
9	1.11	0.94
10	1.20	0.68
11	1.23	0.83
12	1.22	1.11

Table 5. Comparison of mean diameter of perforators between the distal & proximal side-using student paired t test.

Sides	N	Mean	SD	S.E.M	Mean Diff	95% CI of the Diff		t	P-Value
						Lower	Upper		
Distal	12	1.11	0.13	0.04	0.25	0.08	0.43	3.132	0.01*
Proximal	12	0.86	0.21	0.06					

Table 6. Mean number & diameter on both sides.

Sides	Mean	Sides	Mean	Mean
Radial side	10.6	Distal side	7.5	1.11
Ulnar side	7.9	Proximal side	11.0	0.86

A chi square test was done to compare mean diameter of perforators on distal side, which were more than 1 mm (80%) & less than 1mm (20%) & on proximal side more than 1 mm (35.6%) & less than 1 mm (64.4%). Chi square value of 42.406 was obtained, degree of freedom value was 1 & P value of <0.001 was achieved which was found to be highly significant (**Table 7**) (**Figure 5** and **Figure 6**). In almost all the dissected anatomical specimens at least one clinically significant perforator was found within 2cm proximal to radial styloid (**Figure 7**). Methylene blue injections into the proximal part of radial artery demonstrated clusters both in proximal & distal forearm & also reveal a large flap cutaneous territory (**Figure 7**). Three-dimensional computed tomographic angiography (**Figure 8**) reveals a network of linking vessels found to communicate between adjacent perforators & running parallel to radial artery. Large network of linking vessels could be found between fascia & dermis, which also explains the ability to harvest forearm flap at the supra-fascial level.

In its clinical application 15 patients were reconstructed following oncological resections. The youngest being 31 yrs old & oldest being 72 yrs of age (**Figures 9-13**). Total follow up period following reconstructions ranged between 6 - 12 months. 13 patients were treated for head & neck squamous cellcarcinoma & one patient for basal cell carcinoma (**Figure 10**) & one patient for oral sub-mucous fibrosis (**Figure 13**). Time taken for donor site healing was approximately 2 weeks, following which suture removal was done. In all 15 patients there was no sensory disturbance over the first web space on dorsum of hand & motor function was good (**Figure 14**). Pedicle length though shorter, in all cases we managed to get a length of 8 cm to 10 cm, which was sufficient enough for anatomizing to neck vessels. Scar assessment fared better (**Figure 14**). We developed a quality of life assessment score (total points 25) in which shape modified radial forearm flap showed better quality 23 (Score **Table 8**).

5. Discussion

Head & Neck oncologists are often seem to confront with the difficult task of

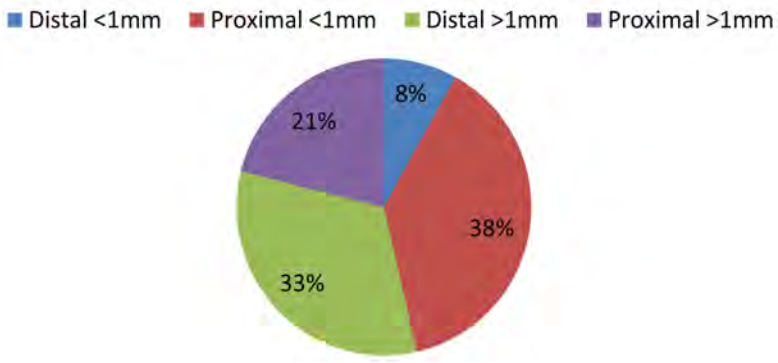


Figure 5. Pictorial presentation of chi square test.

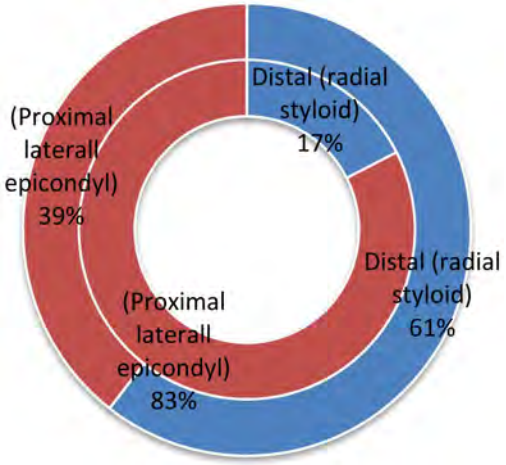
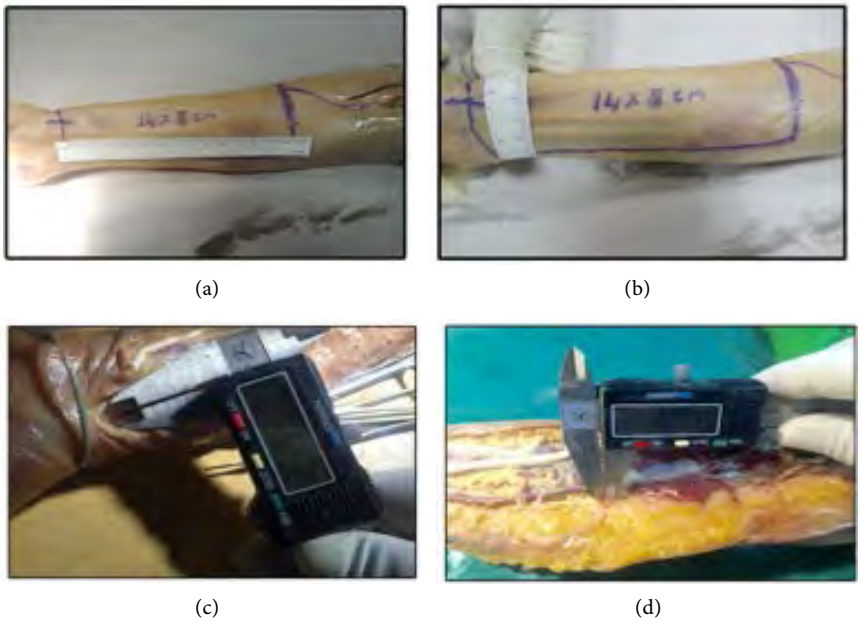


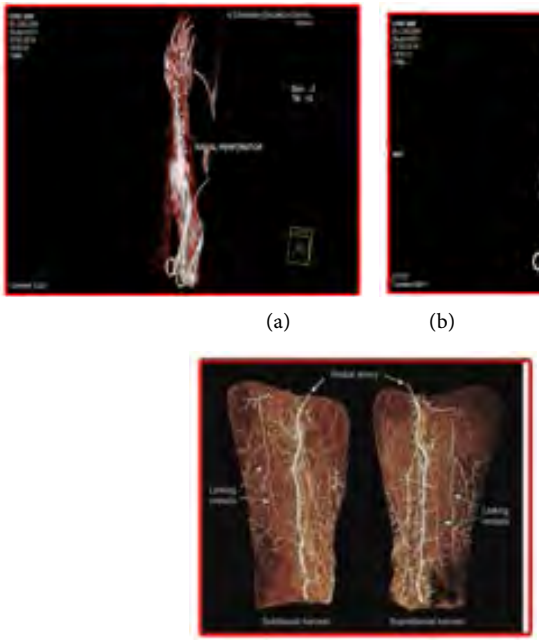
Figure 6. Component chart.



(a) (b)

(c) (d)

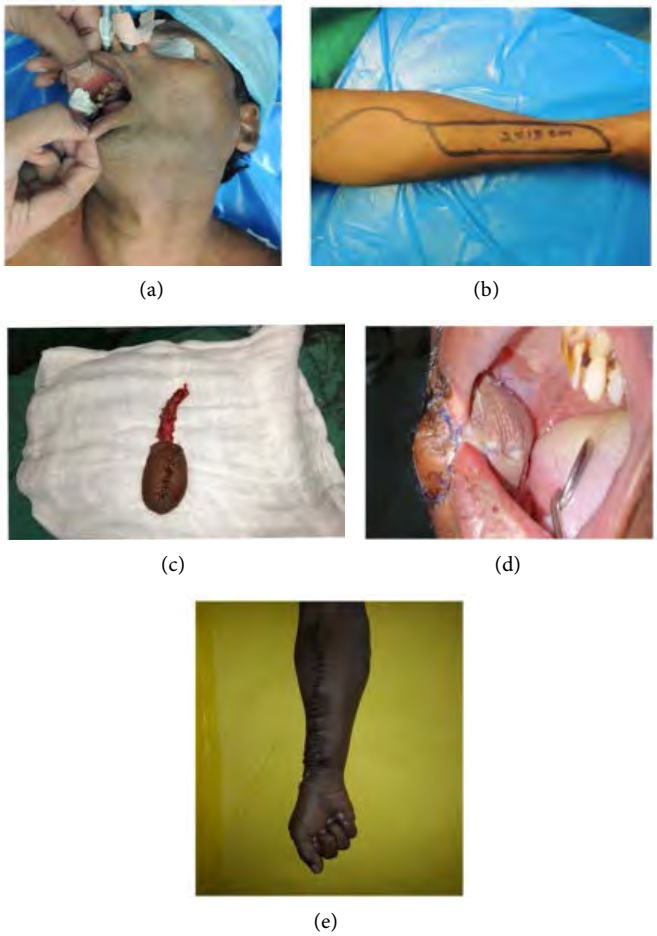
Figure 7. Cutaneous territory & distal & proximal perforators from radial artery. (a) Cutaneous territory of radial artery distal; (b) Perforators and maximum flap dimensions; (c) Distal perforator; (d) Procimal perforator.



(a) (b)

(c)

Figure 8. CT angiography of radial artery perforators.



(a) (b)

(c) (d)

(e)

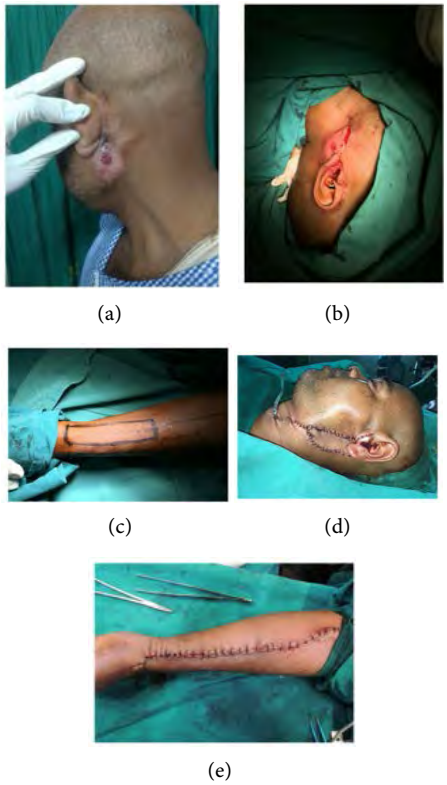
Figure 9. Case 1.

