DENTAL DECISION SUPPORT AND TRAINING SYSTEM FOR ATTACHMENT SELECTION IN REMOVABLE PARTIAL DENTURE DESIGN

BY

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ABSTRACT

Background: Attachment selection in removable partial dentures (RPD) design is considered one of the most challenging treatment modalities in dentistry. Any error that occur during attachment selection due to lack of proper knowledge, overwhelming number of attachments, mistreatment, multiple adjustments and repairs could result in adverse clinical consequences, and significant inconvenience to the patient as well as financial implication to both patient and provider. Attachment selection is indeed very challenging for several reasons. Firstly, the topic itself has not been widely researched and published in dental literature, and therefore the best attachment selection still remains an area prone to high error rates in decision-making. Secondly, the complexity of the topic and lack of proper knowledge that requires sound knowledge of attachment principle, which spans multiple dental displaces of endodontic, orthodontics, periodontics and prosthodontics. Furthermore, now there are an over whelming number of attachments available in the market due to high patient demand for cosmetic and aesthetic dental enhancements. It is therefore extremely difficult for dental practitioners to readily recall an extensive list of factors that determine an appropriate attachment for RPD design. This is more as for dental education students, especially for students, residents, and less experienced clinician who may not possess the adequate education, training and competencies. Although clinical experts in the area of RPD design and attachment experience and skills may be able to assist with knowledge and years of experience they may not always be around or readily available. To address this problem and gab in the education and training of dental students, residents and practitioners seeking continuing education, we have developed a clinical support and training system for RPD attachment design and implementation based on dental experts' knowledge and literature evidence-based clinical and practice guidelines.

Methodology: The RPD attachment clinical decision support system was developed using Exsys Corvid Core software. The knowledge based of the system was setup using dental experts' and literature evidence-based practice guidelines. In all the knowledge base was successfully loaded with more than 100 rules representing many different clinical scenarios for variable types of attachment selection in RPD. For any new input attachment case, based on the information entered by the user, the system comes up with an appropriate evidence-based recommendation and treatment plan. To ensure that the clinical decision

support and training system was indeed fully capable of training and educating dental students and residents it was validated by nine expert prosthodontics using a survey style questionnaire on the various aspects of the setup and functionality of the system. The questionnaire results were statistically evaluated using Cronbach's Alpha Coefficient Test.

Results: The Cronbach's Alpha reliability coefficient was 0.893, which represent a good internal consistency and indicates an overall agreement among the prosthodontic experts as to the need and viability of the system for training dental students and residents in the area of RPD attachment design. Likewise, the results of the validation questionnaire showed that all prosthodontics agreed that the system contained all of the most relevant factors for attachment selection in RPD design ensuring its utility for training and education in a real-world practice.

Conclusion: The clinical decision support and training system for RPD attachment design was successfully developed using Exsys Corvid Core software. Expert prosthodontists concurred that the system can be effectively employed for training dental student, inexperienced dentists and residents to select an appropriate attachment for RPD. It can be used to complement traditional teaching methods even in the absence of patients as part of a dental degree curriculum.

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Table of Contents

LIST OF FIGURES

LIST OF TABLES

1 CHAPTER I: INTRODUCTION

1.1 Introduction

An attachment is a connector consisting of two or more parts. One part is connected to root, tooth, or implant and the other part to prosthesis[1]. Attachment-retained Removable Partial Denture (RPD) is not an outdated treatment modality. Dr. Heman Chayes first reported the invention of attachments in early 20th century.[2] It is even more existing in today's appearance than when it was first introduced. There are numerous number patients who could benefit from this treatment option, both in the short and long term. However, the overwhelming number of attachments available in the market, the lack of proper knowledge, issues with repairs and problems regarding multiple adjustment are making dentist reluctant to provide RPD attachments to their patients[1].

"Dentistry is not limited to prevention and treatment of dental disease, but it extends its use to meet the esthetic demands of the patient"[3]. There are many treatment modalities available for patients with few missing teeth in either the upper or lower arch. In such partial edentulous situations, there are many treatment options available. The first and best treatment option is the implant prosthodontics, but it is not always possible due to local and systemic factors or economic reasons[4.]

While replacing missing teeth, restoring function and esthetics should be prioritized.

RPD attachment is a treatment plan that can provide both function and esthetic requirement for patients. However, not all treatment modalities can restore both function and esthetics, many RPD's that were made were negligence to above-mentioned factors.

This is because the main focus was on the replacement of missing teeth. This led to harmful effect on remaining natural dentition.[5] The use of conventional methods of fabrication of the removable partial denture continues, especially when implant therapy is not used to replace missing teeth. Attachment retained partial dentures have paved their way for such cases in prosthodontics. RPD attachments wear less, last longer, have a superior esthetic, work better, protect abutment teeth and are easier to clean[3]. Attachment retained partial dentures, provide long-term stability and more satisfaction to the patient compared to clasp retained denture[3].

The success of attachments has improved the field of dentistry dramatically. (Makkar et at, 2011) concluded that attachment –retained RPD is a viable option for patients to whom fixed prosthesis, implants are contraindication. In order for the treatment to be successful and to preserve a patient's existing dentition. Dentists have to properly diagnose the patient and design the right treatment plan. Attachments have always been surrounded by mysteries because of the lack of experience and familiarity. The only way to solve this mystery is by using artificial intelligence expert systems in diagnosis and treatment plans.

We propose an evidence-based decision support system that helps in training residents, and young skilled dentists. It also aids in critical thinking to ensure long term treatment success based on scientific principles imbedded in the system. The system will consider a series of factors which will be analyze, to calculate the finding. It then assigns scores to give proper feedback that includes: recommendations, treatment plans and other important

information. RPD attachment requires a complex thinking process and extensive dental training that relies on support and guidance of expert clinicians. Clinical experts have the knowledge and years of experiences in treating patients that can help in the process. However, they may not always be around to help. According to the American Dental Association[6], 79% of all active dentistry in the United States practice as general dentists, while 21% are practicing in a specialty and prosthodontics represent 8.6% of all dentists. Therefore, there are not enough prosthodontics specialists to guide residents and inexperienced dentists. This called upon an urgent need to develop an expert decision-making system that combines evidence-based data and expert clinicians' knowledge and input to facilitate consistent clinical decisions among dental practitioners.

This system will ensure a systematic analysis of all clinical relevant data in order to reduce dental treatment errors, and therefore improve patients' dental care. Furthermore, the system will help residents and fresh graduates learn how to effectively produce a treatment plan for difficult clinical cases before starting any clinical interventions. The proposed decision support system will be structured to include a series of clinically oriented multiple-choice questions that require feedback from the end-user. It will train the users to think like an expert through the decision-making process. The system will acquire the collected data and process it according to the pre-structured decision trees, the given rules and the assigned scores, to provide an ideal treatment plan along with other alternatives.

1.2 Background and statement of the problem

According to The American Dental Association (ADA)[7] 2010, treatment planning is

defined as " the sequential guide for patient's care as determined by dentists' diagnosis and is used by the dentist for the restoration to and / or maintenance of optimal oral health" In order for this to be achieved the following steps need to be taken : firstly, to take the patients' chief complaint. Secondly, to collect clinically relevant data, including the patients' medical dental history and undergo a clinical examination. Thirdly, the practitioner must establish an accurate diagnosis that correctly addresses the problem. Fourthly, the clinician must form treatment options that meet any emergency, or immediate treatment plans that need to be directly performed. However, the management of comprehensive/ long time treatment cases would probably take a course of time, depending on the selected treatment option. The final step is the definitive treatment plan in shared decision-making with the patient.

Hook, Comer, Trombly, Guinn, and Shrout[8] explain the treatment planning process as an important aspect of clinical education in dental school curriculum. It is essential to educate students about the necessity of formulating a comprehensive treatment plan, when treating at the individual tooth level. This involves making decisions about treating tooth in the context of the rest of the dentition. As well as, managing the rest of the dentition in the context of the masticatory function and the individual. Such holistic views of the patient as a person with specific needs and preferences ensures, patient compliance, satisfaction and expected treatment outcomes in the near and distant future[9].

It is also important to educate students about prevention- oriented diagnosis and treatment planning and finding the best way to solve it. Rather than only focusing on fixing

the issue. For example, there is no point in providing a patient with an attachment if the patient has not had high treatment expectations and esthetic demands. The primary indication of attachment is superior esthetic.[10] Many conventional RPDs are not worn simply because the patient does not like the appearance. The elimination of clasp arm is a key factor in launching an esthetically acceptable design. Nowadays, patient's high expectations and improvement the dental technology have resulted in the restoration of RPD's to make them an esthetically pleasing and comfortable. When a fixed prosthesis cannot be fabricated, and an implant is not possible due to insufficient amount of bone or for other economic reasons; attachment retained RPD can be used as a treatment solution. This option can be given both esthetic and functional replacement of missing teeth. (Gupta et at, 2016) mentioned that RPD attachments have improved the field of dentistry, because they facilitate patient requirements by being both function and esthetic pleasing. (Burns, 1990) states that some retrospective studies have shown the survival rate of RPD attachments being 83.3% for 5 years, 67.3% for around 15 years, and 50% for 20 years[11,12].

However, (Makkar et at, 2011)[1] said that Attachment selection for RPD design is very challenging due to many factors including, the lack of proper knowledge, the overwhelming number of attachment available in the market, the problems associated with multiple adjustment and issues regarding repairs. These problems are making dentist reluctant to offer and provide this treatment to attachment their patients. Additionally, the lack of prosthodontics that could help dental school graduates also plays a role in the reduced use of attachments.

According to the American Dental Association[6]. Prosthodontics represent only 8.6% of all dentists giving a number of 3372 prosthodontics in the USA, which is a small percentage. Therefore, it is almost impossible to help young skilled dentist to treat millions of partial edentulous patients. The (According to American Dental Association 2014)[13] reported that in 2013, there were 195.202 practicing dentists in the USA, which is around 61.7 dentists of 100.000 citizens. Currently in 2018, there are 205,834 dentists, which counts as 62.6 dentists per 100.000 population. In addition, the annual number of US dental school graduates is likely to increase to 63.3 in 2033.The relevance of attachments in prosthodontics can be assessed from its wide array of uses.[28] (Figure1-1)

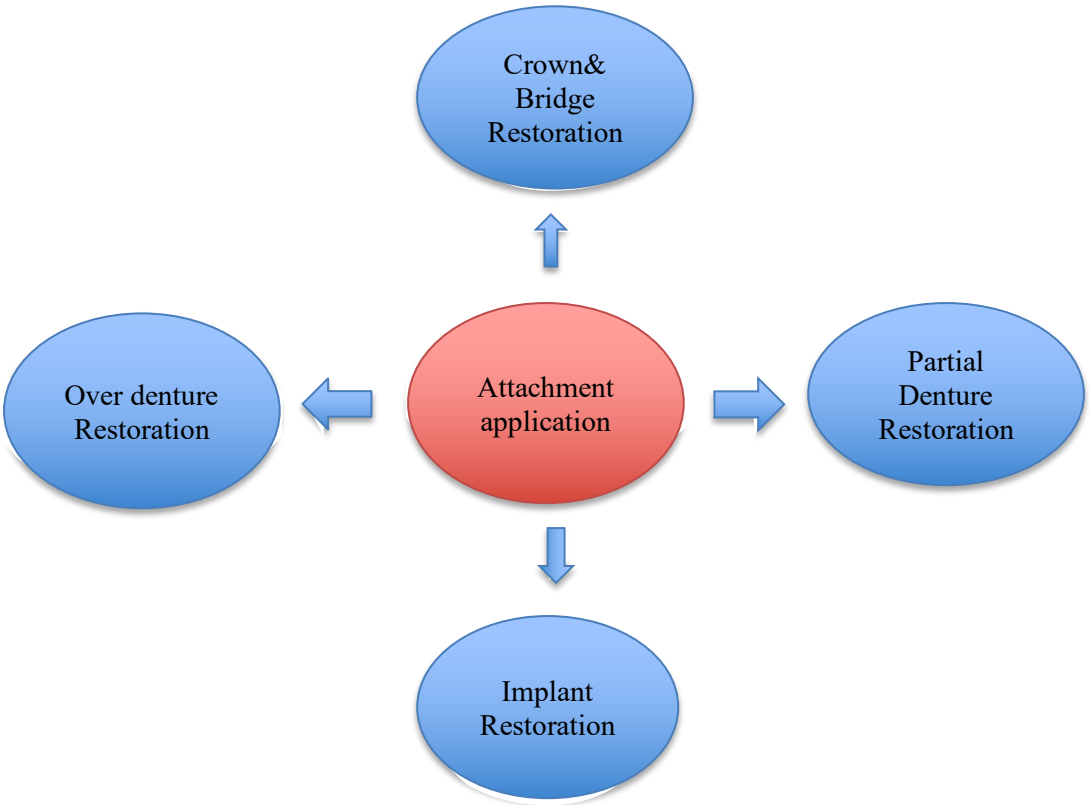


Figure 1-1 Attachment applications in prosthodontics[28]

In this study, we focused on attachment application in partial denture restoration According to (Preiskel,1984)[14] determining a treatment plan for an RPD attachment requires careful evaluation of several factors. There are some criteria that help to decide the appropriate attachment based on the individual need of the case. In order to select an appropriate attachment for RPD design, the practitioner has to review the medical status of the patient first. They then be sure that there are two teeth adjacent to the edentulous area that meet the minimum requirement for using them as abutments for attachment RPD. Though reviewing literature, clinicians will find many factors that should be considered regarding the treatment planning of attachment selection. These are some of these important factors:

1- Location (Intra-coronal, Extra-coronal)
2- Functional (Resilient or non-resilient)
3- Manufacture (precision, semi- precision).
4- Space (Vertically, Bucco-lingually and mesio-distally)

All these factors are considered as very important when making a decision on which attachment should be used on that particular case. The next chapter will explain all these factors in detail. It is extremely difficult for clinicians or young skilled dentists to recall all of the above factors, especially for residents and less experienced clinicians.

CDSS is a computer program which is designed to provide patient related information and recommendations after processing a rich knowledge base. The first example of CDSS in dentistry was used for oral diagnosis back in 1973 (Leonard, Kilpatrick)[15,16.] After that,

the development of CDSS started in the 1980s[17]. (White 1996 identified over forty decision support systems. He grouped these systems into seven subareas of dentistry. These are include, , dental emergencies, oral medicine, orofacial pain, radiology, orthodontics, restorative dentistry, pulp diagnosis. He also classified the systems according to the knowledge representation used including, algorithmic, statistical, rule-based, and image processing systems.

The literature review shows a gap in the area of CDSS for attachment selection in RPD design, because the topic is not widely researched in dental literature. In addition, the complexity of the topic and the lack of proper knowledge makes it tough for dentist to treat patients that need attachments. It is extremely difficult for clinicians to recall an extensive list of factors that determine an appropriate attachment for RPD design. Young skilled dentists may face many errors in decision-making especially when dealing with complex clinical cases. Although, clinical experts' knowledge and their years of experiences with treating patients can help in the process of attachment selection; experts may not always be around to provide assistance. There is a concern about the level of ability of residents and dental students in mastering the skill of attachments. A nationwide study of electronic curriculum implementation at North American dental schools cited a lack of appropriate educational software's as one of the prominent barriers in the adoption of E-curriculum capacities in day-to-day learning.[15]

To address this problem, we have developed a clinical support and training system based on dental experts' knowledge and evidence-based guidelines extracted from

literature. In this study, we propose developing a CDSS for attachment selection in RPD design using the Corvid expert system development tool[18]. Rule-based CDSS will serve as an example of educational software that can be incorporated into the curriculum at dental schools. Our training system focuses on building students' expertise in treatment planning for attachment selection in RPD design.

1.3 Goals and objectives

1. To design and develop a new CDSS based on experts' advice and evidence-based guidelines to support decision –making in the area of attachment selection. As discussed, earlier literature review shows a gap in the area of CDSS for attachment selection in RPD design. The complexity of this problem and multifactorial considerations make decision-making particularly challenging for clinicians.
2. To use CDSS as a training and educating system for residents, PG students, and inexperienced dentists. The new CDSS aims to improve students' skills in the field of prosthodontics. Our clinical users will be trained to think like experts during the decision-making process. The new CDSS can also be used for training students even in the absence of patients, as part of dental students' electronic curriculum. Mastering how to select attachment will help students to avoid making errors.
3. The system aids to reducing the amount of errors made during decision-making. Mastering how to select the correct attachment will help students avoid errors. The knowledge database imbedded into the system is developed using rules obtained from practicing experts and evidence-based literature in the field of prosthodontics. A CDSS treatment plan will be provided along with justifying explanations that can guide young inexperienced dentists through the decision-making process. This

information educates them, and thus allows the clinician to better manage the patient's expectations. As well ensuring patient satisfaction and compliance. Since the knowledge databased was developed using expert guidelines that are known to be effective, we expect to see an improvement in decision -making and treatment plans.

4. CDSS also aims to increase both patient satisfaction and dentist's confidence. Mistreatment or failure to obtain patient satisfaction could affect the dentist in practice. It will also decrease the patients' confidence in their dentist and might lead them to switch to another dentist. Young skilled dentist also needs CDSS to confirm and support their treatment plan.

1.4 Significance

1. CDSS helps reduce the rate of decision-making errors in complex prosthodontics treatment planning and improves patient care. Therefore, the dentists' confidence will increase as well as the patient's satisfaction rates. will increase as well. A systemic review of the computer-based system showed that using the CDSS led to 66% significantly improved clinical practice.[19.] In addition, a systemic review included 70 implemented CDSSs showed that 68% of systems have significant improvement in clinical performance (Kawamoto et at 2005)[20.] The new system will decrease the number of post-delivery visits, saving the trips and money for the patients and saving the clinic time for dentist to see another patient.
2. It can be used with complement with traditional teaching methods to help students understand the different cases of attachment selection. The system helps in

educating students and inexperience clinician to think like an expert. CDSS is used as a consultation. It is not only used in evaluation of difficult cases, but also can aid to geographically isolated area here dentists do not have an easy access to knowledgeable experts in the field.

3. The new system will encourage the inexperienced dentists to treat more patient that need RPD attachment, instead of referring them to specialist. The CDSS can evaluate several considerations that are required to make the right decision. It ensures that all necessary criteria are evaluated before treatment plan is recommended. Residents and inexperienced dentists will be confident if they use CDSS for treating their patients. However, taking into consideration all relevant factors of attachment selection and coming up with treatment plan that addresses immediate needs and good term prognosis only comes with experiences. CDSSs help to do that because it is "computer programs that are designed to provide expert support for health professionals making clinical decisions[21]"

1.5 Hypotheses

1. It is possible to design and develop a CDSS based on evidence-based literature and dental experts in the area of attachment selection RPD design.
2. The proposed CDSS will be used as a training tool for residents as well as inexperienced clinician in the field of prosthodontics.
3. Using CDSS for attachment selection in RBD design will reduce the rate of decision errors and improve dental health.

2 Chapter II: LITERATURE REVIEW

2.1 Prostheses

Prosthesis is an artificial device to replace or augment a missing or impaired part of the body; it is designed for functional or cosmetic purposes. It helps you to perform daily activities such as eating, taking or walking. There are many types of prosthesis such as (arm, foot, joint and tooth). One of the important prosthesis is dental prosthesis which focuses on restoring intraoral defect such as missing teeth or missing parts of teeth.

Dental prosthesis may be removable prosthesis as in the case of replacing missing teeth by complete dentures, Removable Partial Dentures (RPD) or fixed prosthesis such as crowns, bridges, Fixed Partial Dentures (FPD), onlays and veneers. With advance in dental science, a few dental prostheses have been integrated with body tissues, including bone and nerves such as dental implants.

Prosthetic dentistry is the replacements of missing teeth, which may happen for variety of reasons. Prosthodontics is the dental specialty that focuses on dental prostheses. Prosthodontics treatment depends on variety of factors. The traditional approach results in a fairly uniform treatment option bases on the fact that the missing teeth should always be replaced.[22] Modern dentistry is not bounded to prevent and treat dental disease, but also extends to achieve the esthetic demands of patients. With the advancements and knowledge in dentistry more people are retaining their natural teeth into older ages[23], however, decrease the number of teeth present in patient's oral cavity with age, about 30-40% of people over the age of 75 in western countries are edentulous[24].

A nationwide survey study was performed in the early 1990s, reported that the prevalence of edentulous among 75-year old subjects in Swedish, Danish and Finnish cities were found to be 27%, 45% and 58%, respectively[25.] Although the overall prevalence of tooth loss has been slightly decreasing in the US and Canada in the past few years, high percentage still exists among populations of lower socioeconomic education status.[26] It is important to know what the loss of teeth mean to patients, and expectation for the outcomes tooth replacement by various methods.

The significance of missing teeth varies greatly among individuals. Losing one-tooth may be a significant concern for one person; while another person being edentulous is not main concern. In years past, it is not unusual for young adults to have all their teeth extracted before marriage. In some instance, the removal of a sound maxillary central incisor tooth is accepted in a specific population's culture.[24] However, loss of teeth may have several negative impacts, socially and professionally and it is strongly associated psychologically, with losing of self-confidence.

Teeth are important for mastication, function, phonetics and appearance. Many patients are concerned about their appearance when they are missing a single maxillary anterior tooth than about any possible adverse caused by many missing posterior teeth. Some younger patients become concerned when they loss molar teeth. Subsequent problems lead to migration and tipping of teeth adjacent to the extraction sites, and by super-eruption of unopposed teeth. Importantly, before tooth replacement is undertaken, number, site size

of missing teeth and dental health of the patient, must be determined. Although many treatment options for replacing missing teeth are available, some studies have pointed that the acceptability of these options relies on patients' demand, expectation, education, economy, culture background as well as the age[27].

Treatment options for missing teeth should be determined by systemic gathering of information regarding patent's medical, dental and social/family history, followed by extra and intra oral examination. Before a treatment decision is performed the reasons must state for such a decision should be examined. For example, it makes no sense to do attachment RPD to a patient if the patient does not have high treatment expectations, esthetic demands, good oral hygiene, compliance to instructions and financial ability. The primary indication of attachment is superior esthetic[10].