(a) (b)

(c) (d)

(e) (f)

Figure 10. Case 2.



(a) (b)

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(e)

Figure 11. Case 3.

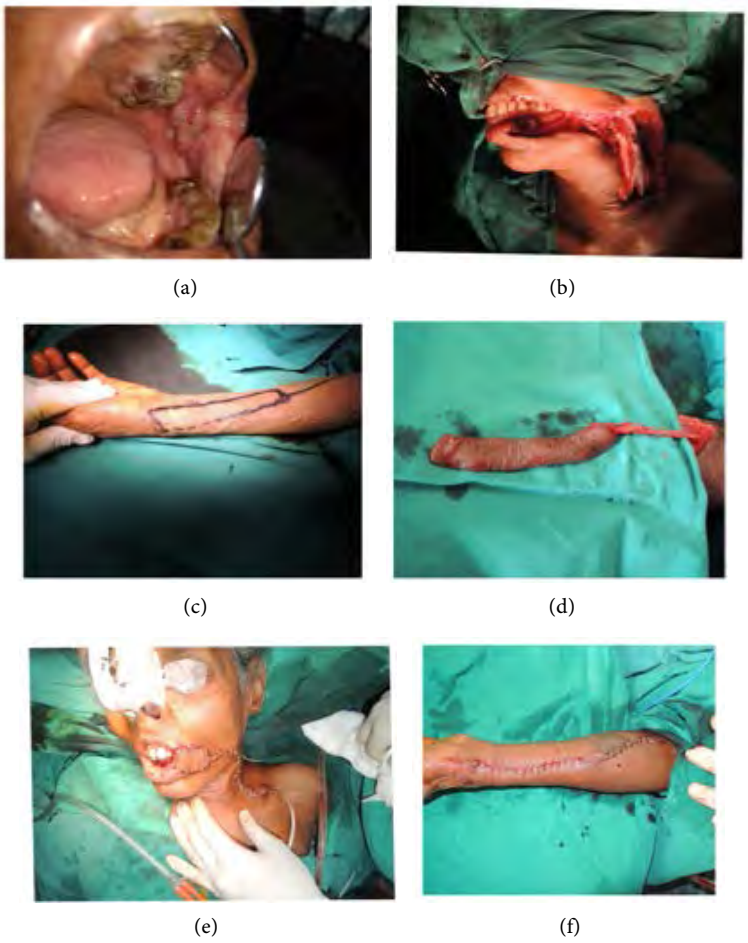

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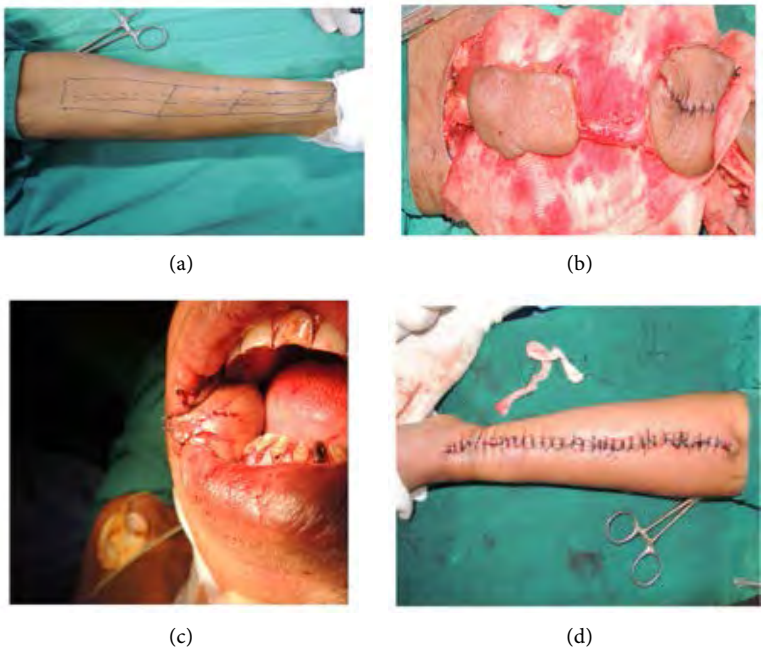
Figure 12. Case 4.



(a) (b) (c) (d)

Figure 13. Case 5.

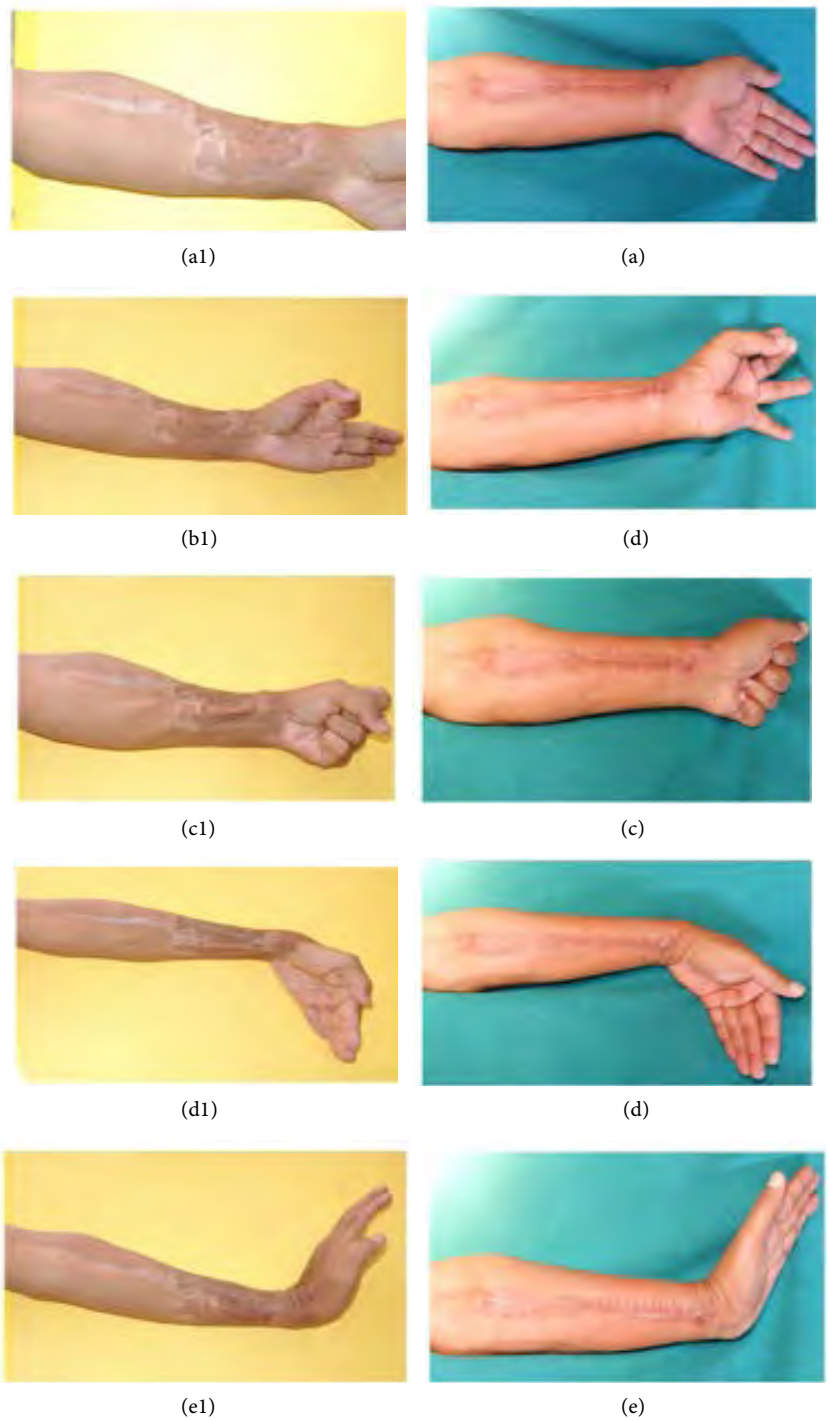


Figure 14. Donar site comparison of traditional radial forearm vs shaped modified radial forearm flap.

Table 7. Chi-Square table.

	Distal (radial styloid)	Proximal (lateral epicondyle)	X^2	df	P value
<1 mm	18 (20%)	85 (64.4%)	42.406	1	<0.001
>1 mm	72 (80%)	47 (35.6%)			

Table 8. Quality of life questioner.

Question no	Below average	Average	Good	Very good	Excellent	Total score (Out of 25)
	1	2	3	4	5	
Are you satisfied by this scar						
Are you in need of change of the clothing style because of scar						
Has your daily manual work or duties influenced by the donor site						
Are you in need of applying special medication for donor site						
Is there problem to wear the ornaments or watch after operation on affected side						

balancing cancer cure with preservation of function, cosmesis, & quality of life when deciding best treatment protocols. Reconstruction in its true sense represents a big challenge for the reconstructive surgeon [3] [4].

Since the original description of radial forearm flap in 1978 by Yang & Yuzhi, this versatile flap has found itself numerous applications in plastic & reconstructive surgery [1] [2]. However its application as both retrograde flow pedicled island flap & free flap has resulted in two major drawbacks drawing great attention among the reconstructive community [4] [5] [6].

1) Donor site morbidity in terms of esthetics, cold intolerance, slight to moderate functional deficit.

2) Sacrificing a major artery of forearm.

Several modifications & innovations in terms of donor site closure, flap-harvesting techniques, and preservation of radial artery have been proposed & practiced [7] [8] [9] [10] [11]. Increased knowledge of vascular anatomy has played a definitive role in increasing our ability to understand & use perforator-based flaps for various clinical applications [12] [13].

As we gradually shift towards perforator based flap reconstructions, knowledge of individual perforators should supersede that of source artery [14]. Many surgeons have reported use of perforator flaps from forearm with ease, success, & good functional outcome [15] [16] [17] [18]. However it is difficult to clinically establish the exact location of dominant radial artery perforator with a hand held Doppler because of superficial course of radial artery [19] [20]. In order to establish the basis for perforator flaps an anatomical study to determine the exact location & vascular territory becomes all the more essential. In our present study we have investigated the location, size & vascular pattern & territory of radial artery in 12 fresh human cadavers involving 24 forearm specimens (**Figure 1** & **Figure 7**). We have demonstrated a total of 222 perforators with an average of 18.5 perforators per forearm. Perforators smaller than 0.5 mm were not considered as clinically suitable. Our study confirms a strong relation between the number & diameter of perforators [16] [17] [20]. Distal side demon-

strates less number of perforators but a large caliber perforator is consistently present within 2 cm of radial styloid in all of the 12 cadavers (**Figure 7**), this finding is found to be consistent with the previous anatomical studies on radial artery [15]. Michel Saint-Cyr *et al.* conducted an anatomical study in 26 fresh human cadaveric forearms to study & determine the location, orientation, external diameter & vascular territory of radial artery cutaneous perforators. The authors concluded that there are two main clusters of clinically significant perforators & increased knowledge of size, location & cutaneous territory of radial artery perforators can lead to expanded use of radial artery forearm flap based on these cutaneous perforators alone, without sacrificing the main radial artery [20].

In both distal & proximal forearms, perforators arising from the main vessel have both radial & ulnar distribution [20] (**Figure 1** and **Figure 7**). These anatomical characteristics suggest an element of safety when harvesting flaps based on either distal or proximal perforator [20]. Our study demonstrates clusters of perforators in both proximal & distal aspect of forearm [13] [14] [20].

Clinical use of perforator based radial artery free flap may have limited applications but nevertheless cases have been reported in literature [21]. The vascular anatomy of the fascia & subcutaneous tissue of the distally based flaps have been well described [18]. The blood supply to the fascio-cutaneous flap is found to originate from 5 to 10 septo-cutaneous perforators arising from radial artery in the anatomical snuffbox [14] [15]. Anatomical & clinical investigation of the radial forearm adipo-fascial flap based on distal perforators has been well described by Hamdy El-Khatib, who reported an anatomic study in eleven fresh & fixed cadavers, designing an island adipofascial flap based on distal five to eight septo-cutaneous perforators of radial artery & their vena commitantes, great advantage being preservation of radial artery [13]. Three-dimensional computed tomographic angiography in our study has shown a comparable vascular territory with linking vessels found to communicate between adjacent perforators & running parallel to radial artery [20] (**Figure 8**). Perforators travel to dermis & form a network of linking vessels found between fascia & dermis. This finding is consistent as reported by previous similar studies [13] [15]. Mark Schaverien conducted a study involving 12 fresh human cadavers & 24 radial forearm flaps harvested from these cadavers to elucidate the role of deep fascia in perfusion of radial forearm flap. The authors concluded that inclusion of deep fascia during flap harvest does not contribute to flap perfusion or vascularity [18]. Although there are several anatomical study reports on vascular anatomy of radial artery, our study demonstrates the cutaneous territory & location of clusters in detail. The results obtained from our study are clinically important in planning the exact dimension of the flap based on distal third perforators of radial artery. Perhaps the most significant finding in this study is the location of cutaneous perforators. Knowledge of these perforators can greatly facilitate the reconstructive surgeon in safe flap harvest & design [21] [22]. Both distal & proximal perforators can be used in designing of potential flaps for various reconstructive needs

[15]. Three-dimensional computed tomographic angiogram confirms that suprafacial dissection does not compromise blood supply of the radial forearm pedicle perforator flap [9] [11] (**Figure 8**). The supply to the skin is ensured by means of multiple perforators originating from the radial & ulnar sides of the radial artery, travelling to the skin & communicating with each other in the subcutaneous tissue plane by multiple linking vessels. Each perforator has its own vascular territory, called a perforasome, which carries a multidirectional flow pattern that is highly variable & complex. These perforasomes are linked to one another by both direct & indirect linking vessels, which themselves are linked by communicating branches. These numerous branches confer further protection form ischemia & vascular injury & explains the survival of single dominant perforator based flaps [20].

Linking vessels allow communication with adjacent perforasomes & follow a direction that is parallel to the direction of perforator flow. Therefore, perforator flap skin paddles should be parallel to the linking vessel orientation, which makes it possible to harvest large flaps based on single dominant perforator [20] [23]. If the radial forearm flap donor-site defect could be repaired primarily, then hand rehabilitation could be initiated earlier and the overall complication rate would be lower, compared with the traditional technique using a split-thickness skin graft to close the defect (**Figure 14**). This has led many surgeons to search for alternate methods of harvesting this flap allowing primary closure of the donor site. These include procedures incorporating tissue expanders or rotation flaps. Mateev *et al.* suggested a novel way of harvesting radial forearm flaps, which was termed "Shape modified method". The series being reported for scalp reconstruction [19]. No such reports are available for reconstruction of head and neck defects even though the methods appear to be elegant and avoids the use of skin grafts. The major advantage of this technique is its ability to reconstruct donor defects primarily in a one-stage operation, with better aesthetic contours of the forearm. In comparison with traditional methods such as split thickness skin grafting, the overall complication rate is minimized because hand motion can be allowed earlier, with the flexor tendons sliding beneath the flap. Soutar *et al.* reported 28% of problems in extension of wrist with traditional method [5]; we have no such reports in modified groups because of primary closure in the later group. Studies by Fenton *et al.* reports specifically the aesthetic problems in traditional method of radial forearm flap [24]. None of our patients had any sensory nerve disturbance associated with radial nerve branch. (Dorsum of thumb and first web space) (**Figure 14**). Our shape modified radial forearm flap has fared much better when compared to other methods of direct closure of donor sites. Ching-Hua *et al.* used ulnar based bilobed flaps but found the final defect has a lengthy and unsightly scar [24] [25]. Elliot *et al.* used V-Y advancement for primary closure but could only harvest 4 × 4 cm flaps and Berge *et al.* used tissue expanded skin but found difficult and used two stages for primary-Closure [26] [27]. We had problems with our method, which included reduction in pedicle length whenever the size of flap is increased. Maxi-

mum pedicle length we could harvest was 10 cm. Another probable problem mentioned in literature is the compression of the forearm due to tight closure. We did not have this complication in any of our 15 patients.

6. Conclusion

Each perforator holds a unique vascular territory. Vascular supply chain among perforators is highly complex & both direct & indirect linking vessels play a major role in maintaining flap perfusion. Our study demonstrates a consistent course of radial artery with clusters originating on both distal & proximal ends, with each end becoming a pivot point for a pedicled flap rotation. Each perforator has the potential to become either a free or a pedicled flap depending on the size. In addition preservation of radial artery & ability of supra-facial harvest further lessens the morbidity burden. This phenomenon allows a myriad of perforator flap designs that can be tailored to match reconstructive defects. Present day reconstructive surgeon has more options & alternatives in replacing like with like. Local flap alternatives become more plentiful & flap design is limited only by the availability of clinically relevant perforators close to the defect. Free style perforator flap alternatives are limited by the size & length of their respective source arteries & veins.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Endoscopic Surgical Procedures for Fungal Maxillary Sinusitis: How to Do It, a Review

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Abstract

Fungal rhinosinusitis (FRS) is categorized as being either invasive or non-invasive based on the histopathological evidence of tissue invasion by fungi. Endoscopic sinus surgery (ESS) has become the gold standard treatment for non-invasive FRS including sinus fungal ball. It is considered to be an effective and safe procedure. It is important to keep a sufficient field of view in order to remove the fungal debris completely. ESS should also prevent damage to the nasal cavity structures including the inferior turbinate. This report mainly describes the endoscopic surgical procedures for fungal ball of the maxillary sinus (sinus mycelia) based on our methods and review of the literature, including written articles in Japanese. ESS procedures include the middle meatus approach for the maxillary sinus, the combined approach (both middle and inferior meatal antrostomy) for the maxillary sinus, and endoscopic modified medial maxillectomy (EMMM).

Keywords

Fungal Rhinosinusitis, Sinus Fungal Ball, Sinus Mycelia, Endoscopic Sinus Surgery

1. Introduction

Fungal rhinosinusitis (FRS) is categorized as either invasive or non-invasive based on the histopathological evidence of tissue invasion by fungi [1]. Invasive FRS includes acute invasive FRS, granulomatous FRS, and chronic invasive FRS [2]. Acute invasive FRS is the most aggressive sinusitis, which shows bone distractions as well as orbit and/or skull base invasion with poor prognosis [3]. Wide resection with high-dose antifungal therapy should be performed immediately for the treatment of acute invasive FRS. Therefore, invasive FRS must be

distinguished from non-invasive FRS.

In contrast, the non-invasive type grows slowly and in some cases, there are no symptoms [1]. Non-invasive FRS can be divided into saprophytic fungal infestation, fungal ball, and fungus-related eosinophilic FRS including allergic FRS [2]. Fungal ball is the most frequent cause of non-invasive FRS, and the maxillary sinus is the most common location [1] [4].

Endoscopic sinus surgery (ESS) has become the gold standard of treatment or chronic rhinosinusitis, including non-invasive fungal sinusitis. It is considered as an effectiveness and safe procedure, and the recurrence rate is about 5% (0% - 22.5%) [4]. This report mainly describes about endonasal endoscopic surgical procedures for fungal maxillary sinusitis (fungal ball, sinus mycelia), based on our methods and a review of the literature, which included Japanese articles (**Table 1**).

2. ESS for Fungal Maxillary Sinusitis

To treat fungal ball of the maxillary sinus, all of the fungus must be completely removed. To verify complete removal of the fungal ball, it is important to achieve sufficient visualization of the sinus. In addition, the use of not only a 0˚ endoscope but also angled endoscopes (30˚, 45˚, 70˚) are required to achieve this. How to ensure the sufficient visualization? It is sometimes difficult to see the anterior inferior or medial inferior wall of the maxillary sinus even when a 70˚ endoscope is used, when the maxillary sinus is observed from a middle meatus window. If 70˚ endoscope does not allow sufficient visualization afterwards, then a flexible scope deployed into the maxillary sinus may avoid any unnecessary surgery. Although the surgery involves a large opening of the sinus, including removal of part of the inferior turbinate in some cases, the surgery should also prevent damage to the nasal cavity structures. It is not necessary to make an additional mucosal incision at the canine fossa. It is better to perform the septoplasty prior to ESS in order to achieve sufficient visualization of the sinus in cases with nasal septal deviation. The biopsy of the fungal debris and its surrounding mucosa is necessary to confirm non-invasive FRS when the fungal debris is removed. Nasal and sinus saline irrigation is performed at the end of the surgery.

Table 1. Summarized surgical procedures.

Surgical procedures	Methods
Middle meatus approach	uncinectomy and middle meatal antrostomy (standard procure of ESS)
Combined approach	both middle and inferior meatal antrostomy with preserved inferior turbinate
Endoscopic modified medial maxillectomy (EMMM)	medial maxillectomy with preserved inferior turbinate and nasolacrimal duct

2.1. Middle Meatus Approach

Endoscopic middle meatal approach is one of the most commonly performed functional ESS procedures. The nasal cavity is decongested using a gauze with lidocaine and epinephrine. The lidocaine with epinephrine is injected at the level of the middle turbinate root and uncinate process. The uncinate process is removed in case of middle meatal antrostomy. Complete removal of fungal debris by ESS through an uncinectomy and a sufficiently wide meatal antrostomy is performed. The large or wide antrostomy means that we have a good visualization of the maxillary sinus and surgical instruments can be inserted easily. There are varying opinions on what the size of the antrostomy should be. If the ethmoid bulla is severely blocked, the ethmoidectomy has to be performed. After widening of the antrostomy for the maxillary sinus, the fungal ball is extracted using curved suctions, forceps, and curved microdebrider blades.