The cross-section study done by (Jayasinghe, 2017)[29], sample was selected from the screening clinic conducted every morning on week-days at the Dental Hospital, peradeniya, Sri Lanka during the years 2015 and 2016, resulted that 76.2% of the study group was in favor of having missing teeth replaced (Table 2-1). Majority was keen in getting them replaced mainly for the comfort in mastication. Out of 425 patients only 101 stated that there is no need of replacing the lost teeth, while 324 had a positive attitude toward the replacement of missing teeth. The highest percentage of the sample with a negative attitude about tooth replacement is that people believed that there was no need for the replaced. The second reason was financial constraints (Table 2-2).

About 58.1% believed that the replacement of both anterior and posterior teeth is equally

valuable, whereas 26.6% felt that the replacement of anterior teeth is more important.

Do you think you need replacement when tooth/teeth are lost?	No	(n = 101) (%)	Yes	(n = 324) (%)	p value	95% CI
Age category (years)						
16–20	3	3.0	11	3.4	p = 0.251	−0.001 to −0.005
21–40	44	43.6	111	34.4		
41–60	41	40.6	167	51.7		
61–80	13	12.9	34	10.5		
Gender						
Male	35	34.7	118	36.4	p = 0.946	−0.089 to −0.083
Female	66	65.3	206	63.6		
Ethnicity						0.049 to 0.102
Sinhala	93	92.1	291	89.8	p = 0.493	
Tamil	1	1.0	8	2.5		
Muslim	7	6.9	25	7.7		
Education level						
Primary education	10	9.9	16	4.9	p = 0.807	−0.041 to −0.053
Up to Grade 8	7	6.9	31	9.6		
O/L	41	40.6	132	40.7		
A/L	33	32.7	114	35.2		
Tertiary education	10	9.9	31	9.6		
Monthly income						
<10,000/= Rs	18	17.8	38	11.7	p = 0.101	−0.006 to −0.068
10,000/ = −20,000/= Rs	23	22.8	75	23.1		
20,000/= −30,000/= Rs	31	30.7	93	28.7		
30,000/= −40,000/= Rs	17	16.8	64	19.8		
>40,000/= Rs	12	11.9	54	16.7		

Table 2-1 Attitude towards the replacement of missing teeth in relation to age, gender, ethnicity, education levels and socio economic level29

Reason-for no need of replacement when tooth/ teeth is lost	Number (total 101)
Financial	16
Did not feel it is needed	68
No time	3
Do not know about treatment options	7
Many reasons	7

Table 2-2 Participants' reasons for not trying to replace missing teeth29. 24% of participants were not agreeing to replace their missing teeth. The majority cause was they did not feel the need for the replacement and financial constraints also important in making the decision

2.2 Type of dental prostheses

As it was previously mentioned, Prosthetic treatment means that entire tooth or part of the tooth is replaced by the construction made by the dental laboratory. Many people hide their smile because of low self-esteem that is caused by their missing teeth. However, the solution to that issue would be visiting the dentists to help you replace your missing teeth. There are various methods to replace missing teeth by different types of dental prosthesis. Thus, dental prosthesis means many kinds of removable dentures, fixed dentures but also "fillings" from gold or porcelain made in dental lab. The right dental prosthesis can give you a lively smile you deserve.

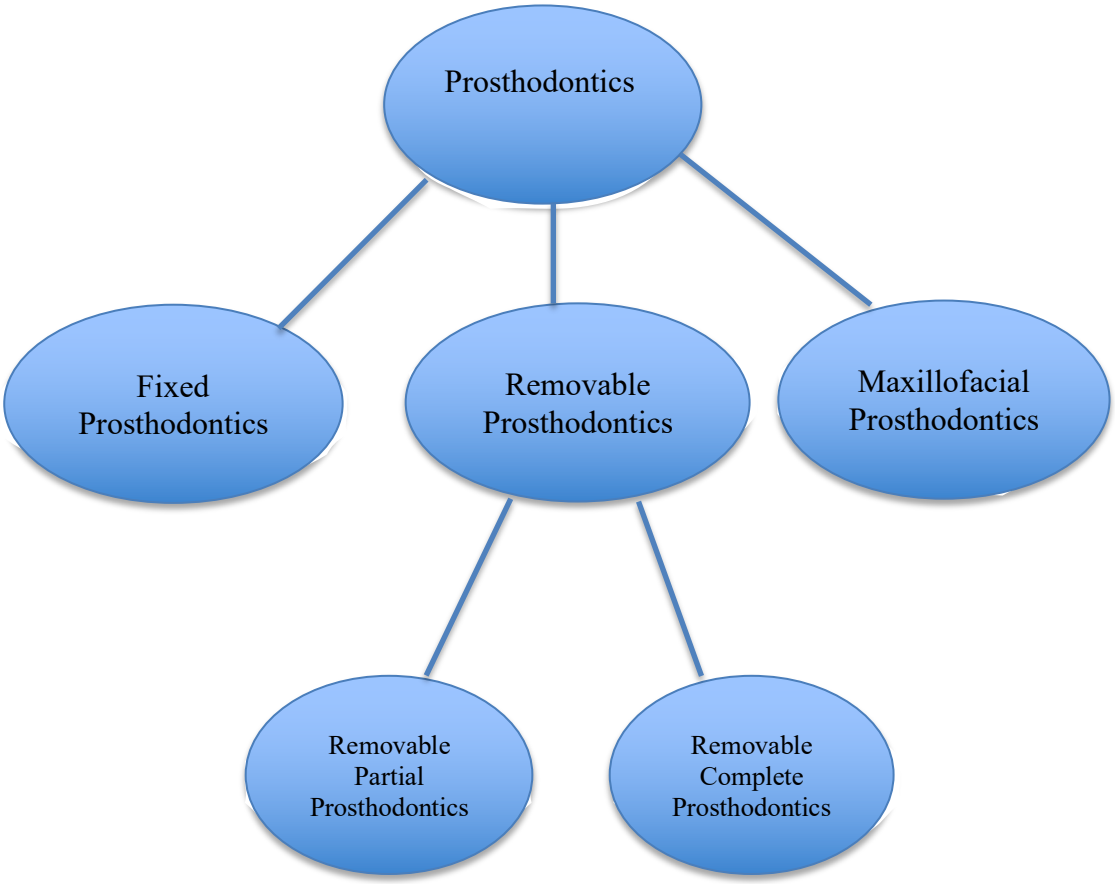


Figure 2-1 Branches of prosthodontics[2002]

Tooth replacement option (ADA, 2013)[30]

- Dental Implants
- Fixed dental prosthesis. Crown and bridge.
- Removable dental prosthesis. Removable Partial Denture (RPD) or full denture.

Carlsson, 2014, mentioned that dentistry can offer a number of treatment options for tooth replacement (Table2-3)[31]

S. No	Type of Treatment
1	Implant-supported fixed prostheses.
2	Implant-tooth-supported fixed prostheses.
3	Resin-bonded bridges.
4	Conventional fixed dental prostheses (FDPs).
5	Removable partial dentures (RPDs).
6	Orthodontic treatment.
7	Autotransplantation.
8	No replacement.

Table 2-3 Treatment options for tooth replacement 31

The selection of suitable treatment option for patient should follow WHO basic methods and according to Kennedy classification of each arch. The final choice between Fixed Partial Denture (FPD), Removable Partial Denture (RPD) and implants, influenced by clinical, dentist- and patient-immanent factors[32]. Choosing between different treatment options depends on many factors, and these factors are case dependent, these factors affect the decision-making. Each treatment options have it owns advantages and disadvantages [33]. Some time when there are more than one treatment options, the definitive replacement depends on patient's decision/financial status or influenced by patient's gender, age,

awareness and patient's knowledge[33]. For this reason, it is important to understand the patient's need and demands. Treatment decision cannot be decided relies on the clinical examination or a dentist's option alone, but also should be discussed with patients.[34]

According to (Jayasinghe at al, 2017)[29], first Sri Lank study attempted to identify if there is a difference between the demand (patient's prospective) and the need (the clinician's prospective) with regard to prosthodontics treatment options. The term "need" is used to describe the amount of treatment that dentist's judge their patient to have, while demand refers to the treatment requested by patients them self.[35]In Jayasinghe' study the prosthodontics treatment was removable partial denture, fixed tooth supported prostheses or implant supported removable/ fixed prostheses. When the participants were questioned regards to their desire to replacing their teeth, 78% of participates were aware of removable partial denture as a treatment option, while awareness of FPD was less than implant prostheses.

However, when the knowledge on different dental prostheses options was provided, the percentage of the awareness of removable denture decreased significantly to 27.5%. In generally, more patients requested tooth and implant supported prostheses than removable ones, but the patients' attitude and demand toward replacing teeth might be different than clinician's assessment[29]. There is some priority for prosthodontics such as preservation of natural teeth, maintenance of periodontal heath, and consider about anatomical structure of the oral cavity while patient's priority is comfort and esthetic. It is very important to evaluate and balance between term need and term demand on prosthodontics treatment

options. Most studies of prosthodontics need and demand showed" that the former is larger than the latter"[36] Dentist with their skills and their accessibility to public and economic realities can affect the decision in choosing the treatment and the attitudes of people towards different treatment options.[37] However, it is hard of young skills dentist to make decision in choosing treatment and achieve patient satisfaction with excellent treatment plan, that last long time, especially when treatment options keep changing due to continuous development.[38] Al-Quran , 2011 when he explained different factors effect treatment options in relation to prosthodontics type, such as rejection to surgical procedure, treatment duration, conditions to adjacent teeth , cost and dental phobia. He pointed that damage to neighboring tooth was one of the most important factors when choosing between different prosthesis type it is about 40% followed by pain and duration of treatment, while cost of treatment was an important factor for only 27% of participants in single tooth replacement (Table 2-4)[32]. The level of education and patients' awareness toward different treatment modalities has significant effect on the treatment option.

	Fixed		Removable		Implant		Control		Total	
	N	%	N	%	N	%	N	%	N	%
Cost	8	(16)	17	(34)	2	(4)	28	(56)	55	(27.5)
Pain and suffer	18	(36)	17	(34)	20	(40)	22	(44)	77	(38.5)
Surgery	4	(8)	9	(18)	7	(14)	16	(32)	36	(18)
Duration	25	(50)	33	(66)	12	(24)	7	(14)	77	(38.5)
Neighboring teeth	17	(34)	18	(36)	28	(56)	17	(34)	80	(40)
Phobia	14	(28)	11	(22)	13	(26)	26	(52)	64	((32)

Table 2-4 Factors affecting treatment option in relation to prosthesis type[32]

(Mukatash et al, 2010)[39] compared between clinical needs and patent's desire, he realized that "the clinical possibilities to prosthetic replacement for each patient according to the missing teeth were significantly different from their patient desire

Type of prosthesis	Clinical need (%)	Patient's desire (%)
RPD	64.4	16.32
FPD	78.8	33.21
Implant	81.4	44.28
No clinical need for replacement	33.4	6.19

.

Table 2-5 Comparison between clinical needs and patient's desires, RPD- Removable Partial Denture; FPD- Fixed Partial Denture[39].

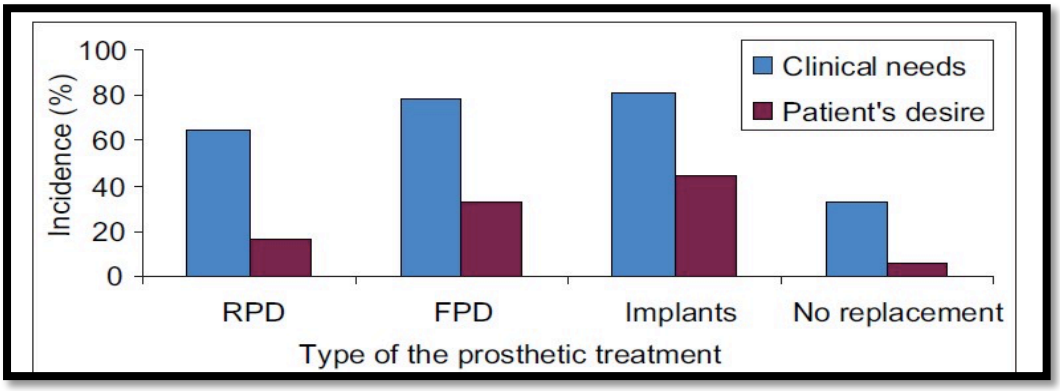


Figure 2-2 Comparison between clinical needs and patient's desires[39]

(Mago, 2012) pointed out that there is a lack of consistency among dentist in choosing treatment plans[40]. According to (Gupta et al, 2016) It is becoming more challenging when unilateral or bilateral distal extension situation exists. There were many treatment options

`

in this case.[3] When implant therapy may not be used due to local or systemic factors or economic reasons[4], so attachment RPD has paved the way for such cases in prosthodontics.

2.2.1 Fixed dental prosthesis

Crown means covering tooth with permanent material (fixed in the mouth) that restores strength and beauty of the tooth, it is cap a damage tooth or cover an implant. In Europe, regarding prosthodontic alternatives, single crowns and small fixed dental prostheses (FDPs) are the most common fixed restorations treatment modality[41].Prosthodontics restoration varies much between countries and over time and is related among other things to differences in oral health and socio-economic situation.

When there is not enough of tooth structure remaining or majority of the tooth has filling material, then making crown is indicated. Large fillings, especially on the posterior teeth, are not suitable to withstand the huge chewing forces, so crown is a good option. Bridge is a structure that replaces missing tooth and is fixed on the neighboring teeth. Bridge is indicated when teeth surrounding the gap are destroyed and need crowns. When neighboring teeth are intact or have small defects, then it is better to replace missing tooth (or teeth) with implant (or implants), but sometime there is inadequate bone support and anatomical structure present at some sites, or due to economic reason implant is not a good option [24]. Since the 1960s metal-ceramic fixed prosthodontics have been extendedly used and they have proven successful both from functional and aesthetic aspects[31]. For a long time ago, metal-ceramics using high gold alloys was the best material of choice in fixed prosthodontics but at present ceramic materials have become popular.[31]

Figure 2-3: 4-unit metal-ceramic FPD seen in a buccal and Lingual view [31]

People don't restore large filling tooth as a result it wears out quickly. This may cause functional and esthetic problems in the future, for this reason large filling tooth is indication for fixed restoration. Root canal treatment is also an indication for making crown. Tooth where root canal treatment was done is weaker than vital one and can fracture easily[42]. Crown protects remaining tooth structure and integrity of tooth and also decreases chance of fractures. If only root remains, then in certain conditions it can be restored also by means of a crown. Then post & core have to be made first. Posts should be used in tooth for retention of core material in cases where remaining coronal tooth structure is not adequate, i.e., one or no cavity walls. High quality crowns can remain in the mouth even for decades. The survival of 2340 high-gold-based metal ceramic single crowns followed up to 25 years was 97 % after 10 years and 85 % after 25 years.[43] High quality crown should be precise marginal preparation, excellent impression technique and usage of precious metal alloys or

Zirkonia caps. A permanent or fixed bridge is cemented onto specially prepared teeth on either side of the space. These two or more prepared teeth are called abutment teeth, and a false tooth/tooth in between them called pontics and can be made from gold, alloys, porcelain, or a combination of these materials. Natural teeth or implants support dental bridges.

According to multiple studied outcome of prosthodontics treatment it is important to differentiate between success and survival. Success refers to the restoration has remained in function without any need of repair up to the follow-up. While survival comprises restorations that are still in situ even if they were exposed to complications needing to be mended during the observation period or need repair or remake at the follow-up[31]. According to systemic review, 2004, 2008. There were few long-term studies were published about metal ceramic restoration. It has been in clinic used for several decades and were for long considered the gold standard in reconstructive dentistry.[44,45] According to Pjetursson & Lang 2008, the survival of various types of FDPs shows in (Table 2-6)

FDP Type	5-year (% Survival)	10-year (% Survival)
Conventional	93.8%	89.2
Cantilevered	91.4%	80.3
Implant-supported	95.2%	86.7
Implant-tooth combination	95.5%	77.8
Resin bonded.	87.7%	59.0

Table 2-6 Survival of various types of FDP according to Pjeturrsson & Lang 2008.[45]

Abutment is as a connected element.[46] Abutment used in a fixed bridge, partial removable denture and implants. It is referring to the teeth supporting the bridge, tooth

supporting partial denture, and in implants (used to attach a crown, bridge, or removable denture to the dental implant fixture). The implant fixture is the screw-like component that is osseointegrated.

Abutment should have a minimal total occlusal convergence (TOC), sometime called a taper in order to ensure an adequate retention of crown and FPD.[47] The total occlusal convergence of a partial fixed denture abutment has been defined as "the convergence of two opposing external walls of a tooth preparation as viewed in a given plane" [48,49] and also "the angle between a single preparation wall and the long axis of thepreparation."[49] Crown and bridge retention is optimal when abutment TOC does not exceed 6-8° along the abutment perimeter.[I] (Figure 2-4)

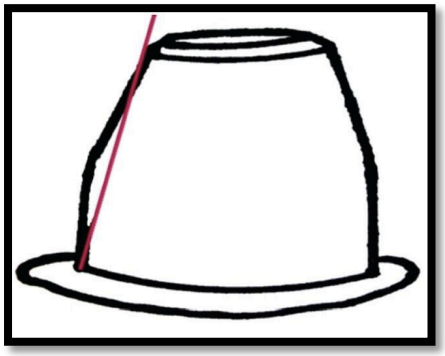


Figure 2-4 Imaginary "best fit" line averaging the angle of two planes of reduction at a specific point along the apical perimeter of the axial aspect of abutment[48]

2.2.2 Removable dental prosthesis

According to the Glossary of prosthodontics 2017, the RPD is **"**A removable partial denture that replaces some teeth in a partially edentulous arch; the removable partial denture can be readily inserted and removed from the mouth by the patient."[50] The aim for

replacement teeth is mastication phonetics, function and appearance. According to National Health and Nutrition Examination Survey, 2011–2012, 18.9% of American citizens over 65 years old are edentulous.[51] The conventional complete denture is considered the most common treatment for patients who missing all their teeth. Almost 90% of edentulous patients ware complete dentures[52]. RPD is commonly used for treating the patients who are not good candidates for conventional fixed partial dentures and implant supported prosthesis. These prostheses can be fabricated from metal alloy, acrylic resin and thermoplastic resins.[53]

Dentures are the most common removable dental prosthesis for replaces missing teeth without any surgical incisions or painful recovery. This type of prosthesis is good for patients who do not wish to undergo any specific type of dental surgery to replace their missing teeth but would certainly benefit from this specific prosthesis. Removable dental prosthesis in the oral cavity is supports by surrounding tissues. It can improve chewing abilities, help maintain muscle tone that gets lost with tooth loss, restore or improve the patient's ability to speak and pronounce words better, and, most of all, give the patients confidences and satisfaction. There are two types of conventional dentures (removable partial denture (RPD) or complete denture). Upper denture used for replacing missing teeth on the maxillary arch, while lower denture used for replacing teeth on the mandibular arch.

However, there are many RPD designs, some depend on bonding or clasping onto teeth (conventional RPD) or dental implants other relies on attachment onto natural teeth or implants (Attachment retained RPD). The majority of the patients are satisfied with their conventional RPD (Burns et al, 1995a)[54]. However, some patients are dissatisfied with

RPD, even if the RPDs are done according to all accepted criteria. (Burns et al, 1995b)[55]. The aesthetics and retention are the most important (Hakestam et al, 1997)[56]. The dentists consider RPDs to be successful when they meet all criteria of technical standards, while the patients evaluate them from their viewpoint of satisfication[57]. The success of RPDs is often judged differently by dentists and patients (Elias& Sheiham, 1999)[58].

Fixed partial dentures	Removable partial dentures
Advantages:	**Advantages:**
More natural appearing tooth substitutes	Generally less expensive
Feel more natural	Minimal tooth preparation
Superior stability with chewing hard foods	Longer edentulous spans can be restored
Minimal soft tissue coverage	Replacement of missing alveolar ridge tissues is possible
Not easily removed	Can be removed for cleaning and adjustments or repairs
Disadvantages:	**Disadvantages:**
More expensive	Clasps may be unattractive
More suitable for short spans	Designs may be bulky, complicated and plaque-retentive
Extensive tooth preparation is usual	May cause gagging
Abutments must be in good alignment and functionally adequate	Retention and stability may be problematic

Table 2-7 Advantages and disadvantages of fixed and removable partial denture (RPD)[2]

2.2.2.1 Basic RPD concept

"The RPD topic is a difficult and challenging area of prosthodontics where more than one design will be acceptable"[59]. Strong basic anatomy and scientific knowledge is important for a successful outcome of this treatment. The dentist must have strong knowledge base and critical thinking skills over a wide variety of patient care situations

The components of RPD can be listed as follows (GPT8)[60] (Figure2-5):

- Major connector
- Minor connector

- Direct retainer
- Indirect retainer
- Physical retainer
- Teeth denture Base

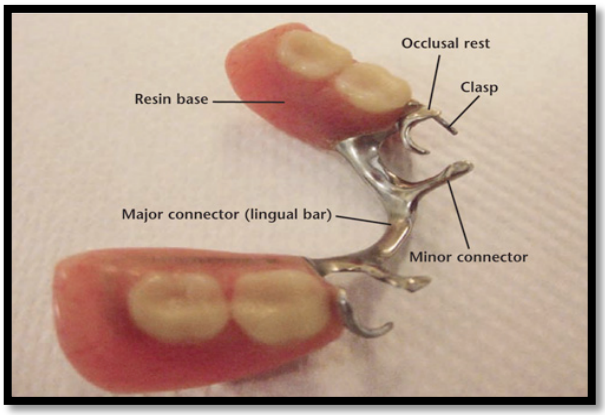


Figure 2-5 Removable Partial Denture Components (Picture courtesy from Dimension of dental hygiene, 2010)

The primary purpose of removable partial denture therapy as stated by Dr M. M Devan is "The preservation of that which remains, and not the meticulous replacement of that which has been lost"[61]After the primary purpose satisfied, then other purpose which is, replacing missing teeth and increases mastication efficiency, phonetic, stabilizing dental relationship, and esthetic.

Direct Retainer

It is the portion of removable partial prosthesis that engages abutments and resists dislodging forces. (GPT 8)[60.] It is preventing displacement of the prosthesis from the patient's mouth during function.[62]

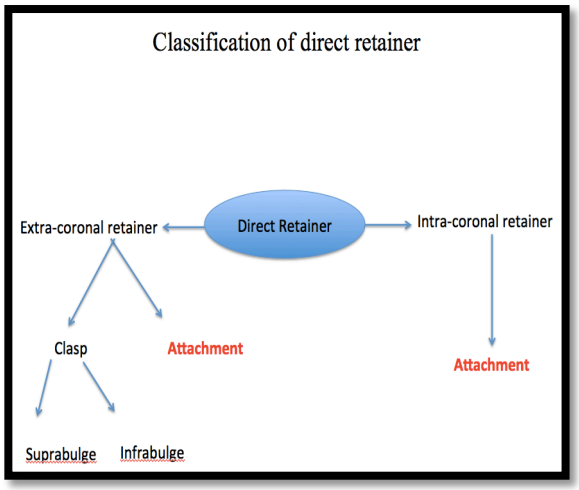
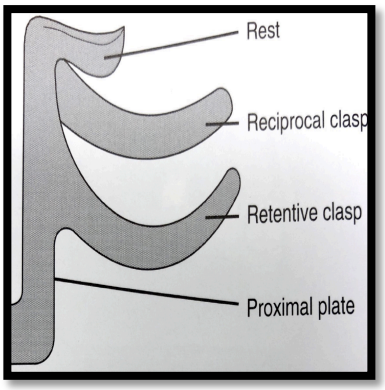


Figure 2-6 Classification of direct retainers. The red word indicate area that will be covered in depth in this study

(1)



(2)

Figure 2-7 Pictures 1 and 2 represent components of an extracoronal retainer, clasp assemblies usually include a rest, retentive and reciprocal clasps, and proximal plate.[62]

The first appeared of the clasp in dental literature with Dr W. G. A. Bonmill's in 1899[63] Clasp is a metal arm that displays a limited amount of flexibility allow the tip of retentive clasp to pass over the greater diameter of the abutment and engage the undercut of the abutment to provide retention [64]. The more flexible of retentive clasp, the fewer loads

transferred to the abutment. Flexibility can be increase by lengthening the clasp. Clasp designed to be passive when it is completely seated on the abutment tooth.

It is very important to understand the mechanism of direct retainer and understand two important points, which is the path of insert and remove the prosthesis and the height of contour for each abutment. Stewatr's, described some terms related to displacement resistance exhibited by prosthesis, theses terms are retention, support, and stability (Figure 2-8). Budtz and Beaumot mentioned that all clasps must be designed to provide 6 basic requirements: retention, support, stability, reciprocation, encirclement and passively[64,65]. Each of the components of a clasp assembly will provide one or more functions: rest provide support, retentive arm provides retention, reciprocal arm provides reciprocation, bracing[62]. RPDs obtain their retention via clasps which reduce the loads on the abutment, as result support and stability of prosthesis may be improved [66]

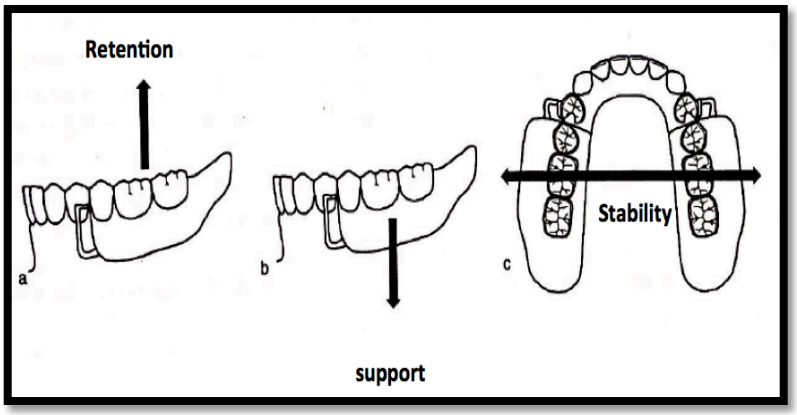


Figure 2-8 (a) retention defines as resistance to displacement away from the underlying hard and soft tissues. (b) Support defines as resistance to displacement toward the associated tissues. (c) Stability defines as resistance to displacement in mediolateral or antrioposterior direction [62]

The majority of RPD design principles are relay more on clinical experience than scientific evidence. Many experts have expressed their opinion on these principles as part of a survey of the departments of removable prosthodontics in all dental schools in the UK and the Republic of Ireland, 2001[67]. Davenport et al, mentioned that 100% of experts agreed that Occlusally-approaching retentive clasps should have the terminal third of the retentive arm entering the undercut, and 88% of them agreed that A retentive occlusally-approaching clasp should engage 0.25 mm of undercut if it is constructed in cast cobalt chromium alloy, while 94% of prosthodontics strongly agreed that A retentive clasp should engage 0.5 mm of undercut if it is constructed in wrought wire. In addition, about 88% of prosthodontics agreed that Retentive clasps should usually be placed buccally on upper teeth and lower premolar and canine teeth.

Furthermore, Davenport pointer out the number of preferred clasps for RPDs restoring each of the Kennedy classes partially dentate arch. The pie charts (Figure 2-9) indicate the percentage of prosthodontics preferring 2, 3 or 4 clasps for each of the Kennedy classes. For all of the Kennedy classes most popular choice is two clasps for RPD retention.

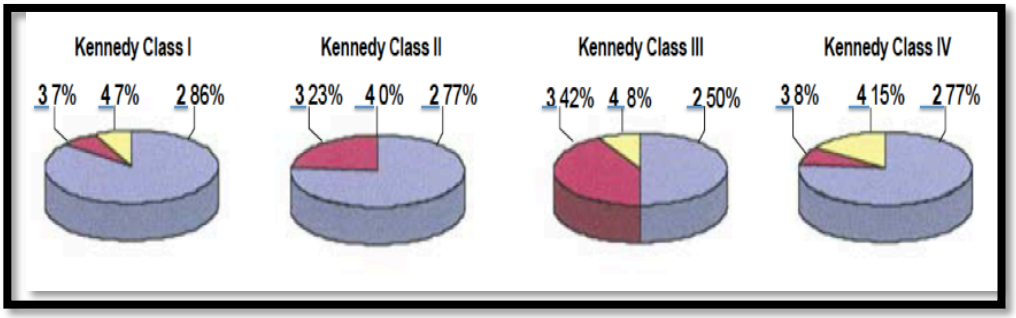


Figure 2-9 The pie chart indicates the percentage of prosthodontists preferring 2, 3 or 4 clasps for each of the Kennedy classes. The number on the blue line represents number of the clasps preferable for each type of kennedy classes.[67]

The majority of time the main reason for seeking treatment is the need for improved aesthetics, treatment should be geared towards achieving this goal[68]. Removable partial dentures (RPD) are an effective and affordable treatment modality to restore function and aesthetics[65]. However, many patients find the display of clasp aesthetically unacceptable[69,70.] (Figure 2-10)

Figure 2-10 pictures show clasps esthetically unacceptable. Courtesy of Dr. Hind El-Hammali Rutgers School of Dental Medicine, New Jersey

2.2.2.2 Classification of Partially edentulous arches

From long time ago 1900s, dental practitioners began many methods for the classification of partially edentulous arches.[71] Now a days, there are numerous numbers of classification system, but few of them meet the needs of the profession. Some of them are

very simple and others are very complex. Professions decided that in order to a classification system to be accepted, it should:[71]

1- Allow visualization of type of partially edentulous arch being considered

2- Clearly identified the different between tooth-supported and tooth-tissue – supported RPD

3- Work as a guide to the type of design to be used

4- Be universally accepted

The most widely classification system was proposed by Dr Edward Kennedy of New York in 1925[72].

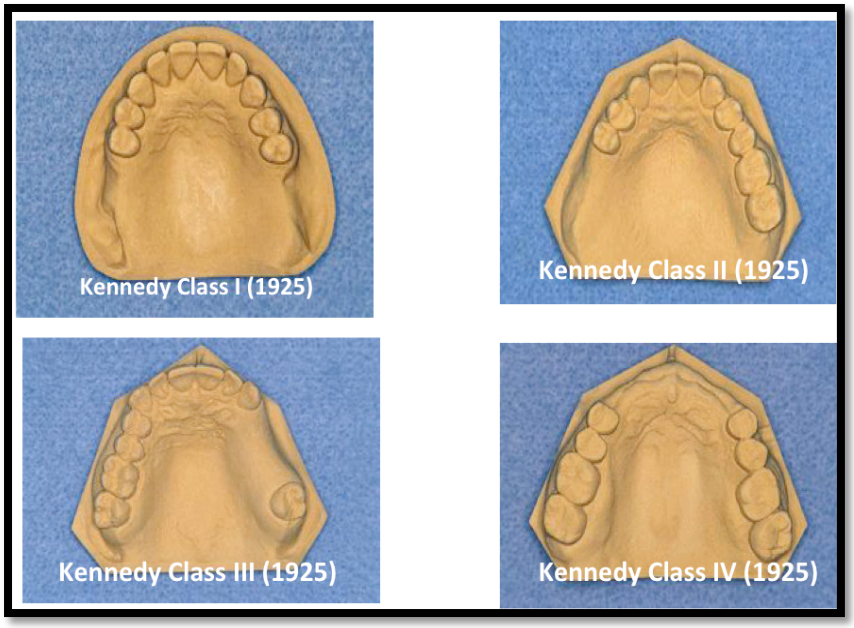


Figure 2-11 Maxillary Kennedy Classification

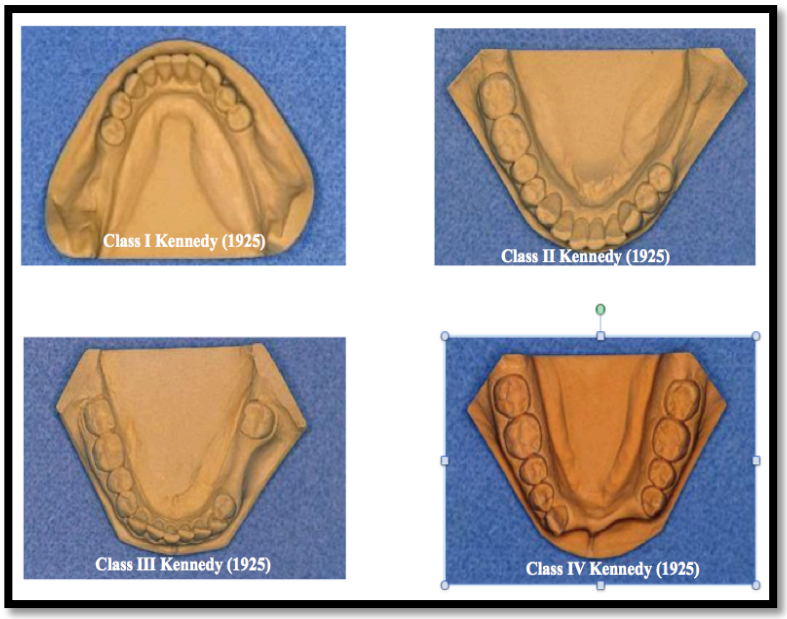


Figure 2-12Mandibular Kennedy Classification

Kennedy Classification (Figure 2-11, 2-12):

Class I - Bilateral edentulous areas located posterior to the remaining natural teeth.

Cass II - A unilateral edentulous area located posterior to the remaining natural teeth.

Class III - A unilateral edentulous area with natural teeth remaining both anterior and posterior to it.

Class IV - A single, but bilateral (crossing the midline), edentulous area located anterior to the remaining natural teeth.

Another method for classified removable partial denture relates to their support (Figure 2-13). RPD that received support from natural teeth at each end of edentulous space is a tooth-supported removable partial denture such as class III, class IV, while RPD that supported by teeth at only one end, it called tooth-tissue- support removable

partial denture, it is not entirely bounded by natural teeth, such as class I, class II, and long –span class IV.

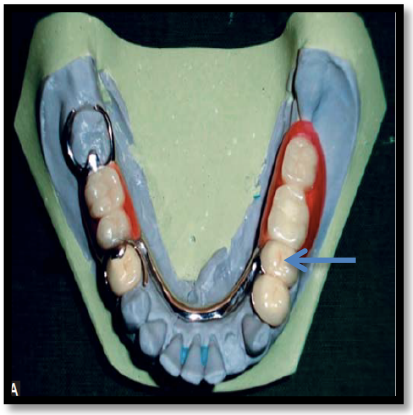


Figure 2-13 shows Kennedy's class II modification I cast partial denture. The arrow demonstrates RPD supported by teeth in only one side. Unilateral distal extension. (Picture courtesy from Ashish et al, 2012)[73]

Kennedy refereed to each additional area not each additional missing tooth as a modification space. He identified the number of modification area in his classification. In 1954, Dr O.C Applegate provides some rules to govern application of Kennedy[74].Figure:(2-14, 2-15, 2-16, 2-17, 2-18, 2-19)

Applegate's Rules (1954)

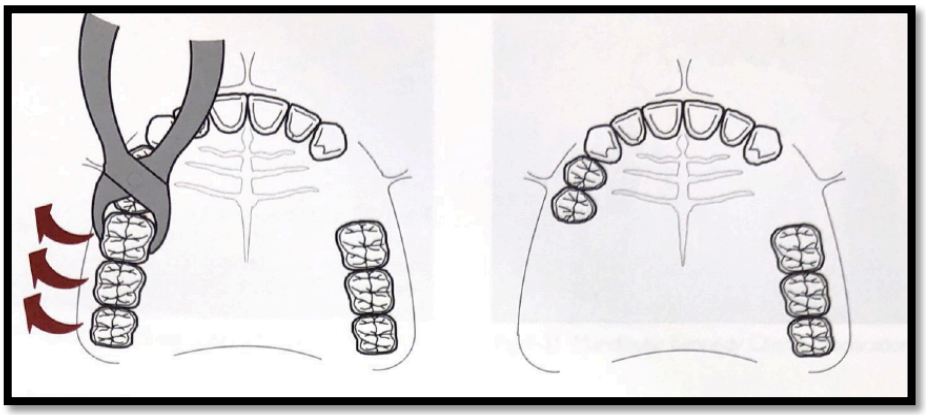


Figure 2-14 Rule one (Picture adapted from: Stewaet's Clinical, 2008)

Rule 1: Classification should follow rather than precede any extractions of teeth that might alter the original classification. (Picture adapted from: Stewaet's, 2008)

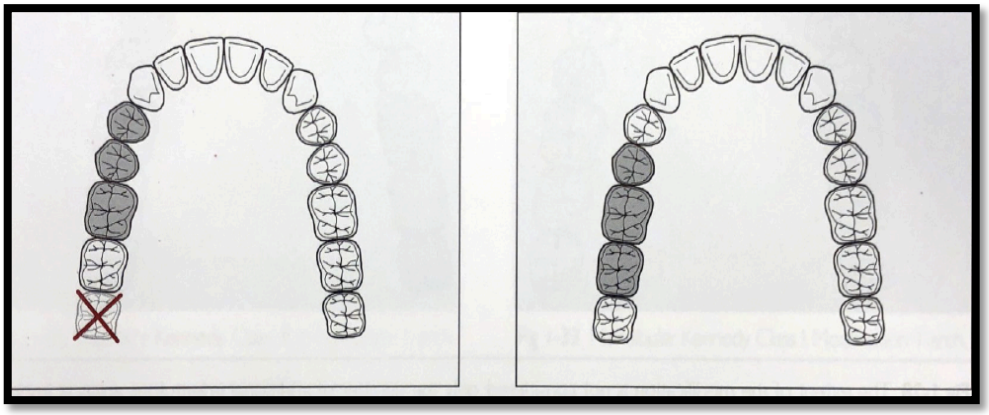


Figure 2-15 Rule 2 and 3 (Picture adapted from: Stewaet's Clinical, 2008)

Rule 2: If a third molar is missing and not to be replaced, it is not considered in the classification

Rule 3: If a third molar is present and is to be used as an abutment, it is considered in the classification.

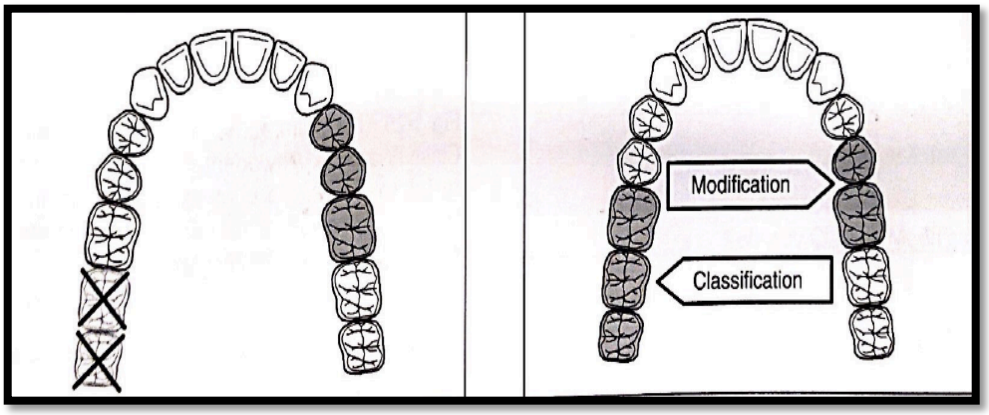


Figure 2-16: Rule 4 and 5 (Picture adapted from: Stewaet's clinical, 2008)

Rule 4: If a second molar is missing and is not to be replaced, it is not considered in the classification

Rule 5: The most posterior edentulous area (or areas) always determines the classification.

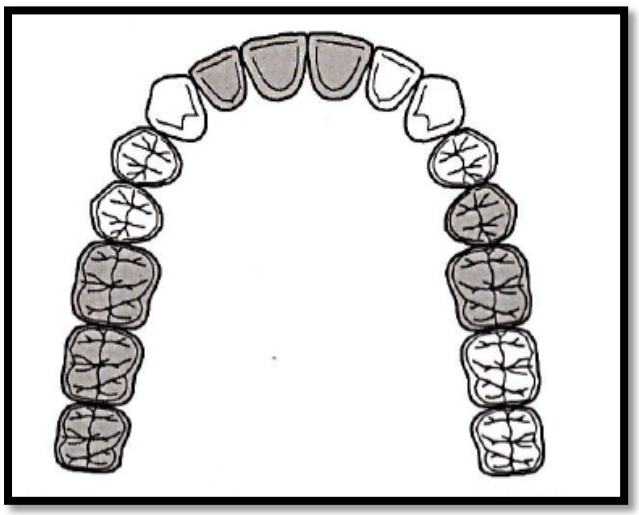


Figure 2-17: Rule 6 (Picture adapted from: Stewaet's clinical, 2008)

Rule 6: Edentulous areas other than those determining the classification are referred to as modification and are designed by their number

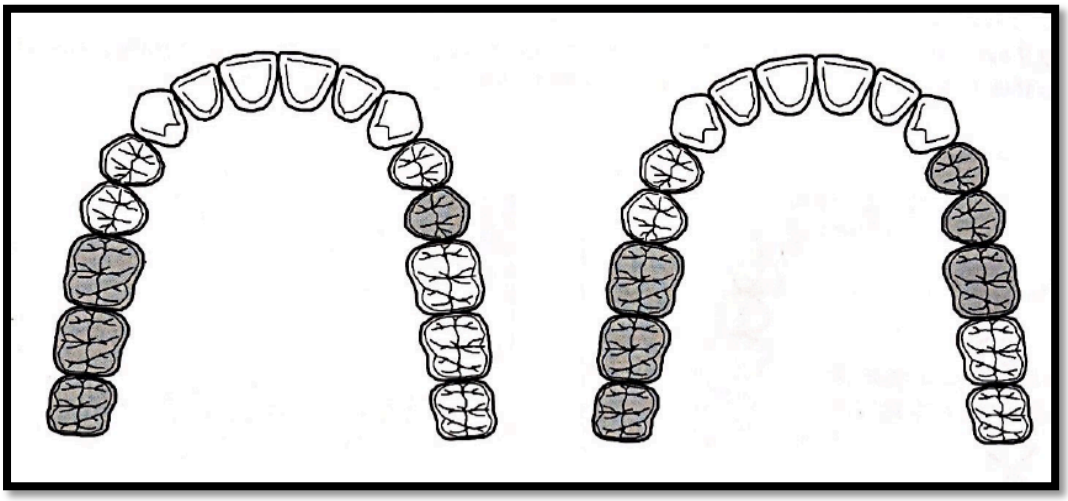


Figure 2-18 Rule 7 (Picture adapted from: Stewaet's clinical, 2008)

Rule 7: The extent of the modification is not considered, only the number of additional edentulous areas.