The "Gauze technique" is a simple and quick method used to be removed the fungal ball in the maxillary sinus [5]. It is a standard ESS using traditional instruments with the gauze. The surgical procedure is following the steps. After making a wide antrostomy, the fungus ball is removed with the curved endoscopic pincers and suction. The gaze soaked in a standard saline solution is introduced into the maxillary sinus through the antrostomy. The bulk of the gauze pushes out the remaining fungal debris using a curved suction or curved pincers, and then a gauze can be used to push the fugal ball out of the antrostomy. The same procedure is repeated several times, after which the gaze can be easily removed with curved forceps from the antrostomy.

When fugal debris can be removed completely, it is not necessary to have a large opening in the middle meatus for sufficient access to the maxillary sinus cavity. Although the mucosa should be preserved, it must be biopsied to exclude any possibility of microscopic invasion by fungi. Infected granulation tissue should be removed using curved forceps and microdebrider blades, but the periosteum of the sinus must be preserved in such cases. When the fungal ball is located near the ostiomeatal complex, it is a good indication for a middle meat us approach (**Figure 1**).

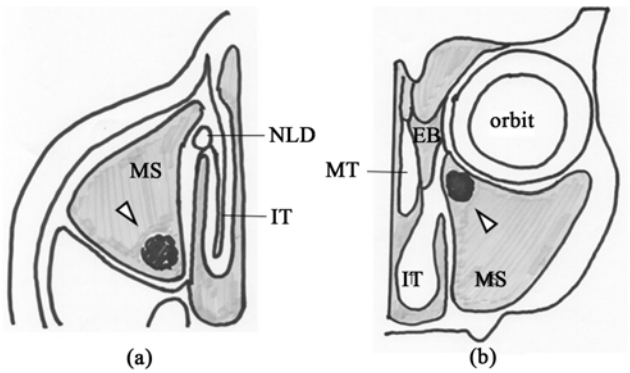

Figure 1. Schema of Axial (a) and Coronal section (b): Fungus ball (Arrow head) is located near the ostiomeatal complex. NLD, Nasolacrimal duct. IT, Inferior turbinate. MT, Middle turbinate. ES, Ethmoid sinus. MS, Maxillary sinus.

It is impractical to make a new window at the inferior meatus for these cases. On the other hand, it is sometimes difficult to see the anterior inferior or medial inferior wall of the maxillary sinus even when a 70˚ endoscope is used, when the maxillary sinus is observed from a middle meatus window. The insufficient visualization of the entire maxillary sinus means that removal of the fungal ball will be incomplete. Thus, it is possible that fungal debris removal will be incomplete from a middle meatus window, and only when the fungus ball is not located in the anterior inferior and medial inferior wall of the maxillary sinus, will complete removal be achieved.

2.2. Combined Approach (Both Middle and Inferior Meatal Antrostomy)

Our department recently published a study that combined both middle and inferior meatal antrostomy. This combination was shown to be effective for the treatment of FRS [6]. Our study showed that the results of ESS with the combined approach were better than the middle meatal approach alone without inferior meatal antrostomy [6]. The post-operative CT examination at 3 to 4 months after the ESS, showed a normal maxillary sinus, and no cases of recurrence were observed in combined approach group in our study (**Figure 2**) [6]. Klossek et al described that the middle meatus antrostomy had to be associated with an inferior antrostomy in about 65% of the cases in order to facilitate access

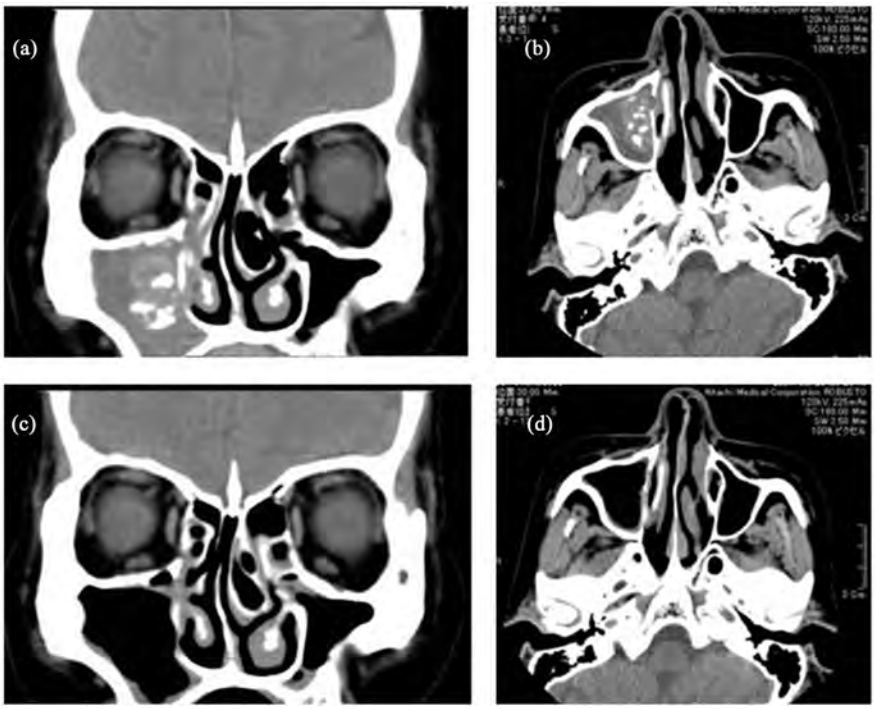

Figure 2. CT examination of a case where the combined method was utilized: **Figure 3(a)** and **Figure 3(b)** show soft tissue attenuation with a high-density lesion in the right maxillary sinus. **Figure 3(c)** and **Figure 3(d)** show the post-operative CT after ESS with both the middle and the inferior meatal antrostomy.

and removal of the fungal ball [7]. Dufour *et al.* reported 150 fungus ball maxillary sinusitis cases that revived the ESS procedure [8]. They performed middle meatus antrostomy (n = 53/150, 35%) and a combination of middle and inferior antrostomy (n = 97/150, 65%) [8]. Based on these reports, the combination of middle and inferior antrostomy appeared to be required in over 60% of fungus ball maxillary sinusitis ESS procedures. The double ventilation pathway operation is superior to the single ventilation pathway. The combined approach makes it easier to observe the whole sinus, especially the anterior inferior and medial inferior wall of the maxillary sinus, compared with the single middle meatus approach. As for the post-operative micociliary function of the maxillary sinus, the previous report suggested that a combination of middle and inferior meatal antrostomy does not disturb the microciliary clearance [9]. Our previous study showed that a combination of the middle and inferior meatus antrostomy approaches did not disturb the post-operative nasal condition [6]. We performed the combined approach of ESS in the following steps. First, the uncinate process was removed for a sufficiently wide meatal antrostomy (see 2-1. Middle meatus approach). The surgeon decided whether or not to perform an inferior meatal antrostomy based on the observation of the maxillary sinus which was observed from the middle meatal window. When the fungal ball was located on the anterior or inferior side of the maxillary sinus, or if the surgeon could not see that area, an inferior meatal antrostomy was performed. In this approach, the bridge of bone between the two antrostomy preserved the inferior turbinate. The inferior turbinate is fractured medially, allowing space for the endoscope (0 or 30 degree) prior to make an inferior meatal antrostomy being made.

Even if the inferior meatal antrostomy is closed after the surgery, which is not a major problem, we usually perform the meatal mucosal flap procedure to avoid closure or stenosis of the inferior meatal antrostomy (**Figure 3**). Tani *et al.* reported that the inferior meatal antrostomy opening ratio was 89% for the inferior

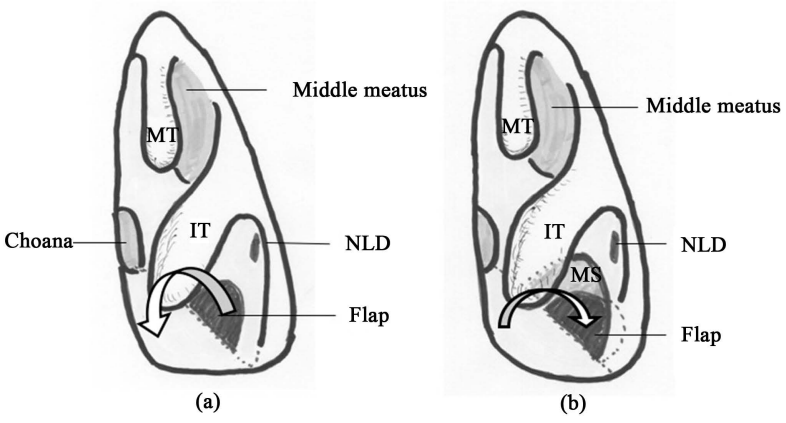

Figure 3. The inferior meatal mucosal flap procedure. (a) The U-shaped mucosal flap was positioned on the nasal floor after the elevation from the meatal bone**;** (b) The flap was positioned across the inferior lip of the bony window into the maxillary sinus after removing boney wall. NLD, Nasolacrimal Duct. IT, Inferior Turbinate. MT, Middle Turbinate.

meatal mucosal flap procedure after ESS [10]. The U shaped meatal flap was elevated on the inferior and lateral mucosa in the inferior meatus. After elevation from the meatal bone, the flap was positioned on the nasal floor (**Figure 3(a)**). Then an inferior meatal window was created using a perforator, or chisel. The bony wall was removed piece-by-piece to make a sufficient opening in the maxillary sinus. When the maxillary bone is hard, and it is difficult to make a hole, it is better to use an angled drill. After making an opening that was sufficiently wide, the mucosal flap was positioned across the inferior lip of the bony window into the maxillary sinus (**Figure 3(b)**). We can easily observe the inside of maxillary sinus and insert surgical instruments through the inferior window or middle meatus.

To remove the fungal ball, a gauze which has a size of either 3 cm × 15 cm or 3 cm × 30 cm is generally used. The gauze is soaked with normal saline or saline which includes epinephrine. The gauze is introduced into the maxillary sinus from the inferior meatal window using curved forceps (**Figure 4(a)**). Several gauzes are pushed into the maxillary sinus (**Figure 4(b)**), and then a gauze can be used to push the fugal ball out of the middle meatus (**Figure 4(c)**). The gauze can then be removed from the middle meatus or inferior meatal window. The same procedure is repeated until fungal ball can be completely removed (**Figure 4(d)**).