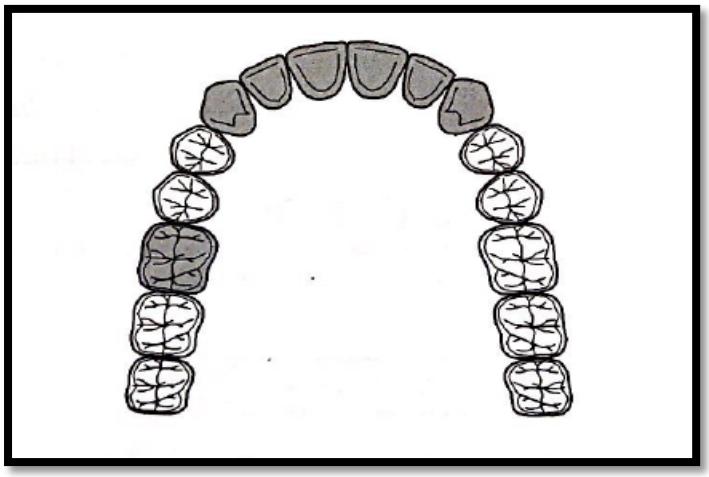


Figure 2-19 Rule 8 (Picture adapted from: Stewaet's clinical, 2008)

Rule 8: There can be no modification areas in Class IV arch

2.3 Attachment

An attachment is a connector consisting of two or more parts. One part is connected to root, tooth, or implant and the other part to the prosthesis (GPT 8). The Academy of Prosthodontics (2017)[50], defines attachment as "a mechanical device for the fixation, retention, and stabilization of prosthesis. It is a retainer consisting of a metal receptacle and a closely fitting part; the former (matrix component) is usually contained within the normal or expanded contours of the crown of the abutment tooth and the latter (patrix component), is attached to a pontic or the denture framework."

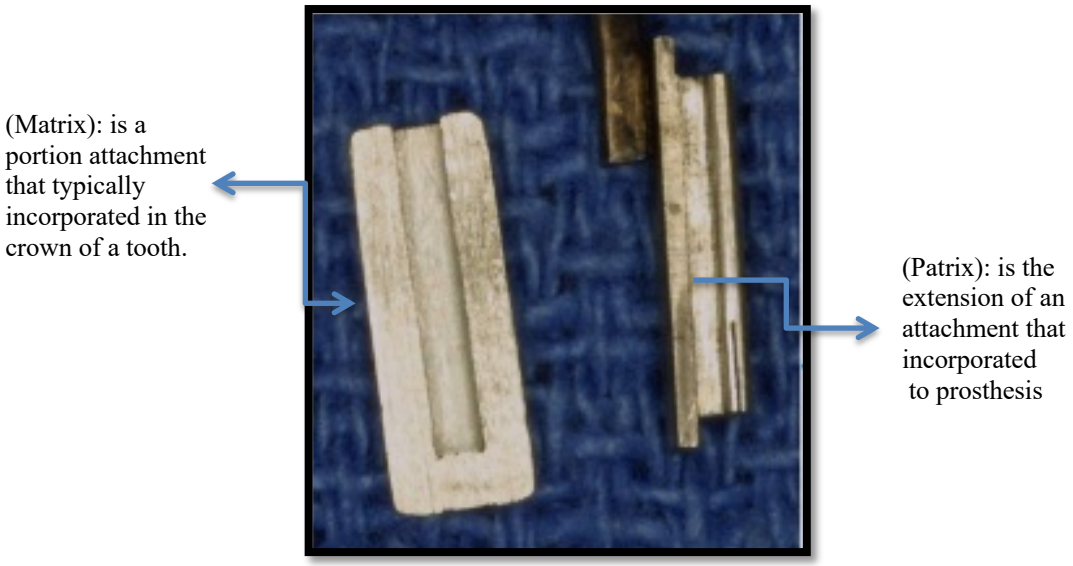


Figure 2-20 Attachment. Glossary prosthodontics Terminology

According to Markkar, 2011, said "Precision attachment has long been considerable the highest form of partial denture therapy"[1.] Some retrospective studies show a survival rate of attachment RPD of 83% for 5 years, 67% up to 15 years, and 50% for 20 years[11,12]. Attachment –retained removable partial denture is not an outdated treatment, it is more existing in today's appearance than it was first introduced. According to Makkar, 2001 there is many advantages of attachment RPD treatment option.

2.3.1 Definition, Indication, contraindication, benefit and drawback of attachment

Now a day, restoration should be esthetic pleasing and comfortable, because the knowledge of oral environment, together with technology improvement impact on patient demands. High demand and expectation of the patient have taken us to give the restoration esthetic pleasing[1]. The primary indication of attachment is superior esthetic.[10] Many conventional RPDs are not worn simply because patient does not like the appearance.

Elimination of clasp arm is a key factor in lunching an esthetically an acceptable design. Preiskel[75], mentioned other indication of attachment where neither the clasp- retained denture nor the fixed bridge is entirely suitable. Also, he pointed out that attachment can be placed in the mouth has a series of crowns that do not share a common path of insertion. He said" extracoronal attachment are often maost effective denture retainers and invisible when the RPD is in place. Intracoronal attachment is clinical and laboratory sensitive, but the result compensates for the time and skill required[76] Attachment provides better looking, neater and more effective connection than clasps. RPD attachment can provide both esthetic and function replacement of missing teeth and oral structure.[1]

According to Prasad 2016, he mentioned that an attachment indication is:

- Aesthetic zone
- Stress distribution
- Minimize trauma to soft tissue
- Mechanical benefits by control of loading and rotation forces
- Non parallel abutment present
- Segmenting of the long span bridge
- Future salvage efforts
- Improved retention

Stewart, 2003 explained that an attachment has more mechanical benefit than clasp (Figure 2-21), because intracoronal attachment when placed within normal contours of abutment, functional load transfer to the abutment may be directed more apically.

Compared to conventional occlusal rests, the apical extension of intracoronal attachment decreases non-axial loading and reduces rotation movement of abutment.

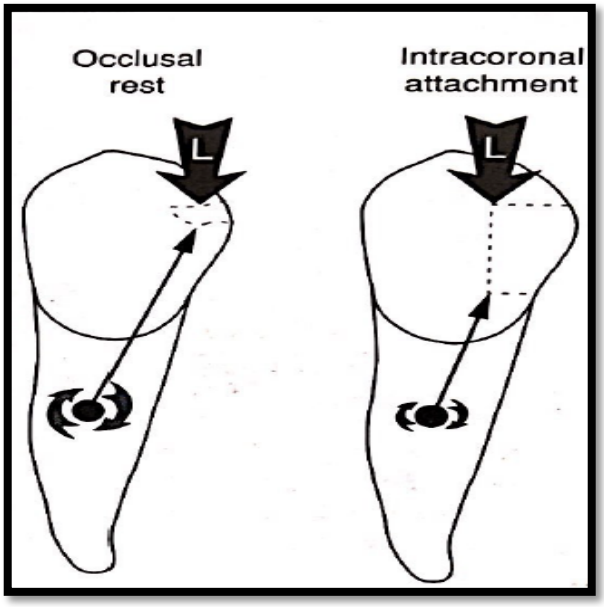


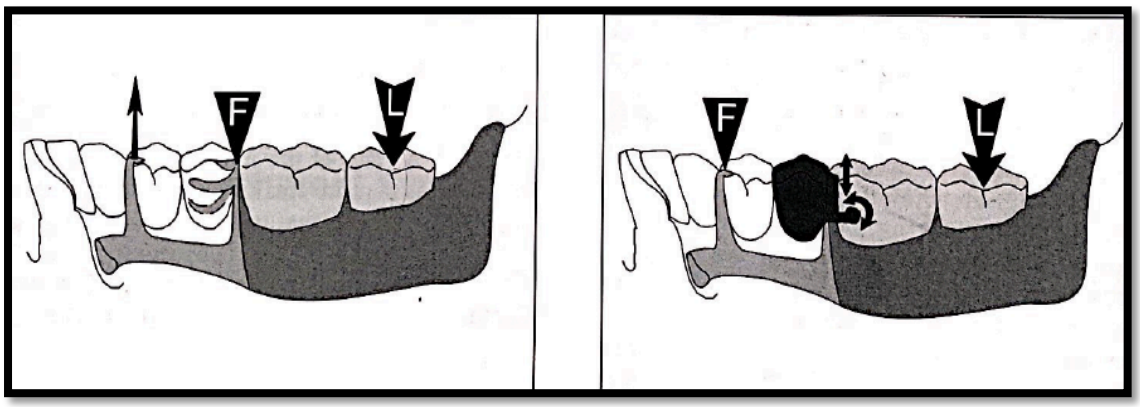
Figure 2-21 When Compared to conventional occlusal rests, the apical extension of intracoronal attachment decreases non-axial loading and reduces rotation movement of abutment

(Picture adapted from: Stewaet's clinical, 2008)

In addition, Etracoronal attachment transmitted vertical force away from the abutment, it may distribute occlusal forces to supporting structure better than clasp assemblies.[77]

Furthermore, when placed attachment between abutment and extension base of RPD framework, in this situation an attachment acts as stress breaker (Figure 2-22), it is permit vertical, horizontal, and /or rotation movement of denture base relative to abutments. So it limit the potentially damaging force imparted to the abutment as the extension bases are mobilized during function[62].Finberg 2011, showed that extracoronal attachments are passive and free moving that dissipate destructive lateral force.[65] In order to distribute functional loads during prosthesis design, so no one area receives excessive stress, you

have to follow the principle of broad stress distribution this stress on the abutment is reduced by by deriving good support from edentulous ridges, providing adequately flexible direct retainer and major connector[62].



A B

Figure 2-22 {A} Conventional RPD design, clasp arms must be sufficiently flexible to dissipate stresses originating from displacement to the extension bases during occlusal loading (L arrow). F represents the fulcrum in this system. {B} With broken stress philosophy, stress transfer to abutments is minimized during occlusal loading (L arrow) of extension bases. Extracoronal attachment permit relatively stress-free rotation and vertical movement (small arrows) between the denture base and abutments. F represents the fulucrum in this system. (Picture adapted from: Stewaet's clinical, 2008)

Stewart 2003 pointed out that clasps' arms in esthetic zone area such as canine and premolar abutments might be esthetically objectionable. The main indication of attachment is eliminating the need for facial clasp arms while provide acceptable retention, support, and stability to the prosthesis. Attachment improved esthetic appearance and increase psychological accepted of the prosthesis (Figure 2-23)

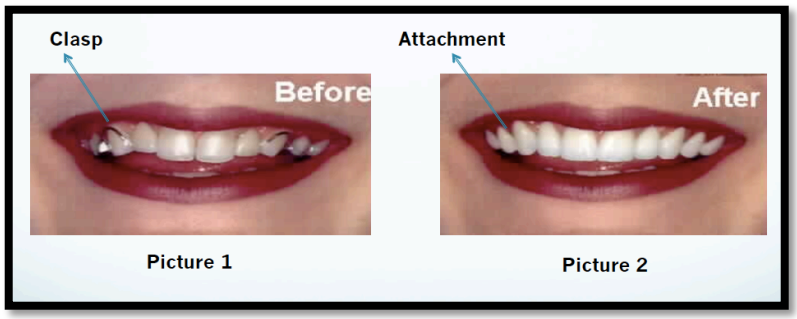


Figure 2-23 Attachment improve esthetic (Picture courtesy of www.dentistrytoday.com)

Additionally, Prasad, 2016 marked that precision attachments offer many benefits because of their flexibility[28]. However, in the past due to the high cost and insufficient grasp of attachment application, a clinician has been ignored them. The last decade has seen the public become better informed, and a dental surgeon will add new dimension to his treatment options.[78] Prasad, 2016 showed that the variation in size, shape and configuration of attachments allow then to be used in many clinical scenarios.

RAR, 2008, showed that among different PRDPs, those with extracoronal attachments type, are considered more efficient in restoring function and providing retention."[79,80]

However, the used of attachment has certain limitation. The practitioner and patient must be aware of the limitations potential problem of attachment RPD. In order to incorporate attachment components abutments must be crowned[81,82]. Splinting abutments may reduce the excessively loading on the abutments. The preferable number of splinting abutments remains controversial. Preiskle suggested that when extraconal attachment is used, you need to splint all the anterior teeth[75], while Kratochvill et al reported that fewer teeth need splinting[83]. Splinting of abutments demanding tooth preparation of sound tooth

structure. When extracoronal attachments are used with free-end saddles, two splinted teeth on either side should be used[75]. Feinberge et al 1996, discovered that" The reduction of number of splinted units from three to two resulted in an insignificant increase of stress recorded, whereas reduction of the number from two to one resulted in a significant increase of stresses nine times greater than the three-unit splint values"[84]

Attachment systems are contraindication for short abutments. In order to incorporate intracoronal attachment, a minimum abutment height of 4 to 6mm is necessary[42]. Poor periodontal health of abutment[61] and poor crown-to-root ration[85], and compromised endodontic[42] may contraindication the use of attachment. Fixed splints have negative effect on periodontal health care because of the wide joints between the units of the splint that can interfere with oral hygiene measures.[75] Patients who are visually, manually challenged, poor oral hygiene, and geriatric patients with inadequate manual dexterity normally contraindicate for attachment RPD [28]

The most common drawback of attachment RPDs are complexity of design, fabrication and clinical treatment that need appropriate training, experience, technical skills and clinical ability and judgment. This complexity of design contributes dramatically to overall cost of treatment.[28] Prasad et al mentioned that many attachment and complex designing should be avoided and sticking to the simplest once and avoid the complexity.[28] Additionally, extracoronal requires intraocclusal space, and additional maintenance.

2.4 Factors considered and challenges of attachment selection in RPD design

When selecting an attachment, dentist hopes to use the best attachment in specific cases. There is probably no such thing as “best attachment” but there may be several attachments that will work equally well. So, one should not select an attachment by name rather by understanding basic principles, which never change. Prasad et al 2016, reported that there are some criteria that help to decide an appropriate attachment based on the individual need of the case[28.]

Attachment selection criteria according to preiskel, 1995 (Figure 2-24). Proper attachment selection required evaluation of some factors such as:

1- (location) according to their relation of the abutment teeth. Attachment can be (Internal attachment) intracoronal or (External attachment) extracoronal.

2- (Function) based on stiffness of the resulting joint. Attachment may be rigid (non resilient) or resilient.

3- (Manufacture) basic on method of fabrication and tolerance of fit. Attachment can be precision (prefabricated types) or semiprecision (custom made/ laboratory made) types.

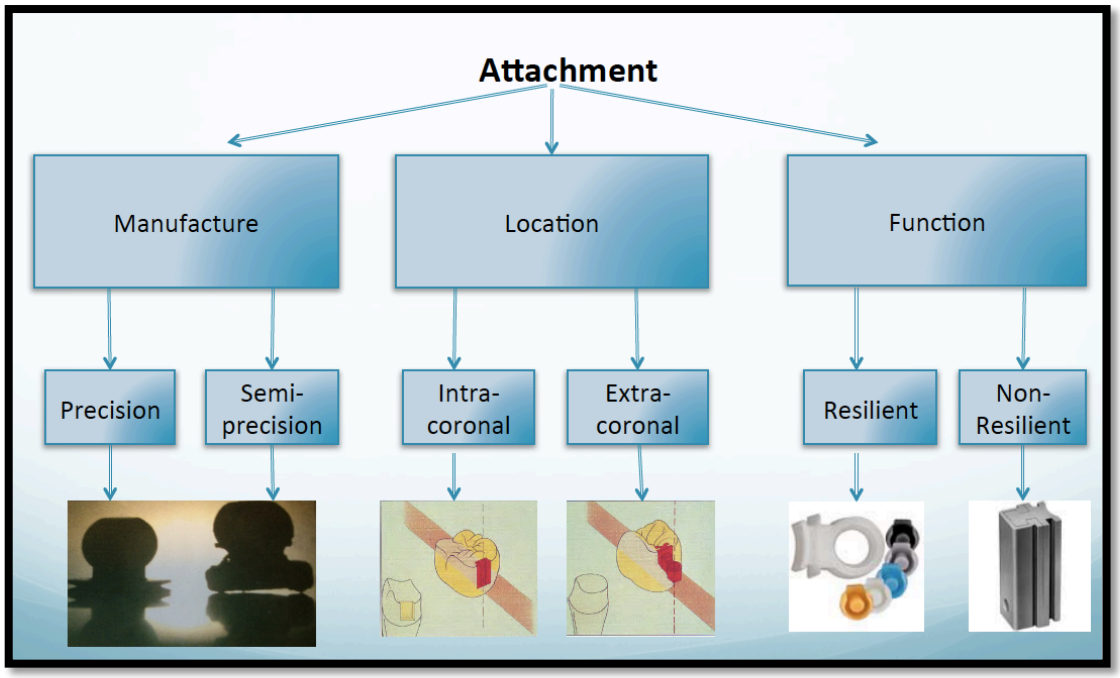


Figure 2-24 Classification of attachment. Presikel HW

Ashish et al 2012, suggested that attachment selection principle is based on the following:

- Abutment condition
- Location of the attachment
- Function of the attachment
- Manufacture of the attachment
- Space available
- Financial ability and oral hygiene status

2.4.1 Abutment condition

When natural teeth are being considered as potential abutments for fixed or removable prostheses, many factors need to be considered.[23]Evaluation of hard, soft, periodontal

tissues are important and occlusal evaluations too. McCord and Smales, 2012 mention that the ideal condition is:

- The teeth should be structurally sound
- The teeth are in good alignment and position not required orthodontic therapy
- The previous restoration and RCT are satisfactory
- The abutment tooth roots and support alveolar bone are in good condition
- The alveolar bone of the edentulous ridge is adequate in quantity and quality
- The soft tissue of edentulous ridge is satisfactory in quantity and quality.

Additionally, mesio distal space between the abutment must be evaluate because may be too small or too large for artificial tooth relative to the size of natural teeth.

There are many parameters involved in periodontal, endodontic and prosthetic point of view, that are relevant for deciding whether we can use an abutment tooth for attachment RPD or not (Table2-8). Many factors we have to put in our consideration when we decide to use natural tooth as abutment for fixed or removable prostheses.[24] Prosthodontics face the difficult task of judging the influence and significance of multiple risk factors of periodontal, endodontic, or prosthetic origin that can affect the prognosis of an abutment tooth.

When restoration therapies required, all factors of periodontal, endodontic and restorative risk must be evaluated and considerable[86]. The process for deciding where, we

can use the abutment for attachment RPD or not “gray area" based mostly on clinical experience and rough predications on the long-term prognosis of the tooth in question. As a result, the clinician often makes decisions on "feelings" rather than clinical parameters. For this reason basic knowledge and experienced of dentists play an important key in decision-making.[43] When developing a treatment plan, tooth prognosis is first assessed and all pretreatment requirements are considered, including periodontal treatment, RCT, posts and cores, crown lengthening, and/or orthodontic extrusion.[43] Before the definitive restorative therapy is conducted, any questionable tooth is reevaluated in terms of periodontal stability, or healing of periapical radiolucency following RCT. As soon as multiple risk factors are identified for a tooth intended as an abutment for an RPD, complexity increases, and the entire restoration is at higher risk.

Clinical parameters you have to be considered for abutment selection in attachment RPD[43]:

- Prosthetic consideration such as amount of tooth distraction
- Periodontic consideration such as bone loss, mobility, and attachment loss
- Endodontic consideration
- Special consideration: such as tilted abutment, crown root ration, and opposite arch

In our proposal study we evaluate all these factors in order to select an abutment for used in attachment RPD. (Table2-8)

2.4.1.1 Prosthetic consideration (Amount of tooth destruction):

The extent of the remaining tooth structure is among the most essential and critical factors in determining the prognosis of a damaged tooth used as an abutment (Figure 2-

25). Tooth with extensive damage is one that has lost substantial structure as a result of caries, previous restoration failures, fractures or even procedures related to endodontic treatment and achieving sufficient anchorage in the remaining clinical crown is often impossible. Hence, this extensive loss of tooth structure necessitates complete-crown restorations with pulpal retention.[87]The dimensions of the crown dentin are important and if a dentin thickness less than 1mm increases the risk of failure.[88]

The most factors that classifies an abutment as having a good, questionable, or hopeless prognosis is based on the remaining coronal tooth substance and the strategic value of the respective tooth with regard to the residual dentition.[43] It is considering "good" prognosis of abutment if there is a sufficient residual tooth substance with adequate retention and resistance (ideally, 4mm wall height with 15-20 degree convergence angle but with 1.5 to 2mm ferrule.[89] An abutment is considered "questionable" when there is reduced retention and resistance form (less than 3mm wall height and/or more than 25 degree convergence angle. Insufficient residual tooth substance (less than 1.5mm with circular ferrule) [89] and no crown lengthening or extrusion is feasible in an abutment is considered as "hopeless" abutment.[86]

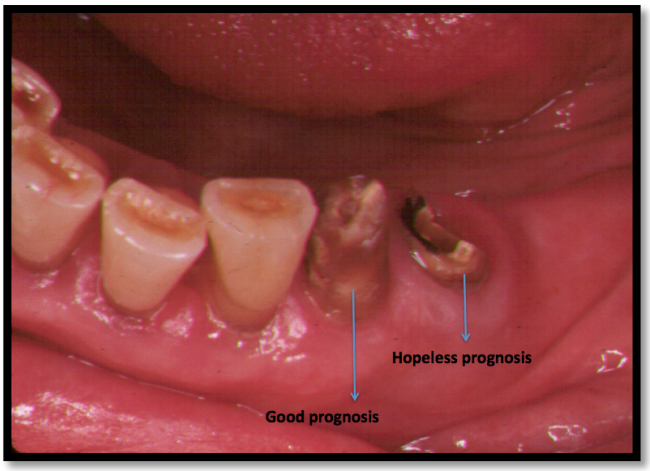


Figure 2-25 Classification of abutment based on remaining coronal tooth substance. The picture shows good prognosis of abutment due to sufficient residual tooth with 2mm ferrule, while the hopeless prognosis of abutment due to insufficient residual tooth with less than 1.5mm ferrule Courtesy of Dr. Louis DiPede. Rutgers School of Dental Medicine NJ

Teeth that serve as FPD abutments bear greater stresses in function than single crown abutments.[90] Teeth using as abutments for RPDs have greater stresses in function than non-abutment teeth.[91]Distal-extension partial denture abutment teeth can stand greater

stresses than any other abutment tooth.[92] These large stresses can fracture teeth that have endodontic therapy with dowel space preparation.[93]

2.4.1.2 Periodontal consideration: (bone loss, mobility, attachment loss):

In periodontics, the classification of abutments as having a good, questionable, or hopeless prognosis is based on the amount of periodontal attachment loss (PAL) and residual probing pocket depth (PPD) or furcation involvement (F.I).[94] The prognosis of an abutment is considered "good" if the probing pocket depth is less than or equal to 3mm with absence of bleeding on probing, periodontal attachment loss less than 25% and furcation involvement less than or equal to 1st degree (considered as good predictors for

abutment)[95]. According to American Academy of Periodontology 2000 (AAP) , Clinical Attachment loss (CAL) designated as slight (1-2 mm CAL), moderate (3-4 mm CAL) or severe (> 5 mm CAL)[96]. (Wu et al, 2018) suggested that good abutment if PPD >3mm to <5mm and CAL 1-2mm[97]. An abutment is considered "questionable" if the residual PPD is more than or equal to 6mm with presence of bleeding on probing, PAL loss of approximately 50% and FI with degree II (predictive of further activity) [95].

(Wu et al, 2018) suggested that questionable abutment considered if PPD ≥5 to < 7 and (CAL) 3-4mm. Insufficient residual attachment is considered "hopeless" abutment[86.] Hopeless abutment considers when the abutment has PAL more that 50% and PPD more that 6mm with present bleeding [86]. Other study done by (Wu et al, 2018) reported that PPD ≥ 7mm and CAL ≥ 5mm is considered hopeless abutment. Teeth with a good Prognosis are used for abutment for RPD attachment, those with a questionable prognosis the decision of use them relay on Dental Decision Support System (DDSS) which analysis all the clinical parameter basic on evidence knowledge literature and dentists' expert's clinical skill, while teeth with hopeless cannot use it as abutment.

When the supporting periodontium is lost the mobility of natural teeth may be increase. Classification system of tooth mobility according to degree and direction of movement was proposed by Miller[98]. He classified tooth mobility into three categories where Class I was given for teeth with mobility slightly greater than normal (<1 mm); Class II for teeth with mobility or slightly more than 1 mm in horizontal projection only; and Class III for teeth presenting more than 1 mm horizontal mobility and vertical displacement with or without

rotation. Muhlemann[99], proposed a technique to assess tooth mobility, in which two metallic (rigid) hand instruments are used to test the tooth in question and therefore record the extent and direction of its mobility within 100-load application, if present.

2.4.1.3 Endodontic consideration:

Dentists believed that endodontically treated teeth are brittle and need extensive restoration. Prosthodontics suggested that endodontic treated tooth should complete coronal coverage by crown or fixed dental prosthesis[29]. Limited clinical studies performed about possibility of use RCT teeth as abutment for fixed or removable partial denture[99]. The prognosis of RCT teeth depends not only on the treatment itself, but also the prompt placement of coronal restoration that withstand the stress from the prosthesis.

The prognosis of endodontic tooth is based on presence or absence of clinical signs and symptoms and periapical radiolucency. An abutment is considered "good" if there are no clinical signs and absence of or decreasing radiolucency. An abutment is considerable "questionable" if there are no clinical signs but persisting radiolucency. In case of symptomatic situation and present of radiolucency so it is hapless prognosis.[29]

Caution was suggested when used endodontic treated teeth as abutment for RPD[93] However, other study proposed that endodontic treated tooth can be used as an abutment.[92] It is seems that endodontic treated tooth must be adequately reinforced if teeth are be subjected to the demands of greater stresses as abutment and reinforcement with dowel is mandatory if these teeth are to be used as abutments for RPD or FPD[90] .In evaluating partial

denture abutments and the resultant forces, it is necessary to differentiate between entirely tooth-borne and combination tooth-tissue-borne partial

dentures.[100]

Krol states: "In the fully tooth borne partial denture occlusal stresses are transmitted to bone by way of the periodontal ligament. It functions similarly to a fixed partial denture. The extension base partial denture, however, derives its support from two different tissues, teeth and edentulous ridge each having different degrees of displaceability. This often results in torqueing stress on abutment teeth."[101] Kratochvil circumvents endodontically treated teeth as abutments for RPDs, especially when the tooth serves as a distal extension partial denture abutment[100].

2.4.1.4 Special Consideration:

Misaligned teeth or tilted teeth are common problem in prosthodontics because such tooth unlikely to offer adequate retention or an adequate guide surface for RPD. Placement of FPD can be complicated by tilted abutment. Misaligned or tilted teeth where the abutments are considerable questionable.[29]

The crown-to-root ratio (CRR) represents the biomechanical concept of class I lever for evaluating abutment teeth. The ratio is defined as "the physical relationship between the portions of the tooth within the alveolar bone compared with the portion not within the alveolar bone, as determined radiographically."[29] Several studies have investigated the value of this ratio to determine the prognosis of periodontally compromised teeth, hence periodontitis is the main factor that control this when clinical ration[102,103] Evaluating

abutment teeth, the status of the alveolar bone height and the total supported root surface of the abutment tooth should be examined. The CRR does not express the actual area of bone support, and therefore, might underestimate the severity of bone loss around the abutment. The radiographic evaluation of CRR should be based on periapical radiographs.

Dykema et al, 1986 stated that CRR for an FPD abutment of 2:3 or 1:2 to be ideal, but in practice this is rarely observed, and this ratio is based on studies of periodontally healthy subjects. Teeth with a normal amount of bone support should be used for abutments and teeth with loss of more than 1/3 of the periodontal support should be of questionable value. A ratio of 1:1.5 has been suggested as an acceptable and desirable CRR for abutments, although a 1:1 ratio may be a minimum acceptable ratio when the periodontium is healthy, and the occlusion is controlled. If the opposing occlusion is composed of tissue-supported prosthesis, a CRR greater than 1:1 might be adequate because of the diminished occlusal forces[104].

It is undeniably important to consider opposing occlusion upon treatment planning as it affects short and long-terms prognosis of abutment teeth in the opposite arch. Occlusal loads, that are applied on abutment teeth, are expected to be the highest in cases with opposing natural dentition and fixed restorations on either teeth or implants followed by opposing occlusion of removable partial dentures, overdentures and conventional complete dentures.[105,106,107]

The Criteria of Abutments that are Used for Attachments RPD
(Prognosis Index Value)

1- Amount of Tooth Destruction[42]	Prognosis Index Value
• Minimum	1
• Moderate	2
• Severe	3
2- Bone Loss	
• Minimum 15%	1
• Moderate 30%	2
• Sever >30%	3
3-Mobility[98]	
• Class I	1
• Class II	2
• Class III	3
4- Attachment Loss[96]	
• Mild (1-2mm)	1
• Moderate (3-4mm)	2
• Sever (≥5mm)	3
5- Crown Root Ratio[85]	
• <1:1	1
• 1:1	2
• >1:1	3
6-Opposite Arch	
• Complete Denture	1
• RPD	2
• Natural Teeth, Fixed	3

Table 2-8 Prognosis Value:

- **1 Good Prognosis (Recommended)**
- **2 Questionable prognoses? (Reconsider Treatment Plan)**
- **3 hopeless prognosis (not recommended)**

2.4.2 Location

According to attachment relation of the abutment teeth. Attachment can be (Internal attachment) intracoronal or (External attachment) extracoronal

2.4.2.1 Intracoronal Attachment

Defined as "any prefabricated or custom-made attachment for support and retention of a fixed or removable dental prosthesis; the patrix and matrix components are positioned within the normal contours of the abutment tooth" (GPT 9)[50]

Dr. Heman Chayes first reported the invention of attachment in late 19th century.

Prasad 2016 mentioned that the most advantage of intracoronal attachment is that the occlusal forces on the abutment tooth are applied close to the long axis of tooth. Most intracoronal attachments consist of a parallel- sided flange engaging a slot. When the RPD is placed in the patient's mouth the two components of attachment interlock in a sliding joint. This joint can be housed within the normal clinical contours of the abutment and must provide retention, support, reciprocation and encirclement (Figure 2-26). Attachment should function for to retain, support, and stability RPD.[2]

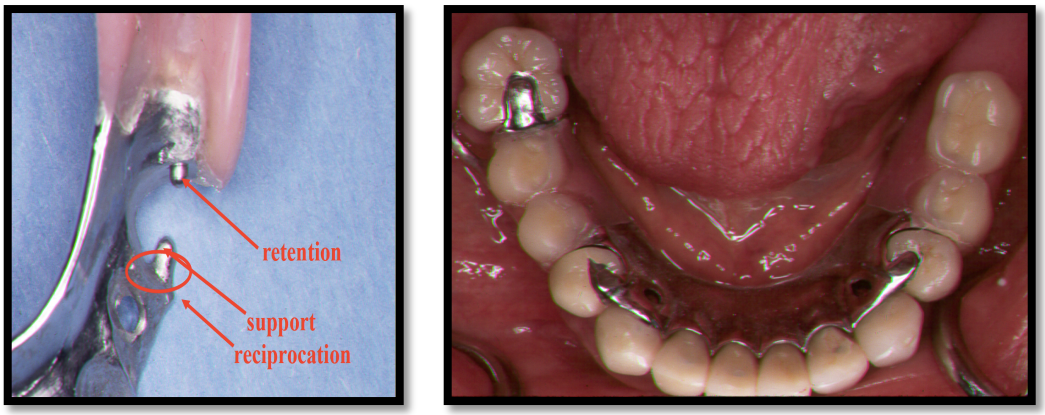


Figure 2-26 All RPD design with attachment must provide retention, support, reciiporocation, and encirclement. Courtesy of Dr. Louis DiPede, Rutgers School of Dental Medicine, New Jersey.

Parallelism of multiple attachment must be considered because path of insertion of the attachment, ie, the long axes of attachments must be parallel to each other and to the path of prosthesis insertion (Figure 2-27)[62]. Intracoronal attachment usually requires a box preparation to house the attachments and double abutting is recommended[14.] (Figure 2-28) A clinical crown of more than 4mm is generally required with same faciolingual width[108]

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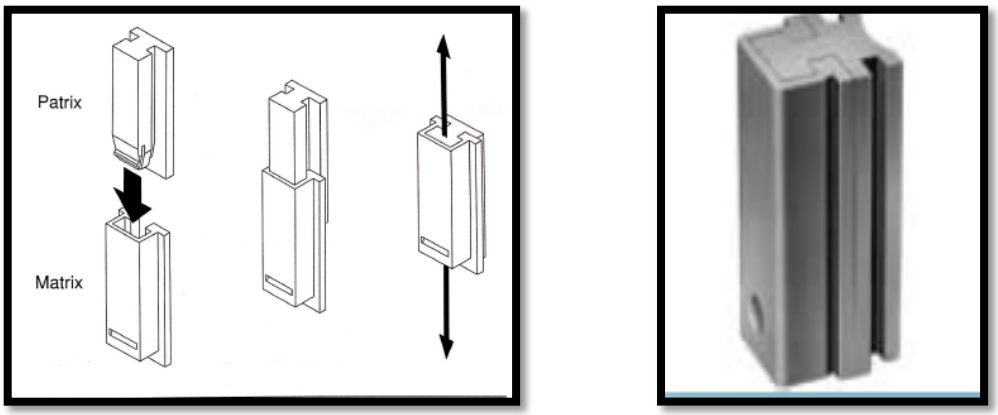


A B

Figure 2-27{A} diagram allustration of an intracoronal attachment. Arrows represent the path of insertion of patrix into the matrix, as well as long axis of the attachment. {B} Picture shows Stern Latch IP/C intracoronal attachment

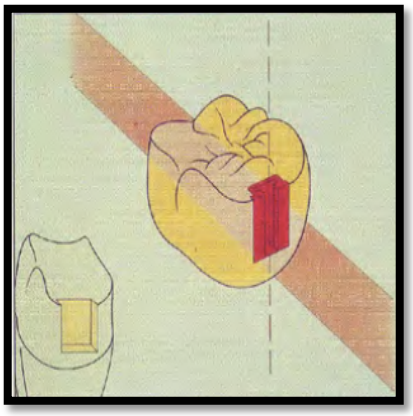


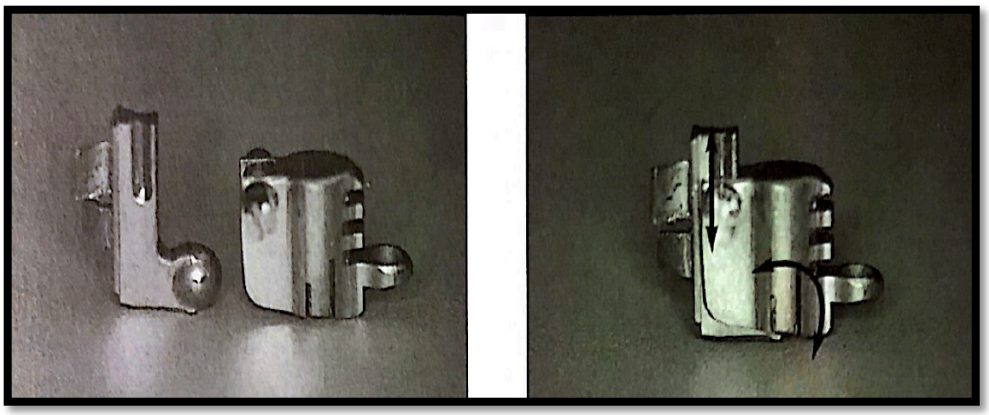
Figure 2-28 Box preparation to allow intracoronal attachment to fit within the crown contour.

2.4.2.2 Extracoronal Attachment

Defined as "Any prefabricated attachment for support and retention of a removable dental prosthesis; the retentive components (the matrix and patrix components) are positioned outside the normal contour of the abutment tooth" (GPT 9)[50]

Henry p. Boos first reported the invention of attachment in the early 1900s and later modified by F. Ewing Roach 1908. Unlike intracoronal, the extracoronal attachment does not requires box preparation or space within the abutment crown, it maintains the normal tooth contour, minimal tooth reduction is necessary and the possibility of devitalizing the tooth is reduced. It is commonly used where buccolingual space is limited, and often employed to retain bilateral distal extension prostheses.

In addition, extracoronal attachment alignment is not critical because the omni planar motion possible. So, the path of insertion is easier for patient with dexterity problems due to multiple paths of placement for the prosthesis[1]. Even with extracoronal attachment double abutting is recommended. Extracoronal attachment acts as "stress- breaking" most them have resilient attributes (stress redirection)[28]. Function movement of the prosthesis may be limited to vertical, horizontal, and /or rotational path or omnidirectional displacement of the prosthesis. These movements allowed by extracoronal attachment for safety valve and not as a means of anchoring an unstable prosthesis to natural teeth. Function movement is intended to minimize the transfer of damaging forces to the abutments. (Figure 2-29), illustrated the function movement of removable partial and attachment.



A B

Figure 2-29 {A} patrix (left) matrix (right) of an extracoronal attachment. Note the spherical projection from the patrix. This configuration allows rotation movement of RPD in response to occlusal loading. {B} Arrow illustrate the sliding and rotational movements

Some authors suggested that the resilient extracoronal attachment could preserve the abutment[109]. Extracoronal resilient attachment (ERA)- retained dentures (Figure 2-30, 2-31) have been founded more beneficial to abutment teeth than bar retainers[110,111]. Kratochvil et al, pointed out that a Dalbo extracoronal attachment (APM-Stern gold) distributed allot of stress to the alveolar ridge and decrease stress on abutment teeth[112]. Furthermore, Heckmann et al, showed that more stress is transferred onto the denture-bearing area with a resilient extracoranal attachment than with a rigid intracoronal one[113].

However, it is not easy job to maintain hygiene with extracoronal attachment, patients should advice to use of dental floss and hygiene accessories. Patient should compliance to instruction and listened to dentist's advices, this will help prevent tissue irritation caused by food entrapment or calculus bulid-up[28].

Figure 2-30 The matrices of extracoronal attachment direct retainers (arrows) extended from the distal surfaces of crowns placed on the mandibular lateral incisors. Courtesy of Dr. Louis DiPede, Rutgers School of Dental Medicine, New Jersey

Figure 2-31 The patrices of extracoronal direct retainers (arrows) attached to RPD. Courtesy of Dr. Louis DiPede, Rutgers School of Dental Medicine, New Jersey

2.4.3 Function

Feinberg categorizes attachments on the basis of function into 2 categories: Rigid (mechanical locking action) Resilient (free moving, stress-breaking action) [114]

2.4.3.1 Rigid Attachment

When the contact of patrix and matrix restrict relative movement between the abutment and prosthesis during functional loading of the removable partial denture, the attachment is considerable rigid (Figure 2-32).[1] However, many attachments are designed to permit movement prosthesis during functional loading. Wang et al 2001, discovered that for the resilient attachment, there was movement between the patrix and matrix component of the attachment, while there was no movement between the 2 component parts for the rigid attachment. Some studies on attachment-retained distal extension dentures have shown that rigid extracoronal attachments could result in torquing forces. This torqueing force can be transmitted to the terminal abutment because the both matrix and patrix are not located on the long axis of the abutment.[115] In addition, Nishimura et al, reported that in distal extension base removable partial prosthesis, rigid connectors, in particular, caused slightly higher stresses in the supporting structure than non-rigid connectors[11,116].

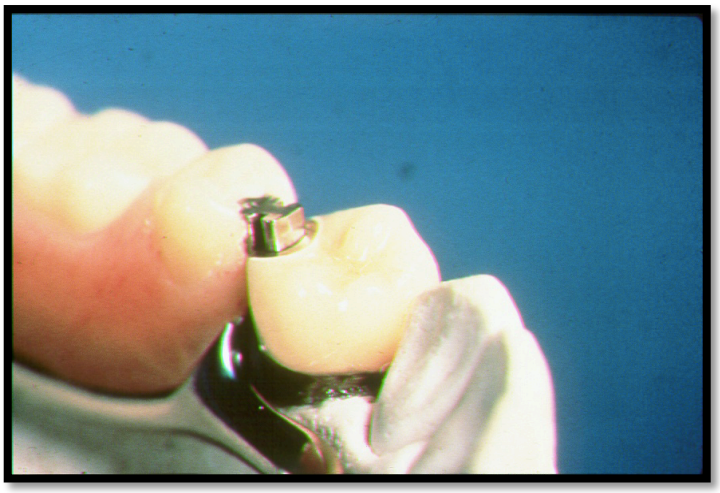


Figure 2-32 C&M McCollum rigid attachment. Photo courtesy of Dr. Louis DiPede, Rutgers School of Dental Medicine, New Jersey.

However, other authors have indicated that rigid contact between the attachment patrix and matrix had more advantages and could reduce the movement of abutment teeth[116]. Saito et al found that the displacement of the denture base tended to be less when design the RPD with rigid connection and with cross-arch stabilization.[117] The RPD may be tooth borne or tooth-tissue borne. Attachment for Kennedy class III and IV tooth-supported prostheses should be Rigid.[1] Abutment/tooth supported restoration are considered solid.[14] Tooth/tooth supported attachment are sub classified into two types, non-locked and locked, while resilient attachments are classified to 5 category[118] (Table 2-9). The higher classification number has a greater degree of resiliency and expects less torque transfer to the abumtment[1]

Class 1a	Solid, rigid, non-resilient
Class 1b	Solid , rigid, lockable with U- pin.
Class 2	Vertical Resilient
Class 3	Hinge Resilient
Class 4	Vertical and Hinge Resilient
Class 5	Rotational and vertical resilient
Class 6	Universal , Omniplanar

Table 2-9 Classification of attachments. (Staubli PE. 1996)

2.4.3.2 Resilient Attachment

When the contact of the patrix and matrix permit movement of denture base during function loading this attachment is considerable resilient (Figure 2-33). Resilient attachment allows for a range of movement ranging from limited uniplanar to universal.[1] Compared with rigid attachment, resilient attachments can decree stress in the supporting tissues around the terminal abutment in distal extension RPDs [119]. Based on the results of Wangs' study, the hypothesis that the resilient attachment design can allocates more stress to the alveolar ridge than a rigid attachment and reduces stress on the terminal abutment. The stress distribution was affected by loading among different loading conditions; maximum buccolingual loading had the highest effect on the periodontal tissues[119].

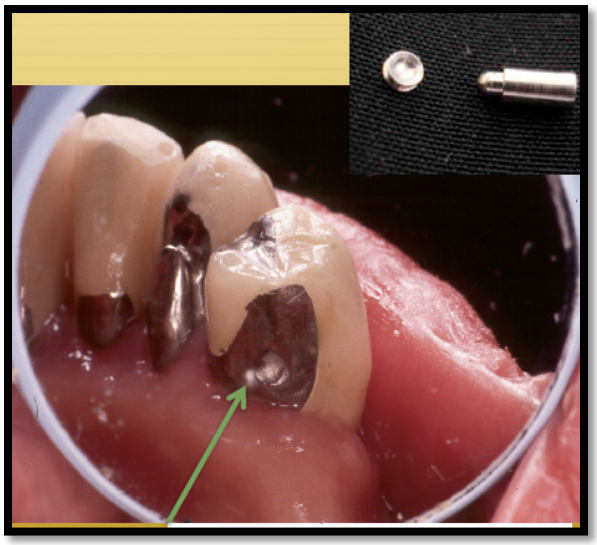


Figure 2-33 IC resilient attachment. Arrow showing the position of the hole for matrice of intracoronal attachment direct retainer. courtesy of Dr. Louis DiPede, Rutgers School of Dental Medicine, New Jersey.

They are many attachment designs in the market and each design permit different movements between the component parts, which affects dental biomechanics. For example, Dalbo attachment belongs to hinge type and permit vertical movement with the limited hinge movement, while ERA permits universal hinged movement.[120]

Large class IV and distal extension I or II prostheses where are increasing tissues supported area should be resilient, which allows movement around a given point, pro viding stress-breaking action to the denture.[1] Wang 2011, described that stress on the terminal abutment can be reduced by the use of an extracoronal resilient attachmentthat distributed more loads onto the distal edentulous ridge. For example, attachment for kennedy classification class I and II should be resilient, while class III and IV should be rigid. (Figure 2-34) shows fracture abutment with rigid attachment RPD. In this case, Kennedy classification class I with rigid intracoronal attachment was done.