Okanoue *et al.* described the combined approach using a Foley catheter instead of the gauze-assisted technique [11]. They insert the catheter into the maxillary sinus from the inferior meatal antrostomy. The inflated balloon (10 ml) causes fungal debris to extrude into the nasal cavity through the middle meatal antrostomy. Debris may remain on inferior or posterior wall of the maxillary sinus, which can then be removed by curved suction, forceps or curved microdebrider blades. This is easy and effective way to remove a fungal ball.

2.3. Endoscopic Modified Medial Maxillectomy (EMMM)

Endoscopic medial maxillectomy with medial sift of preserved inferior turbinate

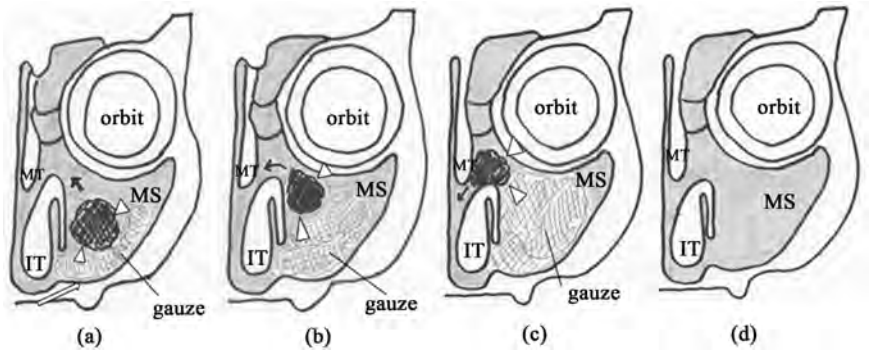

Figure 4. The combined approach using gauze technique. (a) The approaches (white arrow) are managed through the inferior meatal antrostomy; (b) (c) The gauze pushes Fungal ball (arrow head) out from Maxillary sinus (MS) through the middle meatus; (d) Fungal ball is completely removed. IT, Inferior Turbinate. MT, Middle Turbinate.

is a procedure for FRS that was introduced in 2008 (Japanese article) [12]. It was described that the head of the inferior turbinate is cut once using turbinate scissors up to the middle meatal antrostomy. This was done so that there is sufficient visualization of the sinus from the inferior meatus. After sifting the preserved inferior turbinate to the posterior midline position, the medial maxillectomy is performed from the middle meatal antrostomy using the backbiter cutting forceps. After the removal of fungal ball, the turbinate is repositioned and sutured with the anterior mucosa in its original position. This method was effective and has been widely accepted in Japan because it utilizes a relatively easy technique with a straight endoscope and instruments from to the inferior meatus. It is similar to the previously reported endoscopic medial maxillectomy with preservation of the inferior turbinate [13] [14]. These approaches are managed through the posterior side of the nasolacrimal duct. Therefore, it is difficult to obtain good visualization of the fungal ball located in the area between the nasolacrimal duct and anterior wall of the maxillary sinus (**Figure 5(a)**). In such a difficult case, endoscopic modified medial maxillectomy (EMMM) is the preferred choice (**Figure 5(b)**) [15]. Tsuta *et al.* first described this effective procedure for chronic sinusitis showing a transnasal endoscopic medial maxillectomy with preserved inferior turbinate and nasolacrimal duct in 1993 (**Figure 6**)

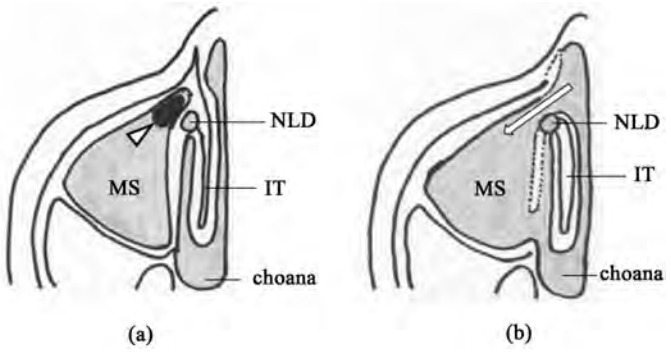

Figure 5. (a) Fungal ball (arrow head) located in the angle of between the nasolacrimal duct (NLD) and anterior wall of the maxillary sinus; (b) Schema of endoscopic modified medial maxillectomy (EMMM). The approaches are managed through the anterior side of the NLD (white arrow). IT, Inferior turbinate. MS, Maxillary sinus.

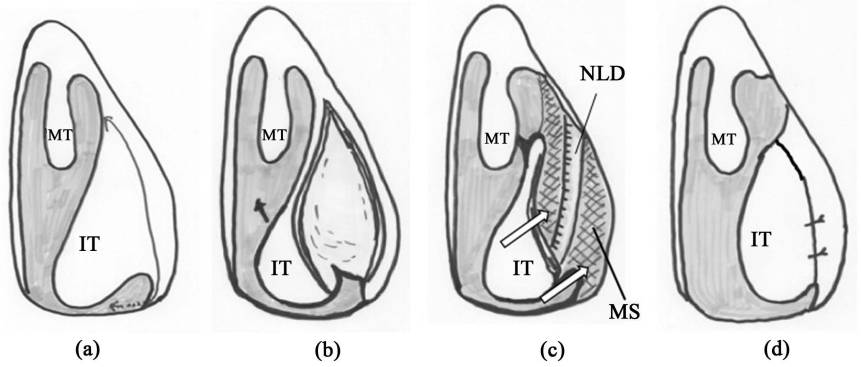

Figure 6. The endoscopic modified medial maxillectomy (EMMM) procedure.

[16]. A vertical incision is made in the mucosa of the lateral wall along the anterior margin of the inferior turbinate to the nasal floor (**Figure 6(a)**). The lateral nasal mucosa is separated from the medial maxillary wall bone (**Figure 6(b)**). They described that this procedure is initiated by an incision similar to the one used for submucosal resection of the inferior turbinate. After resection of the bone of the inferior turbinate, osteotomy of the medial maxillary bone is performed. At this time, the bone around the nasolacrimal duct is removed gently, and then the nasolacrimal duct is free from the bone (**Figure 6(c)**). The preserved inferior turbinate mucosa and the nasolacrimal duct can be swung from side to side. The authors called these steps of the procedure "the swing method." After the removal of fungal debris, the turbinate is repositioned and sutured with the anterior mucosa in its original position (**Figure 6(d)**). This procedure is similar to the modified transnasal endoscopic medial maxillectomy for inverted papilloma published in 2011 [17]. When it is necessary to obtain improved access to the maxillary sinus, osteotomy of the anterior wall of the maxillary sinus can be added. These approaches have become widely accepted and recognized as EMMM (we call it EM-three) for FRS.

3. Using Powered Devices

An electrically powered, cylindrical shaver (vacuum-powered microdebrider) can use continuous suction to remove fungal debris and the related granulation as well as polypoid tissue [18]. The prevent blades are available in a variety of angles. It is better to use the cylindrical shaver after fungal ball debulking. Because these often clog with the sticky fungal material.

A powered saline sinus irrigation system (for example, Hydrodebrider System) will help the removal of the fungal ball or bacterial colonies from the paranasal sinuses [19] [20]. The handpiece delivers a rotating spray of pressurized saline with incorporated suction. The pressured saline spray directly cleans the sinus with angles of 0 to 270 degrees [20].

4. Complications

As with any endoscopic surgery procedure, ESS has associated risks. Although the risk of a complication of ESS for FRS is low, it is important to understand the potential complications. In most studies, complications of ESS for FRS were the same as those described of Functional ESS for sinusitis [1]. According to the review article, minor complications totaled 5%, and major complications were around 0.5% - 1% for ESS [21]. The most common complication is epistaxis, mainly due to injury of the posterior nasal branch of the sphenopalatine artery [1]. In chronic rhinosinusitis cases, the most common complications were postoperative hemorrhage (1.2%, 41 of 3402 cases), cerebrospinal fluid leak (0.56%, 19 of 3402 cases), and orbital complications (0.85%, 29 of 3402 cases) [22]. Before ESS, we should pay attention to certain risk factors and preliminary damage. We must understand the risk factors prior to ESS being performed. There-

fore, it is very important to perform adequate preoperative imaging. We must check the uncinate process attachment zone, medial orbital wall, skull base, cribriform, plate, anterior ethmoid artery, sphenopalatine artery, optic canal, internal carotid artery and so on before ESS [21].

5. Post-Operative Care

Post-operative care is similar to that used after functional ESS for sinusitis. Previous studies have shown that non-invasive FRS does not require adjuvant local or systemic antimycotic chemotherapy after ESS. The patients require nasal and sinus saline irrigation using a bulb syringe after ESS [1]. The short-term use of steroid drops or spray will be effective for treating the edema of the rhinosinus mucosa [1]. The follow-up examination can involve either an endoscopic nasal or CT examination. We performed the post-operative CT examination three or four months after ESS, in order to confirm the patient had healed [6].

6. Conclusion

ESS is the standard treatment for non-invasive FRS including sinus fungal ball. All of the fungus must be completely removed. To verify complete removal of the fungal ball, it is important that there is sufficient visualization of the sinus. We have considered useful approaches such as, the middle meatal approach, combined middle and inferior meatal approach, and endoscopic medial maxillectomy, endoscopic modified medial maxillectomy (EMMM) for fungal maxillary sinusitis (**Figure 7**). These approaches are summarized in **Table 1**. Furthermore, we must understand the risks of these approaches to avoid the complications of ESS.

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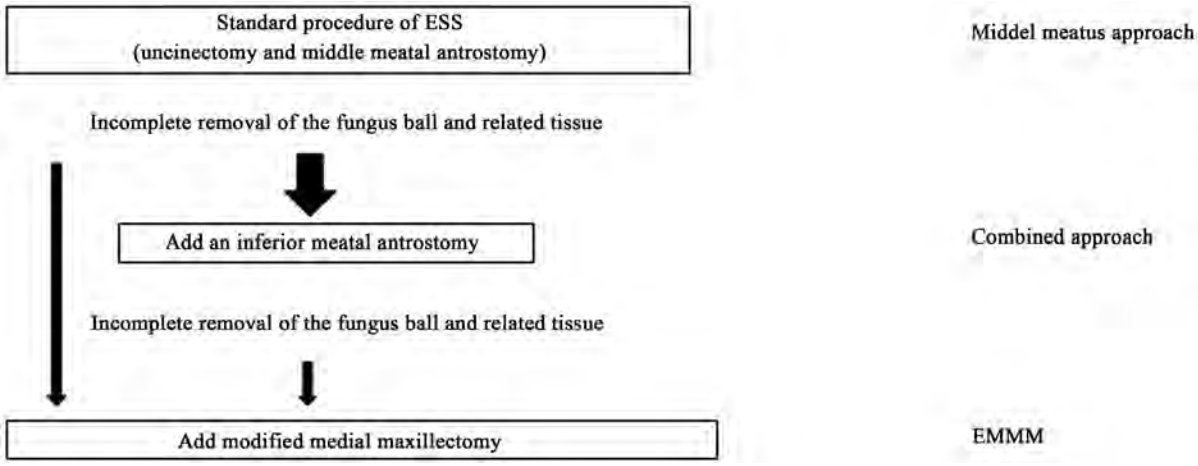

Figure 7. Flow chart of ESS for FRS. This flow shows an example. The following points are important to select ESS procedures. 1) Sufficient visualization of the sinus. 2) Complete removal of the fungal ball with related tissue. 3) Avoid any unnecessary surgery.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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A Finite Element Analysis Study Comparing 3 Internal Fixation Techniques in Mandibular Sagittal Split Osteotomy

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Abstract

Purpose: To analyse, and compare using finite element analysis, the biomechanical properties of the 1.7 mm miniplate fixation against 2 conventional fixation techniques (2.0 mm bi-cortical screws and 2.0 mm miniplate) used in the mandibular sagittal split osteotomy. **Methods**: A 3-D virtual mandible model was constructed using images from CT scan. Sagittal split osteotomy was carried out virtually, and the fixation techniques were applied onto the model. 9 virtual models consisted of the 3 fixation techniques with mandibular movements of 3 mm setback, 3 mm advancement and 7 mm advancement were developed. Bite forces of 50, 75 and 100 N were applied for incisor bite simulation and 100, 200 and 300 N for molar biting force. Finite element analysis was carried out in Solidworks, and readings of stresses and displacement were recorded. Wilcoxon rank sum test was applied and P-value of 0.05 was set for statistical analysis. **Results**: In this manuscript the authors have compared 3 internal fixation techniques in mandibular sagittal split osteotomy. There was a statistically significant difference for both stress and displacement readings between the 1.7 mm miniplate, the 2.0 mm bi-cortical screws and the 2.0 mm miniplate for all mandibular movements. For the 1.7 mm miniplate vs 2.0 mm bi-cortical screws, the stress reading was (P = 3.063e−08, W = 314), and for displacement was (P = 5.811e−05, W = 282). For the 1.7 mm miniplate vs 2.0 mm miniplate, the stress reading was (P = 9.862e−4, W = 263) and for displacement was (2.05e−2, W = 235). **Conclusion**: The 1.7 mm miniplate has adequate strength to be used in mandibular sagittal split osteotomy, although statistically less rigid when compared to the conventional 2.0 mm miniplate and 2.0 mm bi-cortical screws, especially in larger movements.

Keywords

Orthognathic, BSSO, Rigid Fixation, Biomechanical, Finite Element Analysis

1. Introduction

Providing adequate stability after orthognathic surgery is important to minimize complications and relapse. The fixation techniques used in mandibular orthognathic surgery are usually internal fixation, and over the years have switched from non-rigid wires, to more rigid screws, and titanium miniplates [1] [2]. The aim of providing stable fixation for the bone segments is to facilitate good bone healing, early mobilization of the jaws, and to prevent relapse [3].

Internal fixation techniques can be classified as rigid, semi-rigid/functionally stable or non-rigid. Historically, Bernd Spiessl in 1974 published the use of bi-cortical screws as rigid internal fixation that can prevent relapse in mandibular osteotomies, while Hans Luhr in 1979 introduced the principle of mini-plates in orthognathic surgery [2]. The 2.0 mm or larger miniplate system is commonly used for mandibular orthognathic surgery and trauma [4]. However, the use of smaller miniplate fixation in mandibular osteotomies is uncommon, but has been reported in the literature [5].

Biomechanical studies investigating the properties of various fixation techniques in mandibular osteotomies include *in-vitro* and finite element analysis studies [6] [7] [8] [9]. The finite element analysis is a mathematical method for solving problems of engineering, and mathematical physics. There is a growing interest in the use of finite element analysis (FEA) in the studies of human oral and maxillofacial biomechanics including maxillofacial trauma, zygomatic implants, dental implantology, and orthognathic surgery [10] [11]. The finite element method allows the analysis of biomechanical properties of bone and fixation techniques in various situations and loads.

This study used FEA to investigate the biomechanical properties of three internal fixation techniques (1.7 mm miniplate with mono-cortical screws, 2.0 mm bi-cortical screws, and 2.0 mm miniplate with mono-cortical screws) used in mandibular orthognathic surgery, subjected to different biting forces and movements. It is also the first study to compare different mandibular osteotomy lengths on stresses in fixation techniques and displacements. The purpose of this study is to assess the biomechanical performance of the smaller 1.7 mm miniplate when compared to the other techniques.

2. Materials and Methods

The study uses finite element analysis (FEA), which is a computational study. This study was approved by the Dental Ethics Committee, Dublin Dental School and Hospital, Trinity College Dublin, Ireland.

2.1. Model Construction

A pre-operative facial bones CT Scan of a 30-year-old, consenting female, who was undergoing surgery of the maxilla was used construct the mandible virtual model. The images of the scan were in 0.625 mm thickness and were converted into Digital Imaging and Communications in Medicine (DICOM) format. In-Vesalius software was used to extract the CT images, selecting the mandible bone only using the Hounsfield threshold, and converted into a 3D standard tessellation language file (STL) format [12]. The STL model was edited in Net-fabb software, and any defects present were repaired. Only half of the mandible was preserved to reduce model complexity, ensure adequate computer resources, and create virtual models with less elements [13]. Rhinoceros software was used to fit a series of non-uniform rational B-splines (NURBS) around the hemi-mandible STL surface [14]. This created a surface model, which was opened as a solid mandible model, and used for FEA. The mandible's cancellous bone layer was developed separately using the same process.

In Solidworks, both the cortical mandible model and cancellous bone were combined to develop a cortical-cancellous mandible model [15]. This bi-layer mandible solid model underwent a virtual sagittal split osteotomy (Obwegeser technique with DalPont, Hunsuck and Epker modifications), which resulted in 2 segments; proximal and distal segment of the mandible (**Figure 1**).

The fixation techniques were developed in Solidworks. Screws in each technique were developed as smooth cylinders, and threads omitted. The 1.7 mm and 2.0 mm miniplate consisted of 4 mono-cortical screws of 5 mm length, while the 2.0 mm bicortical screws were developed with 15 mm and 11 mm length initially, and adjusted accordingly during model assembly. The 2.0 mm bicortical screws were applied in an inverted-L design, with 2 screws on the superior border and 1 screw inferiorly.

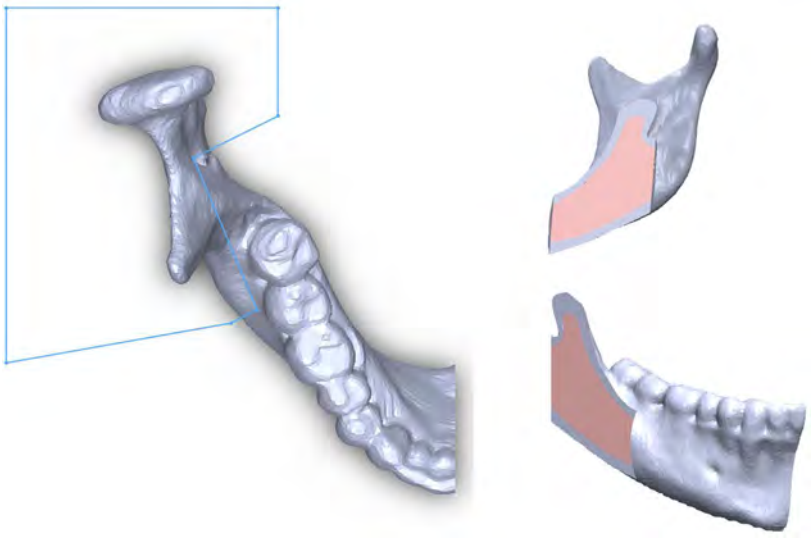


Figure 1. Sagittal split osteotomy carried out virtually resulting in proximal segment (upper right) and distal segment (lower right).

A total of 9 assembly virtual models were developed, which incorporated the solid bi-layer mandible, the internal fixation techniques, and incorporating the various mandibular osteotomy movements as shown in Table 1.

2.2. Material Properties

Cortical and cancellous bone types were homogenous in all regions of the mandible. The bone properties were derived from previous literary data, and an average value was chosen to represent a normal healthy adult bone [16] [17] [18]. The fixation techniques had the properties of commercially pure titanium Ti-4AI-6V.

Table 2 shows the properties of each material used in the FEA. The elastic modulus is the ratio of the stress and strain of an object undergoing elastic deformation. Poisson's ratio is the ratio of the transverse strain and the longitudinal strain in an elastic body under longitudinal stress.

Mesh creation (discretization) and simulation analyses

Mesh creation or discretization is the process of breaking down the whole assembled mandible model into smaller finite elements. Following a mesh convergence test with limit of 5% difference between successive mesh, each model consisted of maximum element size of 3 mm, minimum element size of 0.5 mm.

Table 1. Models with respective fixation technique and mandibular movements.

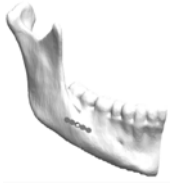
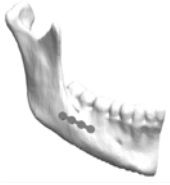
Mandibular movement	1.7 mm miniplate	2.0 mm miniplate	2.0 mm bi-cortical screws
3 mm setback	 Model 1	 Model 2	 Model 3
3 mm advancement	 Model 4	 Model 5	 Model 6
7 mm advancement	 Model 7	 Model 8	 Model 9

Table 2. Material properties used in FEA.

Material	Property	Value
Titanium	Elastic Modulus	104.8 GPa
	Poisson's ratio	0.31
	Density	4428.8 kg/m^3
Cortical Bone	Elastic Modulus	17 GPa
	Poisson's ratio	0.3
	Density	2000 kg/m^3
Cancellous Bone	Elastic Modulus	300 MPa
	Poisson's ratio	0.3
	Density	1500 kg/m^3

1 GPa = 1000 MPa (Pa is the Pascal unit which is the equivalence to Newton/m^2).

The number of elements in Model 4 was 136,450 elements, and this differs slightly in other models due to the type and size of fixation techniques, and mandibular movement.