Figure 2-34 shows fracture in terminal abutments due to inappropriate select of attachment. In this case, Kennedy classification class I (Tissue tooth support) with rigid attachment was done. Courtesy of Dr. Louis DiPede, Rutgers School of Dental Medicine, NJ

Now a days, there is overwhelming number of attachments in the market some of them are rigid and others are resilient, some precision and other semiprecision (Figure 2-35) show some attachment example, ERA, Dalbo, Cross-Arch Roach, IC are resilient attachments, while Stern Latch, C& McCollum, Beyeler are rigid attachment. Major determinants in a dentist's decision between the multiple types of attachment are education, experience, skills and personal preference based on theory. Outlined are some of the major factors to aid in this decision.

Figure 2-35 Different types of rigid and resilient attachments

2.4.4 Manufacture

Basic on method of fabrication and tolerance of fit. Attachment can be precision (prefabricated types) or semi-precision (custom made/ laboratory made) types

2.4.4.1 Precision Attachment

A precision attachment is fabricated from milled alloys and tolerances are within .01mm.[28] Stewart's said if "the component of attachment is fabricated in metal using low-tolerance, precision manufacture technique, the intracoronal direct retainer are considered precision" (Figure 2-36). Precision attachment is machined from wear-compatible metals. The advantage includes consist quality, controlled wear and easier repair.[121] The retention of attachments is achieved through mechanical interlocking and frictional contact between the matrix and patrix.[121,122] Attachment-retained dentures have garnered high patient satisfaction because of their retention characteristics.[123]

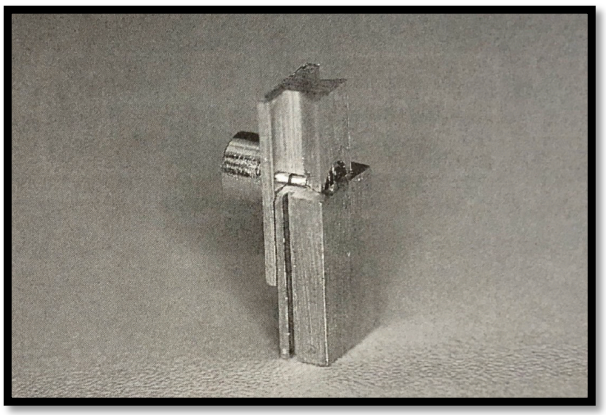


Figure 2-36 patrix and matrix of the attachment engaged and partially seated. Note the precise fit of this sliding joint (Picture adapted from: Stewaet's clinical, 2008

In addition, esthetic superior, maintainable periodontal health, longevity of abutment teeth, and patient comfortable.[124]In addition, Shakell 2013, concluded that "clasp retained partial dentures are still considered to be the most economic treatment for the distal extension cases, but these partial dentures could not satisfy patients expectations and were causing more damage to oral structures." With proper case selection precision attachments are the viable option and can improve retention, esthetics and function." Passively retained precision attachment partial dentures have been used successfully on natural tooth abutments since the 1920s.

Furthermore, about 1500 cases were exanimated and followed-up during a 50-year period by Dr Elliot and Edward Feinberg demonstrating the precision attachment cases offer one of the most successful removable partial denture therapy.[125] Precision attachments have been used in the construction of removable partial denture in an attempt to improve retention and aesthetic of the [126]prosthesis (Goto and Brudvik, 2002, Tsai and Shen, 1999) .As George Klein remarked in 1951 "No amount of skill in one step of the

work will overcome an error in a previous step." Precision attachment cases must fit with precision—the abutments must be stable, and the frameworks must fit properly against the tissue without rock[127]. "Precision attachment partial dentures should be the primary treatment plan rather than long spans of fixed restorations," says Dr Elliot Feinberg[128]

A case report of a patient with mandibular bilateral distal extension Kennedy's class I condition which is prosthetically restored by a cast partial denture retained using an extra coronal castable precision attachment (RHEIN 83 OT CAP attachment) was done by Raiganger, et al 2014. The author concluded, "Distal extension removable partial dentures fabricated with precision attachment are viable options for patients in whom fixe prosthesis, implants are contra indicated"[129]. Raiganger, summarized that adherence to techniques, proper diagnosis & periodic follow up of the patient will result in successful treatment & preservation of patient's existing dentitions.[129]

2.4.4.2 Semi precision Attachment

"Attachment is fabricated by the direct casting of plastic, wax, or refractory patterns"[28] It is incorporate laboratory-fabricated components, that typically involve a tapered wall geometry (Figure 2-37). If accurately fabricated the semiprecision attachment, it shows well –fitting components. They are semiprecision because in their fabrication subject to inconsistent water/powder rations, burn out temperatures and other variable.[28] The way of semiprecision fabrication leads to small degree vary in their components. They are easy to fabricate, less costly than precision.

When compared to a conventional attachment, a (semi)precision attachment for a cast metal frame RPD can perform a number of functions better. (semi-)precision attachments are classified according to measures of freedom. The different types are cast intra- and extra-coronal, adhesive and overdenture (semi-) precision attachments. After few of time, some wear of the attachment parts may occur, so requiring specific care. semi-precision attachments often improved self-confidence of the patient and self-image. However, the relatively high cost is a barrier to apply (semi-) precision attachments[130].

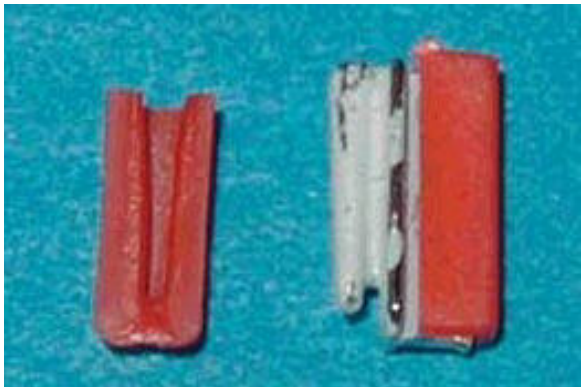


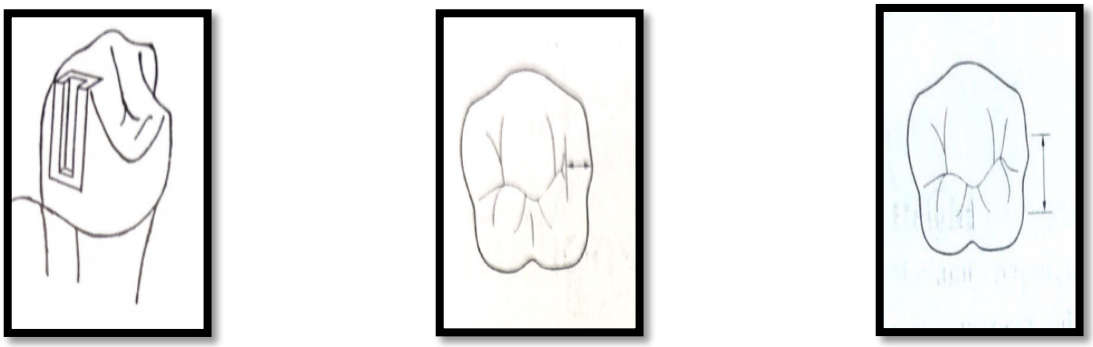
Figure 2-37 FR semi-precision attachment

Shetty et al, 2015[3] mentioned that a custom semi-precision attachment with a partial denture offers strength and improved aesthetics in cases with minimal space[131].

These customised attachments such as CPA semiprcision attachment overcome the disadvantages associated with the use of the intracoronal attachments, which are excessive tooth reduction and compromised embrasures. The other advantage of semi precision attachment is handling- ease, and wide choice of alloys[131.] Burns et al pointed out that semi-precision attachments lead to less precise tolerance and were desired in decrease tooth support[132]

2.4.5 Space

Space considerations also are important while deciding the attachment to be used. The space available vertically, bucco-lingually and mesio-distally play an essential role in attachment selection. For intracoronal attachment, which is the most commonly used of all prefabricated. In order to host the attachment intracoronal preparation are made within circumference of coronal surface, this can reduce the stress on the attachment and leverage on the tooth. Box preparation to allow intracoronal attachment to fit within the crown contour should be enlarged by approximately 0.6mm × 0.2mm in width and depth respectively. (Figure 2-38) shows space available for intracoronal attachment.[28] Makkar et al, 2011 demonstrated that a Box preparation to allow intracoronal attachment to fit within the crown should be prepared. Clinical crown greater than 4 mm is required with the same faciolingual width[1].



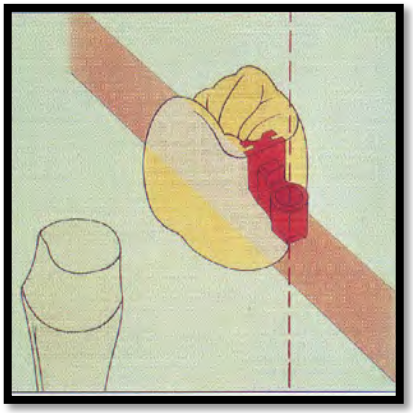
Height (1) Depth (2) Width (3)

Figure 2-38: shows 3 important spaces to house intracoronal attachment. Space available (Vertical 1, mesio-distal 2, buccal-lingual 3)

However, potential problem such as non-alignment of box to other abutment or inadequate size of box can occur.[134] Buccal-lingual space should be measured carefully to avoid over contouring the restoration. An addition 1mm should added to buccal-lingual measurement for metal precision attachment to allow for the casting alloy[28]. Mesio-distal

measurements are critical, pulpal and anatomical consideration must allow the female section to be accommodated within the crown contour. Any mistakes can be very hard and expensive to correct al late stages.[28]

However, for extrcoronal requires no box preparation but conventional abutment preparation is required, which allows for an attachment to be housed outside the coronal circumference of the tooth. (Figure 3-39). Vertical space is critical for extra coronal attachment. Vertical space is measured from the papilla to the opposing occlusal surface or measured from the tissue to marginal ridge, or from marginal of abutment to the margin ridge of the opposing dentition.[28] Use the full length of attachment and placed it as low as possible without impinging on the tissue.[28]



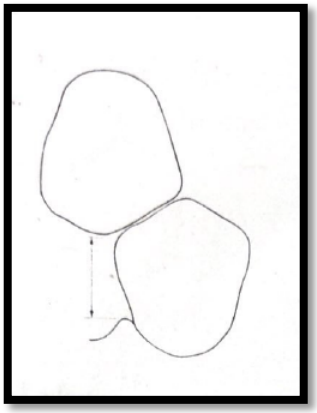


Figure 2-39 Extracoronal preparation Vertical Space

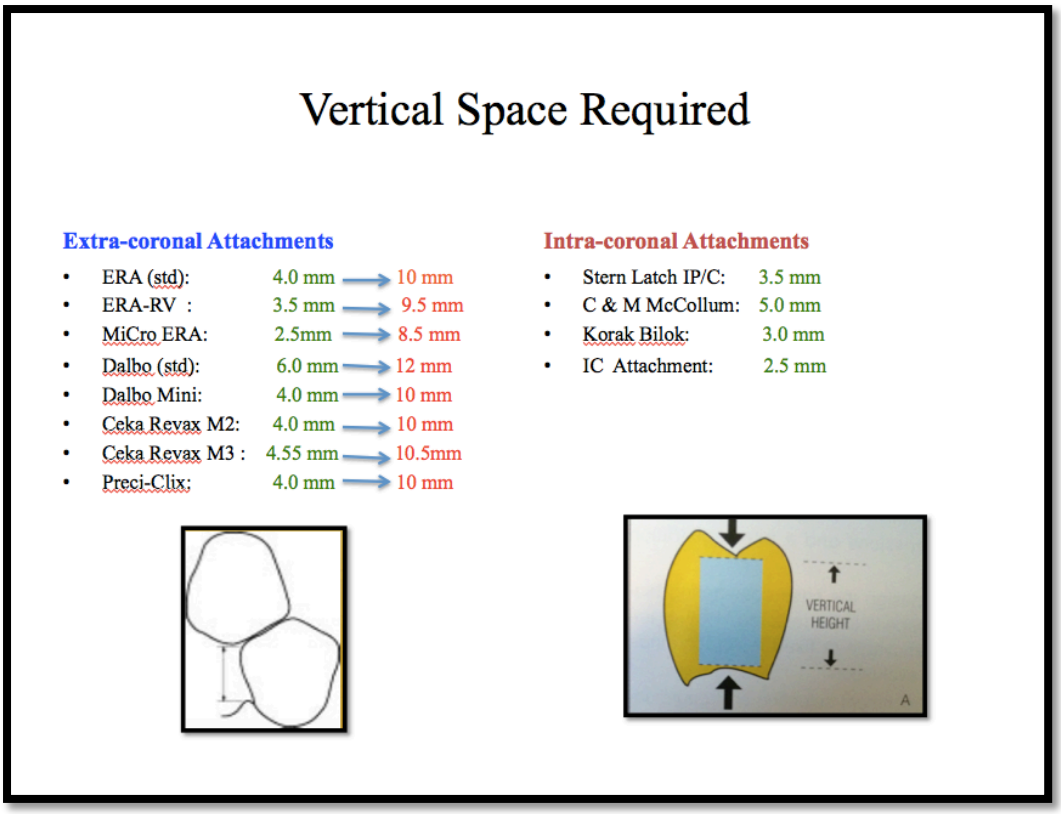


Figure 2-40 shows the vertical space and vertical height required for housed some extracoronal and intracoronal attachments. The green numbers represent the vertical height of the attachments, while the red numbers represent the minimum requirement vertical space

By observing the (Figure 2-40) You can realized that minimum vertical space available (An existing space between opposing dentition and soft tissues) to house an extracoronal attachment is 8.5mm and the minimum intracoronal vertical height (intracoronal space) for intracoronal attachment is 2.5mm.

2.4.6 Financial ability and oral hygiene status

In our fast paced and upwardly mobile society, patients will see a dentist for two main reasons: discomfort and/or Esthetics. The dental professional must be able to relate to the patients concerns, both physically and psychologically. As it mentioned early high demand

and expectation of the patient have taken us to give the restoration esthetic pleasing.[1] Patient's financial status is a key- factor that controls decision-making relative attachment RPD. Relatively high cost of some esthetic restoration treatment such as attachments are a barrier to apply them[133]. In addition, a recent study also indicated that poor financial status is the most contributing factor the population refrains from required dental care[135]. Construction an attachment-retained denture requires more chair side and laboratory time than conventional once[28]. This complexity of design contributes dramatically to overall cost of treatment.[28]

Oral hygiene status is other considered factor for attachment selection. Poor oral hygiene due to poor motivation and inabilities to comprehend instruction normally contraindicate complicated restoration therapies. A clinical follow-up [136] indicated that the chance of caries occurrence and progression, periodontal disease and tooth loss were almost negligible in patients with excellent compliance to oral hygiene instructions and regular recall visits. It has been indicated that compliant patients, who were treated and kept excellent oral hygiene, is good candidate for attachment RPD comparison to negligent patients[137.] Many attachment systems render oral hygiene more challenging, thus increase demands on oral hygiene performance. Conventional RPD may be more appropriate for patients who demonstrate substandard hygiene practices. Attachment designs exist that offer stress-breaking action, but they are generally prone to breakage. Wetherell and Smalles found that 82% of partial dentures with attachments of stress-breaking design failed within 6 years.[138] To compensate for this tendency toward breakage, some attachments, such as the ERA, include plastic or vinyl Snap-on sleeves. Unfortunately, these components usually require frequent replacement; the plastic resilient cap may wear

from usage and has to be replaced[139]. The patient should be advanced to have regular checkups for periodic repair and repayment of attachment components, which is costly, complicated.

2.5 Dental Education

There are intense federal level debates going on in many states concerned with the adequacy of the dentists' workflow and their ability to meet the current and future needs of the population. Fox, K. Spcial, 2014, reported that many dental schools, which have opened in recent years, cite shortage in the number of dentists. This is a key factor that supports the need for more dental school graduates. The Heath Resources and services Administration (HRSA) estimates a currently shortage of 7.300 dentists in the United States[141]. Table 2-10 shows the estimation number of dentists in the USA by 2033 based on various modeling scenarios (Bradley et al 2014). In addition, according to the American Dental Association (2009)[6], 79% of all active dentists in the United States are working in a general practice. In comparison to 21% who are working in a specialty practice. The prosthodontics represent 8.6% of all dentists giving a number of 3372 prosthodontics in the USA which is small number to treat millions of partial edentulous patients.

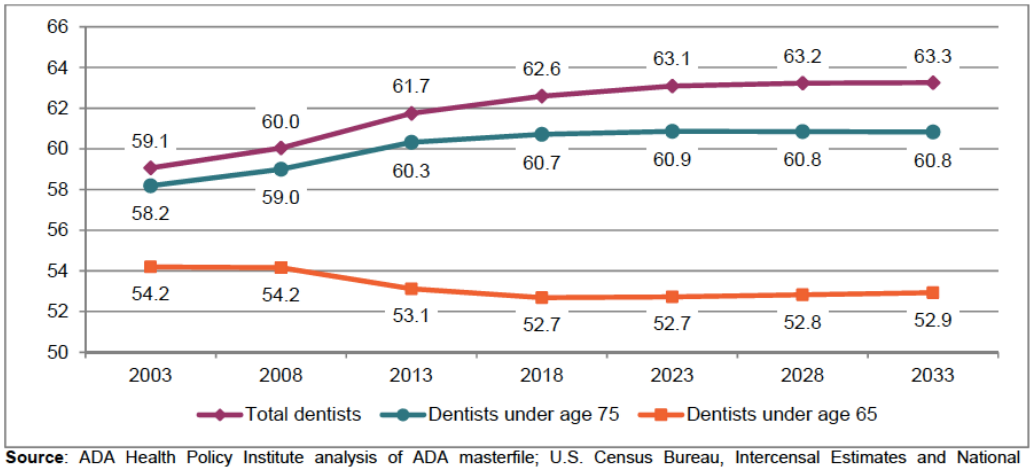
Bradley and his colleagues (2014) used 4 data sources in his analysis. The American Dental Association (ADA) contains the most up-to-date information on dentists in the USA. We relied on the ADA's survey of dental education on the number of graduates from dental schools. According to (ADA) the supply of dentists in the USA is projected to increase through 2033 and the "total inflows to the dentist's workforce in the USA are expected to exceed the total outflows, and the net gain is expected to exceed the growth in

the U.S population". (Table 2-10) and (Figure 2-41) show the age distribution of U.S dentist's workflow from 2003-2033

	2003	2008	2013	2018	2023	2028	2033
Age under 35	25,329	27,539	30,031	33,198	35,070	35,639	35,812
Age 35 - 44	42,726	41,694	44,424	46,778	50,296	53,353	55,272
Age 45 - 54	54,110	50,602	43,393	44,059	45,591	48,125	50,914
Age 55 - 64	35,061	44,855	50,086	49,215	49,057	49,723	51,339
Age 65 - 74	11,564	14,725	22,760	26,409	27,801	28,388	28,869
Age 75 - 84	2,363	2,957	4,147	5,803	7,090	7,817	8,190
Age 85 - 99	182	216	361	372	509	627	697
Total	171,335	182,588	195,202	205,834	215,414	223,671	231,093
U.S. population (thousands)	290,107	304,093	316,128	328,857	341,436	353,718	365,307
Dentists/100,000 population	59.1	60.0	61.7	62.6	63.1	63.2	63.3

Source: ADA Health Policy Institute analysis of ADA masterfile; U.S. Census Bureau, Intercensal Estimates and National Population Projections. **Notes**: Data for 2003, 2008, and 2013 are based on the ADA masterfile. Results after 2013 are projected. Totals in projected years may not match the sum of age groups due to the rounding of fractional numbers produced by the model. Assumes (a.) U.S. total annual dental school graduates will increase linearly to 2018 and then remain flat (b.) future outflow rates are same as 2008-2013 historical percentages.

Table 2-10 Total number of U.S dentists among various ages from 2003-2033, Baseline scenario[13]



Source: ADA Health Policy Institute analysis of ADA masterfile; U.S. Census Bureau, Intercensal Estimates and National Population Projections. **Notes**: Data for 2003, 2008, and 2013 are based on the ADA masterfile. Results after 2013 are projected. Assumes (a.) U.S. total annual dental school graduates will increase linearly to 2018 and then remain flat (b.) future outflow rates are same as 2008-2013 historical percentages.

Figure 2-41 Historical and Projected US dentists per 100,000 populations, by age group, baseline scenario13

By observing the table and figure 2-42 you will find that the number of dentists in the US slightly increase every 5 years. In 2018 the currently number of practicing dentists in the USA was about 205,834, this translated to 62.6 dentists per 100,000 population. Furthermore, in 2005[14] and 2009[143] the study consisted of 2 parts. Part 1(2005) was a survey of US program directors, and part 2 (2009) was a survey on the deans of the US dental schools. Both surveys evaluated of the trends in prosthodontics education. The first survey founded an increase in the number of US dental graduates applying to a prosthodontics program. Therefore, prosthodontics program has become more attractive to dental students. Some factors such as mentoring, society's demand for a higher level of training and credentialing, advances in implant, esthetic and the dollar value of prosthodontics training have all had some impact on increase the applicant for prosthodontics training in USA. In the 2009, the study had almost the same result.

Chang et al, 2012, pointed out that there were faculty shortages in prosthodontics and a huge demand for faculty in all aspects of dental education. As a result, dental students suffer in terms of faculty-to-student ratio and predoctoral exposure to specialty education. Dental students have lower exposure to postdoctoral students, and prosthodontics in private practice and prosthodontics engaging in research. Deans suggest that low exposure of the students to the skills of prosthodontics should be examined more extensively in the future because this issue can have a negative effect on the dental students and dental education in the USA. Despite limited curriculum time and shortage of faculty in prosthodontics, dental students still exposed to complex prosthodontics cases with high frequency. Deans reported

that dental students treat complex prosthodontics cases in 60% of schools and has increase 10% from the 2005 survey.