The contact surfaces of the proximal and distal mandible bone were non-penetrating and allowed movements, while the surfaces between the screws and bone were bonded to assume they were rigidly fixed to bone. (**Figure 2**) The condylar region of the model was fully restrained. The mid-symphysis was restrained with a slider/roller restraint which allows movement in the vertical plane only and simulates the presence of the other half of the mandible (**Figure 2**).

Forces were applied in the angle region of the mandible to simulate the masseter muscle action. To simulate bite forces, either the molar or incisal occlusal surfaces were restrained at one time. Forces of 50, 75 and 100 N were applied for the incisor bite simulation, and 100, 200 and 300 N for molar bite simulation.

FEA was run in all models at the various bite forces and mandibular movements. Maximum von Mises stress in the fixation, and maximum displacement of the whole model were recorded. Von Mises stress is the equivalent tensile stress used to predict the yielding of materials, when they are placed under loads from different directions.

3. Results

3.1. Stress in Fixation Techniques

The maximum von Mises stress in all models are shown in **Table 3**. The 1.7 mm miniplate recorded the highest von Mises stress, when compared to the bi-cortical screws and 2.0 mm miniplate, at all forces and mandibular movements. The maximum stress recorded in all fixation techniques were within the material yield before permanent deformity. Stress distributions in each fixation technique and models, at maximum force application, are shown in **Figures 3-5**. The stresses in the 1.7 mm and 2.0 mm miniplate are mainly concentrated in the

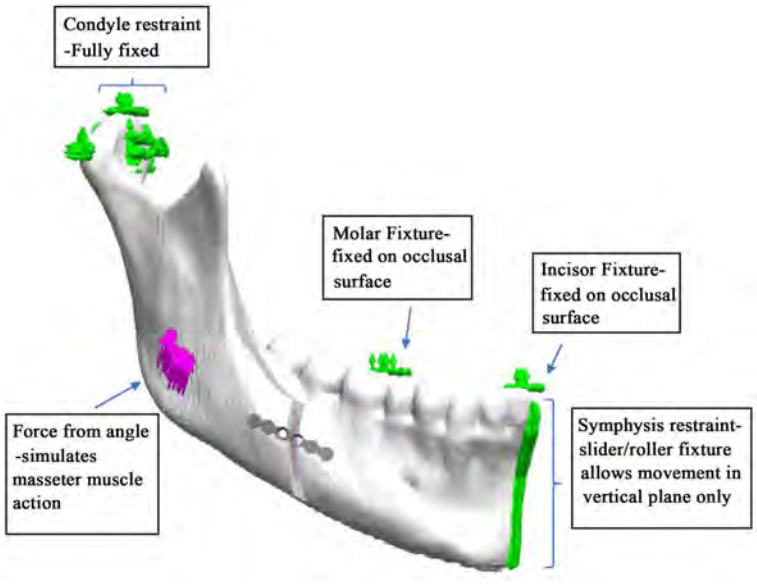


Figure 2. Restraints, boundaries and force application in the FEA simulation model.

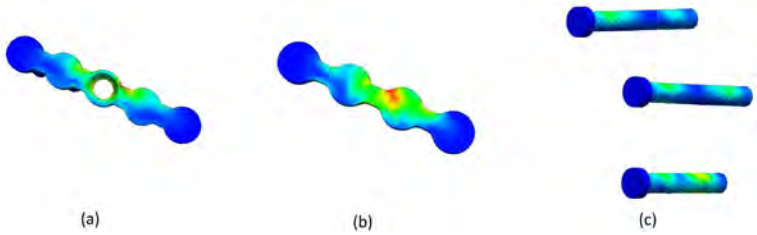


Figure 3. Stress distribution in fixation techniques at 3 mm mandibular setback and 300 N force. (a) Model 1: 5-hole 1.7 mm miniplate; (b) Model 2: 2.0 mm miniplate no gap; (c) Model 3: 2.0 mm bi-cortical screws.

Table 3. Maximum von Mises stress (MPa) in fixation techniques for all simulation models.

Mandibular movement	Model	Force	50 N	75 N	100 N	100 N	200 N	300 N
3 mm setback	1 (1.7 mm miniplate)		107.9	162.0	216.3	229.8	406.3	456.3
	2 (2.0 mm miniplate)		30.7	46.1	61.5	75.8	152.2	229.2
	3 (2.0 mm bi-cortical screws)		38.2	57.3	75.9	67.8	111.4	145.2
3 mm advancement	4 (1.7 mm miniplate)		133.5	200.6	267.8	266.3	537	812
	5 (2.0 mm miniplate)		50.5	75.8	101.3	110.1	221.5	334.3
	6 (2.0 mm bi-cortical screws)		26.5	39.7	52.9	48.7	97.3	146
7 mm advancement	7 (1.7 mm miniplate)		148.7	223.5	298.8	307.5	621.3	929.7
	8 (2.0 mm miniplate)		75.3	131.1	151.1	151.2	304.1	458.1
	9 (2.0 mm bi-cortical screws)		30.4	45.5	60.7	56.3	112.4	168.5

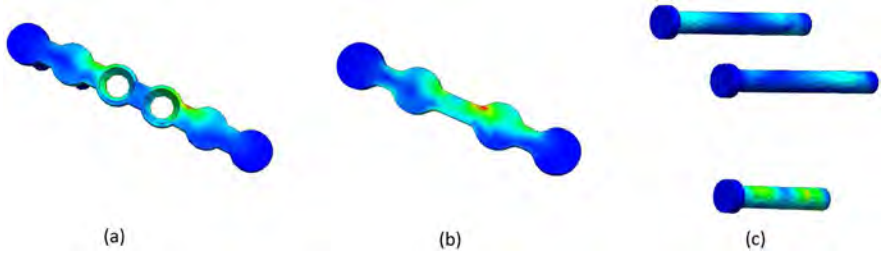


Figure 4. Stress distribution in fixation techniques at 3 mm mandibular advancement and 300 N force. (a) Model 4: 6-hole 1.7 mm miniplate; (b) Model 5: 2.0 mm miniplate with 4.4 mm gap; (c) Model 6: 2.0 mm bi-cortical screws.

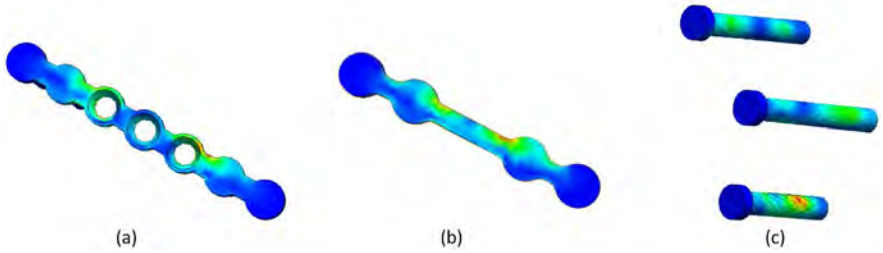


Figure 5. Stress distribution in fixation techniques at 7 mm mandibular setback and 300 N force. (a) Model 7: 7-hole 1.7 mm miniplate; (b) Model 8: 2.0 mm miniplate with 8 mm gap; (c) Model 9: 2.0 mm bi-cortical screws.

superior-distal region of the connector region. The stresses in the 2.0 mm bi-cortical screws are dissipated among all screws, but more concentrated in the inferior-distal screw, and maximum stress is seen at the lingual cortical-cancellous junction.

A Wilcoxon rank sum test was carried out for the non-normal distributed data. The test showed statistically significant difference between the 1.7 mm miniplate and the 2.0 mm miniplate, with $P < 0.05$ ($W = 263$, p-value = 0.0009862). There was also significant difference between the 1.7 mm and 2.0 mm Bi-cortical screws, $P < 0.05$ ($W = 314$, p-value = 3.063e−08), and between the 2.0 mm miniplate and 2.0 mm Bi-cortical screws, $P < 0.05$ ($W = 238$, p-value = 0.01557).

3.2. Mandible Segment Displacement

Maximum displacement was seen in the proximal segment of the mandible model in all cases. This is consistent with the location of force application, which is in the angle region. The maximum displacement for all models is shown in Table 4. The highest displacement is seen in model 7, which consists of 1.7 mm miniplate fixation with a 7 mm mandibular advancement. While the least displacement is seen in model 3 with 2.0 mm bi-cortical screws at 3 mm mandibular setback.

Statistical significant difference was seen between the 1.7 mm miniplate and the 2.0 mm miniplate models, with $P < 0.05$ ($W = 235$, p-value = 0.02046), between the 1.7 mm and 2.0 mm bi-cortical screws models, $P < 0.05$ ($W = 282$,

Table 4. Maximum displacement (mm) in proximal mandible segment for all simulation models.

Mandibular movement	Model	Force:	50 N	75 N	100 N	100 N	200 N	300 N
3 mm setback	1 (1.7 mm miniplate)		0.068	0.102	0.137	0.132	0.252	0.332
	2 (2.0 mm miniplate)		0.049	0.073	0.098	0.092	0.185	0.281
	3 (2.0 mm bi-cortical screws)		0.033	0.052	0.069	0.062	0.118	0.169
3 mm advancement	4 (1.7 mm miniplate)		0.114	0.172	0.230	0.223	0.449	0.680
	5 (2.0 mm miniplate)		0.053	0.079	0.107	0.102	0.207	0.315
	6 (2.0 mm bi-cortical screws)		0.039	0.059	0.079	0.071	0.142	0.214
7 mm advancement	7 (1.7 mm miniplate)		0.146	0.219	0.294	0.289	0.581	0.879
	8 (2.0 mm miniplate)		0.081	0.122	0.164	0.150	0.303	0.459
	9 (2.0 mm bi-cortical screws)		0.042	0.064	0.086	0.077	0.155	0.233

p-value = 5.811e−05), and between the 2.0 mm miniplate and 2.0 mm bi-cortical screws models, $P < 0.05$ ($W = 231$, p-value = 0.02896).

3.3. Effect of Mandibular Movements on Maximum Stress and Displacement

In larger advancements, the fixation techniques absorb more stress when compared to setback movement. The effect of mandibular movements on stresses in fixations can be illustrated in **Figure 6**.

Displacement of the proximal segment increases as the mandible is advanced further (**Figure 7**). Displacements for models in the mandibular setback movement are much less compared to advancement movements.