Echeto, 2016 mentioned that learning the RPD requires that students first have fundamental concepts and then use critical thinking skills to apply that knowledge to different clinical scenarios. [59] Prasad concluded no attachment is perfect for every application. Every case is different and thorough knowledge and good clinical skills are required to decide on an appropriate attachment. Furthermore, Markkar[1], (2011) pointed out that dentist reluctant to provide attachment RPD to their patients due to the lack of a proper knowledge and overwhelming number of attachments in the market.

Nowadays, there are many methods for learning in addition to traditional treating methods. Some studies showed that online learning is as effective as traditional learning and that dental students liked both types equally. Other studies demonstrated that combining online and face-to face learning in a blended approach is superior to traditional learning alone[144]. Additionally, the students described opportunity of blended learning such as it allows flexibility in timing. It also helps to relieve problems of faculty shortages, and is makes it easier for them to understand the information compared to other methods.[145] However, limited curriculum time, shortage in dental teaching staff at US universities[143], increased numbers of dental students[142], the complexity of attachment RPD topic and lack of proper knowledge[1], are all warning signs that show how it is to use blended approach to teach dental students.

This is a clearly gab existing in the education and training of dental students, residents and practitioners that are seeking continuing education. We have developed a clinical support and training online system for RPD attachment design and implementation. The information within the system is based on dental experts' knowledge, evidence-based literature and clinical practice guidelines. The system can be effectively employed by training dental students and residents to aid in the selection of an appropriate attachment for RPD. Also, this system enhances student's learning ability in the absent of teaching staff. It can also be used to complement traditional teaching methods, even in the absence of teaching staff and patients as part of a dental degree curriculum.

2.6 Clinical Decision Support System

The advancement of technology has expanded the amount of clinical information available for patients and clinicians. Unfortunately, the increased complexity of the data, and the difficulty in trying to understand and apply that data within a clinical context can be quite overwhelmed. Therefore, there is a great need for systems that can assist the clinician in developing personalized therapy plans based on statistics and rule sets that are oriented toward patient. Rather than population-specific estimates of risk and outcomes[146]. The rapid expansion of data and knowledge is causing two problems for clinicians. These issues include, a decrease situational awareness and increase in mental workload. This result in the clinician facing a difficulty when trying to keep the information "straight" as described by Karsh.[147] For this reason a computer system (CDSS) that assist clinicians with

diagnosis, treatment planning and therapy recommendations is a good way to solve this problem.[148] CDSS assists in the improvement of health care (Table 2-11)

Clinical Decision Support assists in the improvement of health management decisions by:

- facilitating the detection of potential medical errors
- suggesting risk factors and approaches to patient management
- suggesting optimal clinical strategies based on the best clinical knowledge and cost-effectiveness considerations
- organizing the details of a treatment plan
- helping to gather and present data needed to execute a plan
- communicating to third party payers

Table 2-11 Assistance of clinical decision support to improve health care by Roadmap 2006.148

Clinical decision support systems (CDSSs) can be defined as "computer programs that are designed to provide expert support to health care professionals making clinical decisions"[149]. The main function of these systems is to provide clinicians with patient-relevant recommendations. These recommendations are a result from a series of rules evaluated in a holistic fashion, at the required location and time. The aim is to improve healthcare decision making and therefore avoid medical errors.[148]

Ledley (a dentist) and Lusted were the first to co-relate DSS with medical diagnosis.[150] One of the earliest published CDSS systems is the Leeds abdominal pain system. This system was using the Bayesian probability theory. The system was developed in 1972 and studied in a United Kingdom national trial conducted from 1980 to 1985. The results were then published in 1986. The study concluded that CDSS was very accuracy reached 91.8 % which was significantly higher than the most senior member of the clinical team who saw each case with an accuracy 79.6 %[151]. Additionally, Adams et al. showed that diagnostic accuracy improved from 45.6% to 65.3% with the use of the system.[15] This was

one of the earliest developed systems, and one of the earliest studies to examine both clinician and patient benefit. Most importantly, it heralded 30 years of subsequent development in CDSS.

In the healthcare, there are three important uses of information technology and data management. Firstly, data collection tools allow practitioners to gather meaningful data from the patients' electronic health records. Secondly, data sharing tools allow exchange the patients' health data between the health care providers. Thirdly, data analysis tools, also help healthcare providers in interpreting the patients' data and can then provide them with optimum treatment. An example of this category is the clinical decision support system.[152]

There are three main components of any CDSS (Figure 2-42). The first component is the (Knowledge Base), which is collected from the evidence-based knowledge and/or experts' knowledge. The second component is the computer program 'Infer Engine' to integrate the patient's data with the knowledge base. The third components is 'User Interface' which allows the healthcare provider to interact with the system in order to gather the needed information for decision making.[153] However, 'Explanation module' is not present in all CDSSs, this module is responsible for composing justifications for the conclusions drawn by Inference Engine, while working memory helps for collection of patient data by storing in the database.

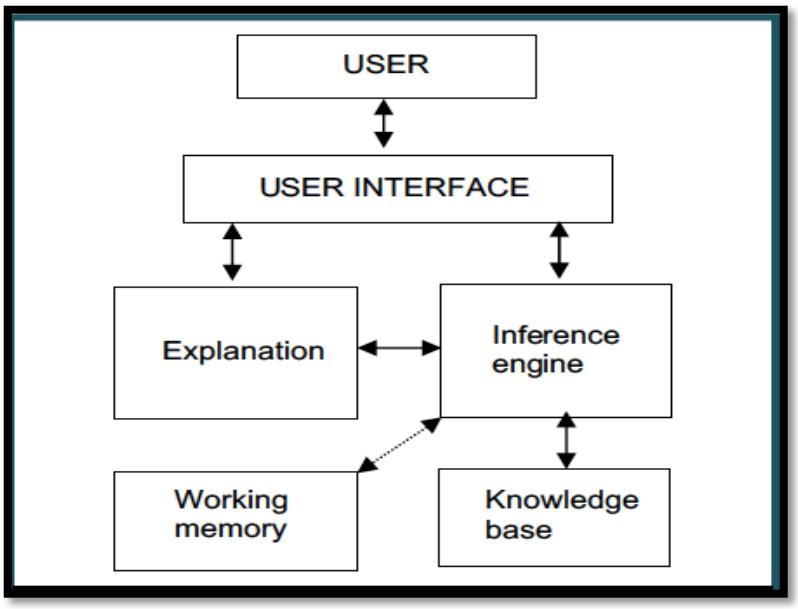


Figure 2-42 Flowchart showing components of the CDSSs and their relationship154

CDSS can be classified by knowledge represented into: the 'algorithmic system', 'neural networks' systems based on human brain functioning and works directly on observation, 'probabilistic systems' works on Bayes Theorem, 'logical/deductive systems' (rule-based) works on the "if-then" principle. Hybrid systems used more than one category of knowledge representation such as CDSS. Hybrid systems attempt to overcome all the drawbacks of other systems by combining both logical/ deductive rules and probabilistic systems.[17] MYCIN a stand-alone system, was the first rule-based system developed in 1970 and served as role-model system for other systems (Table 2-12)

Rule based reasoning	First developed and prototype. Works on "if-then" principle
Artificial neural network	Based on human brain functioning and works directly on observation
Bayesian networks	Based on probability theory and is promising for development of CDSSs
Case based reasoning	Computer based reasoning from previous patient's data

Table 2-12 Types of decision support system by white[17]

Many studies evaluated the utility of the CDSSs in healthcare industry. One of these studies done by Garg et al conducted a systematic review for all implemented CDSSs until 2004. The review included 97 studies. The results showed that 64% of the systems in general improved the practioners performance.[155] In another study done by Mago et al, 2012, the aim of this study was to help the dentists in deciding treatment plan for a broken tooth, the result of the study was that the accuracy of CDSS increases the confidence of the dentists when making decision of treatment plan. Furthermore, a study done by Shah et al 2016 concluded that, it is possible to design a system that serves as decision support aiding in the complex area of restoration of root canal treatment, and this system (CDSS) is a good tool for training and educating dental students as well as inexperienced clinicians in the field of restorative dentistry[156].

In order for CDSS to be implemented in a manner that is clinically useful, Osheroff et al. describe the ‘‘five rights:’’ the right information to the right person in the right format through the right channel at the right time[145]

- The right information (treatment planning, drug interactions);
- To the right people (dentists, patients);
- Through the right channels (mobile devices, workstations);
- In the right intervention formats (alerts, graphics, info-buttons);
- At the right time within the clinical workflow (before drug prescription, at point-of-care).

2.6.1 Use of clinical decision support systems in dentistry

The main objective behind designing CDSS in dentistry is to improve the quality of dental care given to the patients. This can be accomplished through supporting dental students, and dentists when choosing the right treatment plan. Deciding on the appropriate treatment plan is a challenging task especially when dealing with complex prosthodontics cases. This is because dentists have to rely on their intelligence, education, skills and experiences. New clinicians may find difficulty in combining their knowledge and experience by themselves.[157]. All these factors contribute towards higher levels of inconsistency in treatment plans. This also results in confusion for dental patients when they receive diverse treatment planes from different dentists.[162]

The use of CDSS is not only restricted towards helping practitioners diagnose and choose the correct treatment plan for their patients. It also has many other benefits such as,

helping to keep electronic health records, aiding in drug prescribing, as well as to analyzing and reviewing the articles.[158] CDSSs can be classified into several types according to the functions they provided. The active system, it is a monitor system usually integrated with the patients' electronic health records. Any clinical data and lab results that are entered are then analyzed by the system using the information in the knowledge database. The system then sends alerts to the healthcare providers if any abnormalities are detected. This system can alert a user about any dangers, warning, or errors without the need of the user seeking assistance[159]

Another type of CDSSs is the consultation systems, which is a passive system. This system requires the clinicians to seek for advice when they need it. When using this system, the healthcare provider enters the patients' data this include their demographics, medical history, clinical examination findings and lab results. The system then processes the information and provides the user with a list of differential diagnoses, for that particular case. The system will also suggest the needed action or treatment modalities that should be carried out[159]. An example of the passive system is DSSS for attachment selection in RPD design.

The use of a computer to help health professionals has been studied since 1950s.Ledley (a dentist) and Lusted were the first address the used of CDSS in health field.[160]. Newmanalso, reviewed the use of CDSS and pointed out that the system facilities workflow and decrease errors[158]. Tiernney et al, evaluated the economic impact of the use of computerized physician entry and found that costs per admission fell by $887 and length

of stay decrease by 0.89 days[161]. However, problems including the limitation of the scientific foundation and the resistance of practitioners to accept the CDSS lead to a decrease in the implementing of these systems with usual workflow. This has also prevented the widespread establishment of these systems.[162]

Many researchers working are going into dentistry related CDSSs. A review study done by Siegel et al was intended to investigate the effectiveness of computer use for the purpose of oral diagnosis.[163] They reported that many computer-based systems existed around the period of 1970s. However, the best example of this system was in 1973 during an oral diagnosis, when an automated diagnosis and treatment plan in the field craniofacial pain was established.[164,165]

White[17], Benn et al, and Brikley et al are some of many researchers that have contributed to the success of these systems. These systems have used different types of knowledge representation and have addressed several important areas of dental practice.

White identified more than 30 CDSSs; he grouped them to seven subareas of dentistry (Table 2-13). These areas are dental emergencies and trauma, oro-facial pain, oral medicine, radiology, orthodontics, pulp diagnosis and restorative dentistry.[17]White has classified the systems according to knowledge represented used, including algorithmic, statistical, rule-based, and image-processing systems.

a. Dental emergencies and trauma
b. Oro-facial pain
c. Oral medicine
d. Oral radiology
e. Orthodontics
f. Pulpal diagnosis
g. Restorative dentistry

Table 2-13 Classification of CDSS in dentistry, showing 7 subareas of dentistry by White[17]

Many studies have been carried out in CDSS in all 7 subareas of dentistry, some of these studies are:

A. Dental Emergencies and Trauma: Some studies were done such as System for diagnosis of dental emergencies[166] by (Ralls el al 1986), and Clinical decision support system for utilization of CT in the emergency department[167](IP et al, 2012) these studies concluded that CDSS can help clinician make correct and timely decisions about patient care.

B. Oral Facial Pain: Many studies were done in this field and one of these studies was carried out by an expert of system for diagnosis of oral facial pain[168] (Zusman, 1991)

C. Oral Medicine: many systemic reviews were done, one of the latest studies was CDSS a potential solution for diagnostic accuracy improvement in oral squamous cell carcinoma: a systemic review (Ehtesham et al, 2017). The result of this study that machine-learning methods have a high potential to manage the data

and diagnostic improvement in oral squamous cell carcinoma intelligently and accurately[169].

D. Oral Radiology: One of the latest studies is appropriates of advanced diagnostic imaging ordering before and after implementation of clinical decision support system. (Hussey et al, 2015). The authors concluded that implementing CDS systems in real-world settings has many challenges that must be addressed to manfully affect patient care[170]

E. Orthodontics: the latest study was done in Effectiveness of a clinical guided line to improve dental health among orthodontically treated patients: study protocol for a cluster randomized controlled trial (Oosterkamp et al 2016). The result of this study was that DSSS is very good tool for guide line and reduce errors and cost in dental health field[171]

F. Pulpal Diagnosis: one of the latest studies was done at Rutgers university entitled CDSS for management of root canal treatment teeth (Shah et al, 2016) concluded that, it is possible to design a system served as decision support aid in the complex area of root canal treatment, and this system (CDSS) is a good tool for training and educating dental students as well as inexperienced clinicians.[156]

G. Restorative Dentistry: study was done by (Mago et al, 2012), entitled CDSS for dental treatment, concluded that the accuracy of CDSS for treatment of broken tooth enhance the confidence level of the dentists while making decision regarding the treatment plan[40].

In addition to White, Benn et al, have also contributed to the success of CDSS. In their study about chancing the behavior of clinicians about caries risk and reduce over treatment.[173] The dental decision system has been designed for managing dental caries using a risk assessment model. CDSS with a moderate accuracy specificity risk model for predicting low risk individuals may produce a significant improvement in caries management. A study was done at the University of Florida Colleges of Dentistry and Engineering.

Some of the recent studies in dentistry confirmed the efficiency of CDSS in dental diagnosis and treatment plans. Table 2-14

Systems	Comments
Selection of Implant Abutments (Lee et al., 2012)	Uses expert knowledge from dentists and abutment suppliers
Treatment of Tooth Fracture (Mago et al., 2012)	Uses fuzzy logic to help identify complaints from patients
Treatment of Cavitated Lesions (Park et al., 2012)	Considers the patient's preference
Management of Dental Caries (Bessani et al., 2014)	Considers the patient's oral history and health risk factors

Table 2-14 Recent Dental Decision Systems in Dentistry[172]

3 CHAPTER III: METHODS

3.1 Exsys Corvid Core software basic features:

The selection of an appropriate attachment in RPD is one of the most difficult areas in clinical dentistry. The new clinical decision support and training system was developed using Exsys Corvid Core software. The new system is called " Dental Decision Support and Training System for Attachment Selection in RPD Design". DDSS is designed mainly to provide dental students and unexperienced dentists with the required knowledge needed to select an appropriate attachment to their patients.

Due to Exsys Corvid core is being an expert system, it simulates the discussion making process between human experts. This allows them to make the right decision and solve any difficult problems. The system can carry out this discussion online through the user's web browser and provide an excellent suggestion with dental expert recommendations.[104]

There are three components for Corvid Core system:

1- The user interface: provides the user with an online access to the system, also allows interacting with the CDSS and getting the recommendation.

2- Knowledge bases: contains all the knowledge and heuristic rules needed for the decision-making process.

3- The inference engine: analyses the rules from the knowledge based and produce the advice so that the right decision can be made to solve the problem

The main building blocks in the Corvid Core system are variable, logic block and command block (Figure 3.1). The knowledge base rules are set in the system using

IF/THEN statements. The variables are the fundamental components that are used to set these statements. Both ends of the IF/THEN statement are stored in the system as variable. The logic block is used to connect all the variables to produce a true IF/THAN statement that is executed by the command block. The command block also controls the method of running the inference engine of the system. The dental decision support system for attachment selection in RPD design was developed using the Exsys Corvid Core framework (Exsys Inc. version 1.0.9). A summary of the system rules and knowledge are presented in table (3-1 to 3-8). They will be explained in the next section

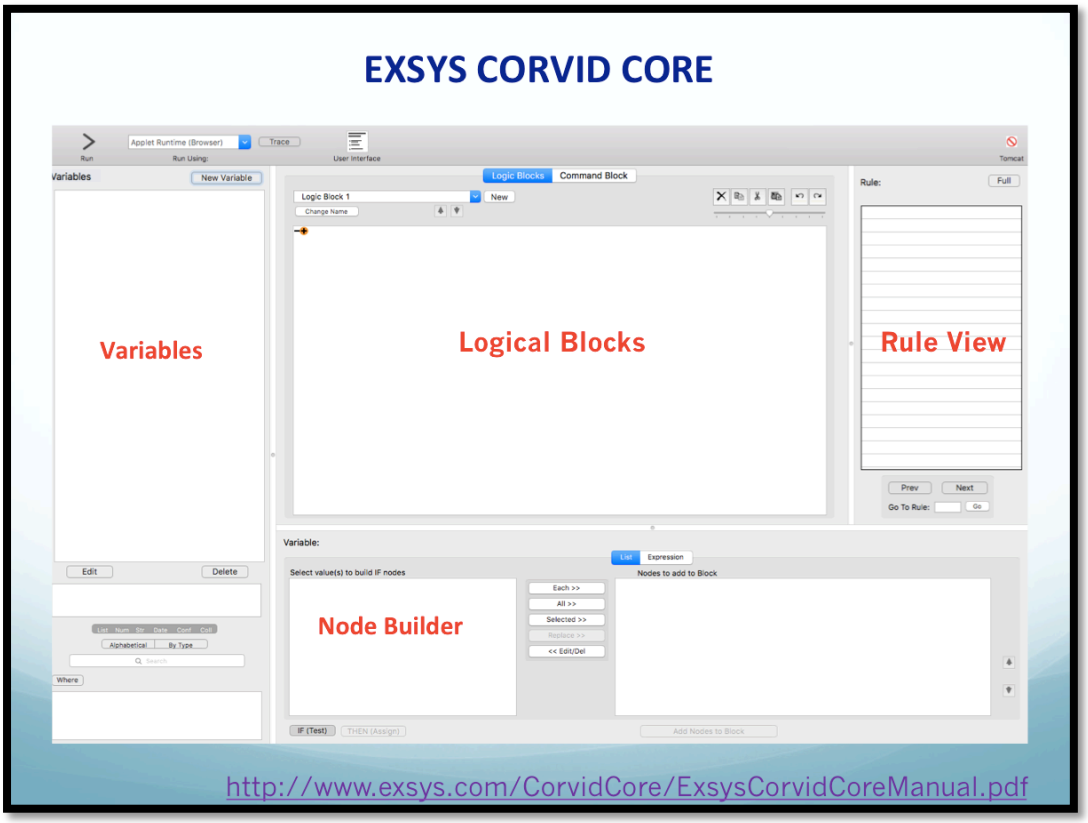


Figure 3-1 The main building blocks in Exsys Corvid Core

3.2 Rules and Knowledge Database

In continuation to the previous section, there are many types of knowledge representation methodologies that can be used to build clinical expert systems. The clinical decision for attachment selection in RPD can be very challenging even for expert clinicians. To choose the most accurate decision in this aspect of dentistry, a clinician must develop extensive knowledge of all factors that govern it based on the available literature as well as long trail of clinical experience in this field of dentistry.

The selection of an attachment depends on several factors resulting in different treatment processes. Overall 18 relevant factors for attachment selection in RPD were retrieved from published literature, dental catalogues and dental experts (Table 3-1to 3-8). The system is programmed to simulate expert clinicians, because the data is made up of knowledge that was extracted from experts. All-important factors are taken into consideration and matched with an accurate decision to formulate an appropriate treatment plan. This decision-making process is converted to the Exsys Corvid software language in the form of 'if/then' rules. For instance, a simple 'if/then' rule-based clinical decision-making would be represented.

Example Rule:

IF: patient medically stable
And
IF: abutment condition is good
And
IF: intra-coronal space more than 2.5 mm
And
IF: type of RPD is tooth- tooth support
And
IF: type of attachment is intra-coronal
And

IF: type of Attachment is Rigid
And
IF: the attachment is precision
THEN The decision is C&M McCollum Attachment (Figure3-2)

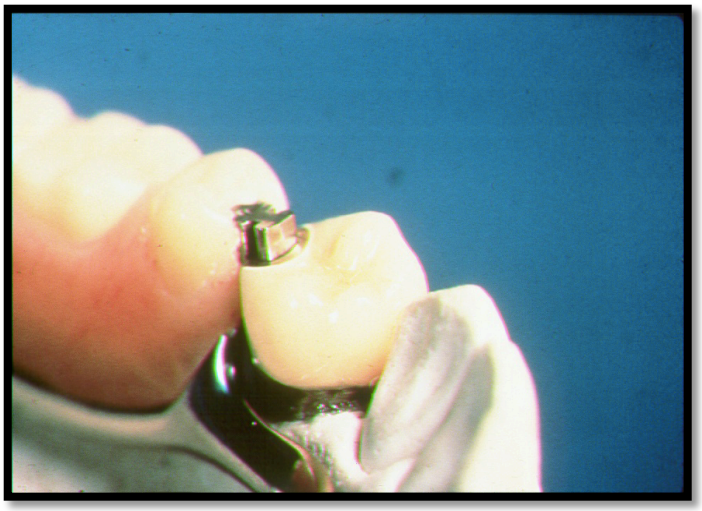


Figure 3-2 C&M McCollum Attachment. Photo Courtesy of Dr. Louis DiPede, Rutgers School of Dental Medicine, New Jersey.

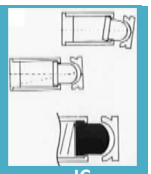
The rules are then combined to maintain the functionality of the decision-making process using varied operations such as 'AND', 'OR', 'NOT', and relational operations such as less than, less than or equal to, greater than, greater than or equal to.