4. Discussion

The use of miniplates smaller than 2.0 mm in mandibular fixation is uncommon, but has recently gained interest by clinicians and researchers. In 2010, Burm *et al.* studied the use of 1.2 mm microplate and mono-cortical screws in the management of mandibular fractures and found considerable success compared to other conventional 2.0 mm miniplates [19]. He explained the advantages of smaller microplates, which include less foreign body reaction, less palpability, and improved patient acceptability. Ahmed *et al.* in 2017 who compared 2.0 mm miniplates with 1.5 mm miniplates in the management of mandibular symphysis fractures using FEA [20]. They found that there was no significant difference in the stresses developed in either of the bone plating system. Yeo *et al.* in 2017 compared the effects between 1.7 mm upper border sliding plates and positional screws in neurosensory disturbances following BSSO advancement.

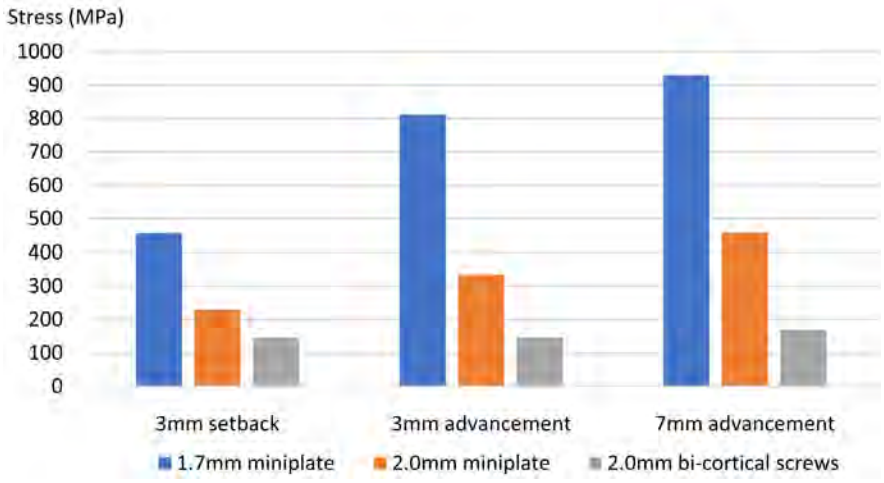


Figure 6. Maximum stress in fixation techniques in all mandibular movements.

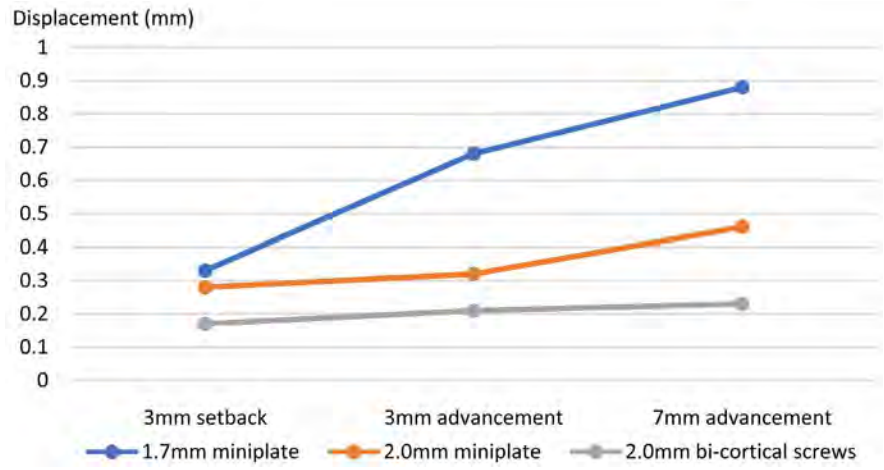


Figure 7. Maximum displacement in simulation models for all mandibular movements.

He showed that there was insufficient evidence to prove one was better than the other [5].

The present study has shown the comparison of biomechanical properties in 3 fixation techniques when various forces and different mandibular movements are applied. The results of this study support the findings of previous FEA studies by showing that the 2.0 mm bi-cortical screws are more rigid than miniplate fixations [6] [7] [21]. These studies however, have not made biomechanical comparisons of fixation techniques at various mandible movements.

The 2.0 mm bi-cortical screws recorded the least stress and displacements compared to the 2.0 mm miniplate and 1.7 mm miniplate for all mandibular movements and forces. The bi-cortical screws are more rigid than the miniplates with monocortical screws, probably because they penetrate both buccal and lingual cortices of the mandible segments [22]. This study does not show any deformation in the miniplates, and areas of high stresses represent as red color can be either tensional or compressional stresses (**Figures 3-5**). Minimizing manipulation of the miniplates in these high stress regions is highly advised to avoid

complications such as plate fracture.

The amount of displacement is an indication of fixation rigidity, and the bi-cortical screws were shown to be the most rigid fixation. Miniplates can be rigid or functionally stable and clinically have both been proven to be successful in the treatment of mandibular fractures [23]. In our study, the maximum displacement is less than 0.9 mm which was seen in Model 7 that consisted of the 1.7 mm miniplate at 7 mm mandibular advancement. The amount of displacement is small in the simulation models and is probably not clinically significant. Claes in 1998 claims that some degree of micromotion in bone in-fact enhances callus formation during bone healing, and this may be an advantage of semi-rigid fixation [24]. Least displacement is seen in the setback models, and is likely due to the close approximation of the mandible segments. Like mandibular fractures, the close approximation of bony segments increases stability of the fracture [22].

In FEA, the setup of simulation models is important, as any changes in force locations or restraints can affect the results. Comparing results with other FEA orthognathic studies is difficult due to difference in model construction, mesh element numbers, and various simulation protocols. There are studies that use a full mandible [25] while others opted for the hemi-mandible [6] [7] [21]. The reason highly depend on the computer resources and in certain instances, the models require simplification to reduce computational demand.

This study simulated a hemi-mandible with a cortical and cancellous bone layer. The condyle was fully restrained, while the symphysis region had a slider/roller restraint which permits movement in the vertical plane only and simulates, in our simplified model, the other mandible half. The occlusal surface of the molar and incisor were fixed according to the type of load applied. Forces of 50, 75 and 100 N were applied with the incisor fixed to simulate incisal biting while 100, 200 and 300 N applied for molar bite force. Bite forces were obtained from studies investigating post-operative bite forces in orthognathic surgery patients [16] [17] [18]. During the post-operative period, bite forces in healthy adults can drop to 50% or more, and gradually increases to normal after 3 months to 2 years. This study did not include maximum normal bite forces as the fixation techniques are most crucial during the bone healing period of 3 to 6 months.

Mandibular sagittal split osteotomy is a recognized orthognathic technique and it allows various movement such as advancement, setback, and rotation. The type of mandibular movement required is the result of surgical and orthodontic planning and reflects the patient's dentofacial deformity. The fixation technique applied must be strong enough to provide sufficient stability, while minimizing risks and complications. Bi-cortical screws are rigid but known to have increased risks to the inferior alveolar and lingual nerve [26]. Miniplates are less rigid, have higher removal rates, and can cause irritation to the mucosa and gingiva, even when placed appropriately [27]. Both bi-cortical screws and miniplate fixation have been shown to provide similar skeletal stability in the long term [28]

[29]. The successful outcome of orthognathic surgery does not only rely on the fixation techniques but other factors, including severity of the dentofacial deformity, surgical planning, surgeon's technique, and patient's soft and hard tissues.

Limitations exist with any computational experiments. This study only involves the use of a single Caucasian female mandible CT scan. Although replicable and capable of being manipulated in the software, it does not represent a full population of different sized mandibles. Condylar torque was not considered following fixation placement. Condylar torque is a known phenomenon following fixation of a mandibular osteotomy. As the models did not include the temporomandibular joint soft tissue structures and the condyle was fixed during simulation, condylar torque was not assessed. Although these limitations were present, they were mitigated by being present in all models, which were compared with one another.

5. Conclusion

This study looked at the biomechanical properties of using a smaller 1.7 mm miniplate in mandibular orthognathic surgery with various movements. Although it recorded the highest stress among the other techniques, the stress was within the material yield of 950 MPa for all mandibular movements. In conclusion, the 1.7 mm miniplate has adequate strength when applied and can be used in mandibular osteotomy, although statistically less rigid when compared to the conventional 2.0 mm miniplate and 2.0 mm bi-cortical screws, especially for larger movements.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Terms and Abbreviations

Term	Definition
Anisotropic	A material that consists of more than one property in various areas and direction
Bi-cortical screws	Screws that penetrate both cortices of bone
Biomechanical	Study of the action of external and internal forces on the living body, especially on the skeletal system
CT	Computer tomography-computer-processed combinations of many X-ray measurements taken from different angles to produce cross-sectional images of specific areas of a scanned object
DICOM	Digital imaging and communications in medicine. It is an image format usually containing CT images
Discretization (Meshing)	The process of changing a solid body into smaller finite elements
Elastic Modulus (Young's Modulus)	Measurement of stiffness of a solid material
FEA	Finite Element Analysis, a computerized method for predicting how a product reacts to real-world forces, vibration, heat, fluid flow, and other physical effects
Hooke's Law	The principle of stress imposed on a solid is directly proportional to the strain produced, within the elastic limit
IGES	Initial Graphics Exchange Specification, file format that allows the digital exchange of information among computer-aided design (CAD) systems
Invesalius	Computer software that allows conversion of DICOM images into STL
In-vitro	Studies performed outside of biological context
Isotropic	A material that is uniform in all areas and direction
Mono-cortical screws	Screws that penetrate a single bone cortex
Netfabb	Computer software that allows editing and repair of surface polygons
Newton (N)	A measurement unit for force
NURBS	Non-uniform rational basis spline (NURBS) is a mathematical model commonly used in computer graphics for generating and representing curves and surfaces
Pa (Pascal)	Pascal, SI unit to quantify stress which is equivalent to 1N per square meter. 1 Mega Pascal (MPa) = 1000 Pa, and 1 Giga Pascal (GPa) = 1000 MPa
Poisson's ratio	The ability of a structure to resist deformation in a direction perpendicular to that of the applied load.
Rhinoceros	Computer software that allows creation and manipulation of NURBS
Simulation in Solidworks	An internal programme of Solidworks that runs FEA
Solidworks	Computer software that allows creation, editing and manipulation of 3D solid models
STL	Stereolithography, a file format used to represent surfaces with a series of triangles
Strain	The measurement of the deformation of a material
Stress	The force per unit area applied to an object
Von Mises Stress	The equivalent tensile stress used to predict the yielding of materials, when they are placed under loads from different directions

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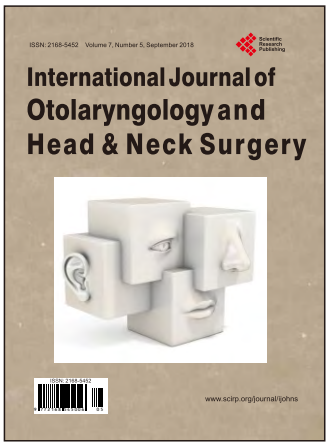

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