The knowledge database retrieved from the literature and expert prosthodontics (Table 3-1 to 3-8). The software was successfully loaded with more than 100 rules representing many patients in need for attachments. After a carful discussion with the patient the clinician has to undergo RPD with attachment. The DDSS is designed mainly to provide dental students and unexperienced dentists with the required knowledge in order to select an appropriate attachment for patients. Dental clinicians, whether they are unexperienced or residents, could all utilize CDSS for assistance in terms of a treatment plan for selection an appropriate attachment.

Treatment planning in this instance relies on rules of the systems. Treatment recommendations include, an appropriate attachment, attachment provides, attachment required, sources of attachment and other additional information. The first step in this multi-phase process begins when the patient examination, in which the provider will review the patient's medical history, current status and dental history. Then the related clinical parameters such as, the location of the tooth, the condition of abutments (Table 2-8), the available intra-occlusion space, and the evaluation of type of RPD. After that, the clinician can start using the system. The system takes the user through a step-by-step process based on information entered. The Corvid Core system then comes up with a recommendation and a treatment plan.

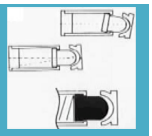
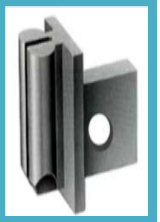
Treatment options are provided with justifying explanations, advice, recommendations that can help clinicians provide an accurate decision. In addition, the system comes up with specific information with regards to multiple types of attachments. The following sections will provide additional explanations concerning the methodology used the rules that should be followed, which are represented in a logical system flow. The following 8 tables describe the 18 factors that should be considered regarding the treatment planning of attachment RPD.

Table 3-1 Relevant Factors for Attachment Selection in RPD Design

Type of Attachment	Eliminate Visible Clasp	Tooth to Tooth Support	Tissue to Tooth Support	Intra-coronal	Extra-coronal	Rigid	Resilien	Type of Resilient	Crown need
 IC	✓	✓	✕	✓	✕	✕	✓	Class3 (Hinge)	✓
 Stern Lathch IP/C	✓	✓	✕	✓	✕	✓ Class 1	✕	✕	✓
 C&M McCollum	✓	✓	✕	✓	✕	✓ Class 1	✕	✕	✓
 Koral Bilok& Plasta	✓	✓	✕	✓	✕	✓ Class 1	✕	✕	✓
 PT-snap	✓	✓	✕	✓	✕	✓ Class 1	✕	✕	✓

√= yes, X= No

(Continued)

Type of Attachment	No Crown	Attachment Dimension	Inter Occlusal space	Metal to Metal	Metal to Plastic	Meta to Cast	Provide	Require	Source
 IC	✓	H=4 W=2 D=4	×	✓	✓	✓	R E	S Rest Re	S
 Stern Lathch IP/C	×	H=3.5 W=3.3 D=2.2	×	✓	×	×	R S Re E	×	S
 C&M McCollum	×	H=3.5 W=3.8 D=2.4	×	✓	×	×	R S Re E	×	S
 Korak Bilok& Plasta	×	H=3 W=3 D=3	×	×	✓	✓	R S Re E	×	S
 PT-snap	×	H=3.5 W=3.3 D=2.2	×	✓	×	×	R S Re E	×	S

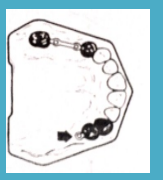
H= Height. W=FC Width, implies to the minimum faciolingual space necessary for fixed attachment component. D= Prep Depth, implies to the minimum depth of tooth structure needs for preparation of the attachment space.
√= yes, X= No
R= Retention. S= Support. Re= Reciprocation. E= Encirclement.
S= Strengold. P= Preat Corporation. B= Bredent. R= Rhein 83

Table 3-2 . Relevant Factors for Attachment Selection in RPD Design

Type of Attachment	Eliminate Visible Clasp	Tooth to Tooth Suppor	Tissue to Tooth Support	Intracoronal	Extracoronal	Rigid	Resilien	Type of Resilient	Crown need
 Micro ERA	✓	✕	✓	✕	✓	✕	✓	Class2 Vertical	✓
 ERA-Offest	✓	✕	✓	✕	✓	✕	✓	Class 2 Vertical	✓
 Standard Dalbo	✓	✕	✓	✕	✓	✕	✓	Class 4(H&V)	✓
 Mini Dalbo	✓	✕	✓	✕	✓	✕	✓	Class3 (Hinge)	✓
 Octolink Minature Anchor	✓	✕	✓	✕	✓	✕	✓	Class2 Vertical	✓

√= yes, X= No

(Continued)

Type of Attachment	No Crown	Attachment Dimension	Inter occlusal space	Metal to Metal	Metal to Plastic	Metal to Cast	Provide	Requires	Sources
 Micro ERA	×	H=2.5 W=2.2 D=Nor	8.5 mm	×	✓	✓	R E Re	S Rest	S
 ERA-Offest	×	Offset=2 .5Offset =4.5	9.5mm 10.5m m	×	✓	✓	R E Re	S Rest	S
 Standard Dalb	×	H= 6 W=3.5 D=1.5	12mm	✓	×	✓	R E Re	S Rest	S
 Mini Dalbo	×	H=4 W=3.4 D=1.6	10mm	✓	×	×	R S Re E	×	S
 Octolink Minature Anchor	×	H=4 W=2 D=Nor	10mm	×	✓	×	R S Re E	×	S

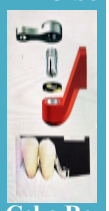
H= Height. W=FC Width, replies to minimum faciolingual space necessary for fixed attachment component. D= Prep Depth, replies to minimum depth of tooth structure that need it for preparation of the attachment space.

√= yes. X= No

R= Retention. S= Support. Re= Reciprocation. E= Encirclement.

S=Strengold. P= Preat Coporation. B= Bredent. R= Rhein 83

Table 3-3 . Relevant Factors for Attachment Selection in RPD Design

Type of Attachment	Eliminate Visible Clasp	Tooth to Tooth Support	Tissue to Tooth Support	Intracoronal	Extra-coronal	Rigid	Resilient	Type of Resilient	Crown need
 Preci-Clix	✓	✕	✓	✕	✓	✕	✓	Class 5 (R&V)	✓
 O-So	✓	✕	✓	✕	✓	✕	✓	Class 6	✓
 Ceka Rev M2	✓	✕	✓	✕	✓	✕	✓	Class 5	✓
 Ceka Revax M3	✓	✕	✓	✕	✓	✕	✓	Class 5	✓
 Preci Vertix AT	✓	✕	✓	✕	✓	✕	✓	Class 5	✓

√= yes, X= No

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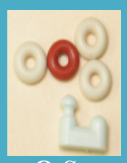
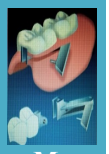
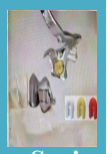
(Continued)

Type of Attachment	No Crown	Attachment Dimension	Inter occlusal pace	Metal to Metal	Metal to Plastic	Metal to Cast	Provide	Require	Source
 Preci-Clix	×	H=4	10mm	✓	✓	✓	R E Re	S Rest	P
 O-So	×	H=3 or 2.50 , Ø2.00	9mm	×	✓	✓	R E Re	S Rest	P
 Ceka Revax	×	H=3.80 Ø3.40	9.80mm	✓	×	✓	R E	S Rest Re	P
 Ceka Revax M3	×	H=4.3 Ø4.40	10.3mm	✓	×	×	R E Re	S Rest	P
 Preci Vertix AT	×	H=4.40 Ø2.60	10.40 mm	✓	✓	×	R E Re	S Rest	P

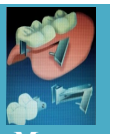
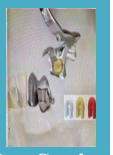
H= Height. W=FC Width, implies to the minimum faciolingual space necessary for fixed attachment component. D= Prep Depth, implies to the minimum depth of tooth structure that need it for preparation of the attachment space.
√= yes, X= No
R= Retention. S= Support. Re= Reciprocation. E= Encirclement.
S= Strengold. P= Preat Coporation. B= Bredent. R= Rhein 83

Table 3-4 . Relevant Factors for Attachment Selection in RPD Design

Type of Attachment	Eliminate Visible Clasp	Tooth to Tooth Support	Tissue to Tooth Support	Intra-coronal	Extra-coronal	Rigid	Resilient	Type of Resilient	Crown need
 Mays Unilateral	✓	✕	✓	✕	✓	✓ Class 2	✕	✕	✓
 Pre Sagix	✓	✕	✓	✕	✓	✕	✓	Class 5	✓
 OT stratey	✓	✕	✓	✕	✓	✕	✓	Class 4(H&V)	✓
 OT Cap	✓	✕	✓	✕	✓	✕	✓	Class 2 Vertical	✓
 OT Unilateral	✓	✕	✓	✕	✓	✕	✓	Class 2 Vertical	✓

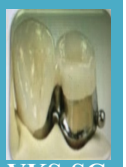
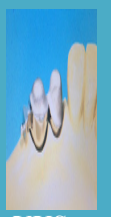
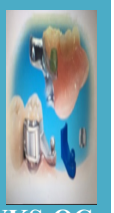
√= yes, X= No

(Continued)

Type of Attachment	No Crown	Attachment Dimension	Inter Occlusal space	Metal to Metal	Metal to Plastic	Metal to Cast	Provide	Require	Sources
 Mays Unilateral	×	H=3.0, Ø2.0	9mm	✓	×	×	R E Re	S Rest R	P
 Pre Sagix	×	H=4.10 Ø4.20	10.10mm	✓	×	×	R S Re E	×	P
 OT stratey	×	H=3.5mm	mm	✓	×	×	R E Re	S Rest	P
 OT Cap	×	H=3 mm	10mm	×	✓	×	R E Re	S Rest R	R
 OT Unilateral	×	H=4 mm	10mm	×	✓	✓	R E Re	S Rest R	R

H= Height. W=FC Width, replies to the minimum faciolingual space necessary for fixed attachment component. D= Prep Depth, replies to the minimum depth of tooth structure that need it for preparation of the attachment space.
√= yes, X= No
R= Retention. S= Support. Re= Reciprocation. E= Encirclement.
S= Strengold. P= Preat Coporation. B= Bredent. R= Rhein 83

Table 3-5 Relevant Factors for Attachment Selection in RPD Design

Type of Attachment	Eliminate Visible Clasp	Tooth to Tooth Suppor	Tissue to Tooth Suppor	Intracoronal	Extra-coronal	Rigid	Resilien	Type of Resilien	Crown need
 VS-3mini/SV	✓	✕	✓	✕	✓	✕	✓	Class2 Vertical	✓
 VKS-SG	✓	✕	✓	✕	✓	✕	✓	Class2 Vertical	✓
 VKS-SG/SV	✓	✕	✓	✕	✓	✕	✓	Class2 Vertical	✓
 VKS-OC	✓	✕	✓	✕	✓	✕	✓	Class 2 Vertical	✓
 Exchangable SG	✓	✕	✓	✕	✓	✕	✓	Class 2 Vertical	✓

√= yes, X= No

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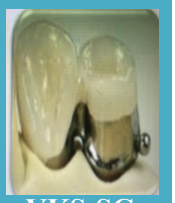
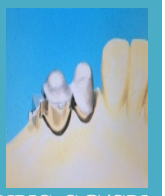
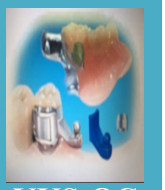
(Continued)

Type of Attachment	No Crown	Attachment Dimension	Inter Occlusal space	Metat o Meta	Metal to Plastic	Meta to Cast	Provide	Requires	Source
 VS-3mini/SV	×	H=6 W=2.6 D=2	12mm	✓	×	×	R E Re	S Rest	B
 VKS-SG	×	Ø2.2 1.7	9mm	✓	×	×	R Re E	S Rest	B
 VKS-SG/SV	×	Ø2.2 1.7	9mm	✓	×	×	R E Re	S Rest	B
 VKS-OC	×	Ø2.2 1.7	9mm	✓	×	×	R S Re E	×	B
 Exchangable SG	×	Ø2.2 1.7	9mm	✓	×	×	R E Re	S Rest	B

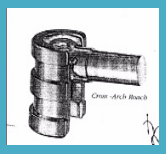
H= Height. W=FC Width, replies to the minimum faciolingual space necessary for fixed attachment component. D= Prep Depth, replies to the minimum depth of tooth structure that need it for preparation of the attachment space.
√= yes, X= No
R= Retention. S= Support. Re= Reciprocation. E= Encirclement.
S= Strengold, P= Preat Coporation, B= Bredent, R= Rhein 83

Table 3-6 Relevant Factors for Attachment Selection in RPD Design

Type of Attachment	Eliminate Visible Clasp	Tooth to Tooth Support	Tissue to Tooth Suppor t	Intracoronal	Extracoronal	Rigid	Resilien	Type of Resilient	Crown need
 Bil ®Plasta	✓	✓	✕	✓	✕	✓ Class 1	✕	✕	✓
 CrossArch - Roach	✓	✕	✓	✓	✕	✕	✓	Class 4 H&V	✓
 Comi Snap	✓	✓	✕	✓	✕	✓ Class 1	✕	✕	✓
 ERA(Std)	✓	✕	✓	✕	✓	✕	✓	Class 2 Vertica	✓
 ERA-RV	✓	✕	✓	✕	✓	✕	✓	Class 2 Vertical	✓

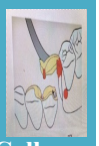
√= yes, X= No

(Continued)

Type of Attachment	No Crown	Attachment Dimension	Intra occlusa space	Metal to Metal	Metal to Plastic	Metal o Cast	Provide	Require	Sources
 Bil ® Plasta	×	H=3 W=3 D=3	×	×	✓	×	R S Re E	×	S
 Cross Arch-Roach	✓	H=4 W=4.5 D=4.5	×	✓	×	✓	R Re E	S Rest	S
 Comi-Snap	×	H=5.2 W=4.4 D=2.7	×	✓	×	×	R S Re E	×	S
 ERA (Std)	×	H=4 W=2 D= Nor	10 mm	×	✓	×	R E Re	S Rest	S
 ERA-RV	×	H=3.5 W=2.8 D=Nor	9.5 mm	×	✓	✓	R E Re	S Rest	S

H= Height. W=FC Width, implies to the minimum faciolingual space necessary for fixed attachment component. D= Prep Depth, implies to the minimum depth of tooth structure that need for preparation of the attachment space. D=Nor, Normal Crown
√= yes, X= No
R= Retention. S= Support. Re= Reciprocation. E= Encirclement.
S=Strengold, P= Preat Coporation, B= Bredent, R= Rhein 83

Table 3-7 Relevant Factors for Attachment Selection in RPD Design

Type of Attachment	Eliminate Visible Clasp	Tooth to Tooth Support	Tissue to Tooth Suppor	Intracoronal	Extracoronal	Rigid	Resilien	Type of Resilient	Crown need
 Hadern Vertical	✓	✕	✓	✕	✓	✕	✓	Class 2 Vertical	✓
 McCollum	✓	✓	✕	✓	✕	✓	✕	✕	✓
 FR	✓	✓	✕	✓	✕	✓	✕	✕	✓
 Preci-Vertex "p"	✓	✕	✓	✕	✓	✕	✓	Class2 Vertical	✓
 Preci 52	✓	✕	✓	✕	✓	✕	✓	Class 4(H&V)	✓

√= yes, X= No

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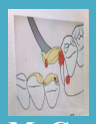
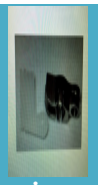
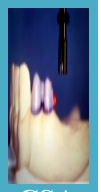
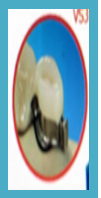
(Continued)

.

Type of Attachment	No Crown	Attachment Dimension	Inter occlusal space	Metal to Metal	Metal to Plastic	Metal to Cast	Provide	Require	Sources
 Hadern Vertical	×	H=4.5 W=1.8 D=Nor	10.5mm	×	✓	✓	R E Re	S	S
 McCo llum	×	H=3.5mm	×	✓	×	✓	Re E R S	×	S
 FR	×	H=7 W=3.2 D=1.7	13mm	✓	✓	×	R S Re E	×	P
 Preci-Vertex "p"	×	H=3 Ø3.30, 4.10	10mm	✓	✓	✓	R E Re	S "Rest"	P
 Preci 52	×	H=3.40 Ø3.40	9.40mm	×	✓	✓	R E Re	S "Rest"	P

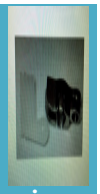
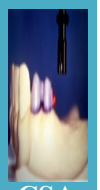
H= Height. W=FC Width, implies to the minimum faciolingual space necessary for fixed attachment component. D= Prep Depth, implies to the minimum depth of tooth structure that need for preparation of the attachment space. D=Nor, Normal Crown
√= yes, X= No
R= Retention. S= Support. Re= Reciprocation. E= Encirclement.
S=Strengold, P= Preat Coporation, B= Bredent, R= Rhein 83

Table 3-8 Relevant Factors for Attachment Selection in RPD Design

Type of Attachment	Eliminate Visible Clasp	Tooth to Tooth Support	Tissue to Tooth Suppor	Intracoronal	Extracoronal	Rigid	Resilien	Type of Resilient	Crown need
 American Mini	✓	✕	✓	✕	✓	✕	✓	Class 2 Vertical	✓
 CSA	✓	✕	✓	✕	✓	✕	✓	Class 4(H&V)	✓
 VS-3 mini	✓	✕	✓	✕	✓	✕	✓	Class 2 Vertical	✓

√= yes, X= No

(Continued)

Type of Attachment	No Crown	Attachment dimension	Intraocclusal space	Metal to Metal	Metal to plastic	Metal to Cast	Provide	Require	Source
 American Mini	×	H=3 Ø3.5	10mm	×	✓	✓	R E Re	S "Rest	P
 CSA	×	H=3.10 Ø4.30	10mm	✓	✓	×	R E Re	S "Rest	P
 VS-3 mini	×	H=6 W=3 D=2	12mm	✓	×	✓	R S Re E	×	R

H= Height. W=FC Width, implies to the minimum faciolingual space necessary for fixed attachment component, D= Prep Depth, implies to the minimum depth of tooth structure that need it for preparation of the attachment space.
√= yes, X= No
R= Retention. S= Support. Re= Reciprocation. E= Encirclement.
S= Strengold. P= Preat Coporation. B= Bredent. R= Rhein 83

3.3 Inference Engine:

The third component of the Exsys Corvid System is the inference engine, which analyses the heuristic rules from the knowledge database and produces the advice that allows the user to make a decision. Our proposed system operates in a way in which a series of multiple-choice questions are presented to the end-users. It then analyses the provided case' specific information in order to determine what additional information is needed to make a final decision. The engine will extract set rules within the database, so that the user is not presented with unnecessary questions. The engine will also make sure that all respective areas are examined in detail, so that adequate information is collected. This will decrease the number of choices that pose as solutions, making it easier to find the correct option. Once all the required data is entered into the system, it will reach definitive conclusion relative to specific domain. These conclusions may include several treatment recommendations that are ranked in the order according to their suitability and fulfillment of a given patient' needs.

There are two inference methods that are used in running any decision support system these are, the backward chaining method and the forward chaining method. Backward chaining is a goal driven method that starts from the goal and works backward. It is usually used when the system is intended to test if a certain goal is true or not by testing all the rules starting from the goal and moving backward. Consequently, backward chaining is defined as a goal-oriented method that processes rules in a backward direction. Going through a chain of goals starting from the highest to the lowest level. This is repeatedly until lower level goals are satisfied or eliminated from the chain and the data becomes

available from the user end. The process is upward moving upward to achieve high- level goals and provide relevant recommendations or instructions to the end-users. A list of goals controls which rules are chosen and utilized, therefore, this inference methodology is described as the goal-driven method.

On the other hand, the forward chaining is a data-driven inference method. The user begins by entering the data into the system. The data is extracted using logic from built-in rules or from users' input, to reach a conclusion and solve the issue. Amongst the advantages of forward chaining method is the availability of new data that directs the process to new inferences. This is most beneficial for problems of dynamic nature in which conditions are expected to change over time[174]. In the contrary, backward chaining is adequate for clinical domains that may have many unknowns field from the beginning. Therefore, they need to be carefully investigated to come to a valid conclusion.

In a dental setting, the forward chaining method is more applicable and user-friendly in contrast to its counterpart. Especially for dental students, newly skilled dentists, and recent specialty graduates. This is due to the fact that clinical investigational data are readily known to end-users given that the system is pointing them in the right direction. This is done through a series of logically sequenced and easily structured multiple-choice questions, to ensure system's objectivity. The forward chaining inference method has an advantage over the backward chaining method if the needed data is available upfront. This will allow the system to test the following rules and easily produce the conclusion.

For this reason, DDSS utilized forward chaining inference methodology to provide adequate treatment plans, and recommendations relative to clinical decision-making for attachment selection in RPD design. . The rules in our proposed system were structured in a unique and clinically relevant approach to avoid redundancy. Therefore, our proposed system utilizes the forward chaining inference technique only to ensure its simplicity and objectivity. As well as avoid potential complexity and possible of its outcome

3.4 System Design and Development:

DDSS for attachment selection in RPD was developed using the forward chaining inference method. About 18 relevant factors for attachment selection in RPD were retrieved from published literature, dental catalogues and dental experts. This database was then incorporated into the system. The system contains more than100 rules that will be retrieved according user interaction. The variable section of the system contains all relevant factors for attachment selection, all type of attachments, and additional information that will help clinician to avoid any decision errors. The logic block of the system connects between the different variables to produce a large decision tree.

To maintain copyrights of DDSS, a custom title screen was designed using Photoshop software that includes the title of the system, diagrammatic representation of our knowledge-based system that are supported by the evidence based dentistry (literature data, clinical experience and dental catalogues), the name of the developer, the year in which the system is developed, and a declaimer was added to notify the public that such system

should only be used by residents, general dentists and specialists only

(Figure 3-3).

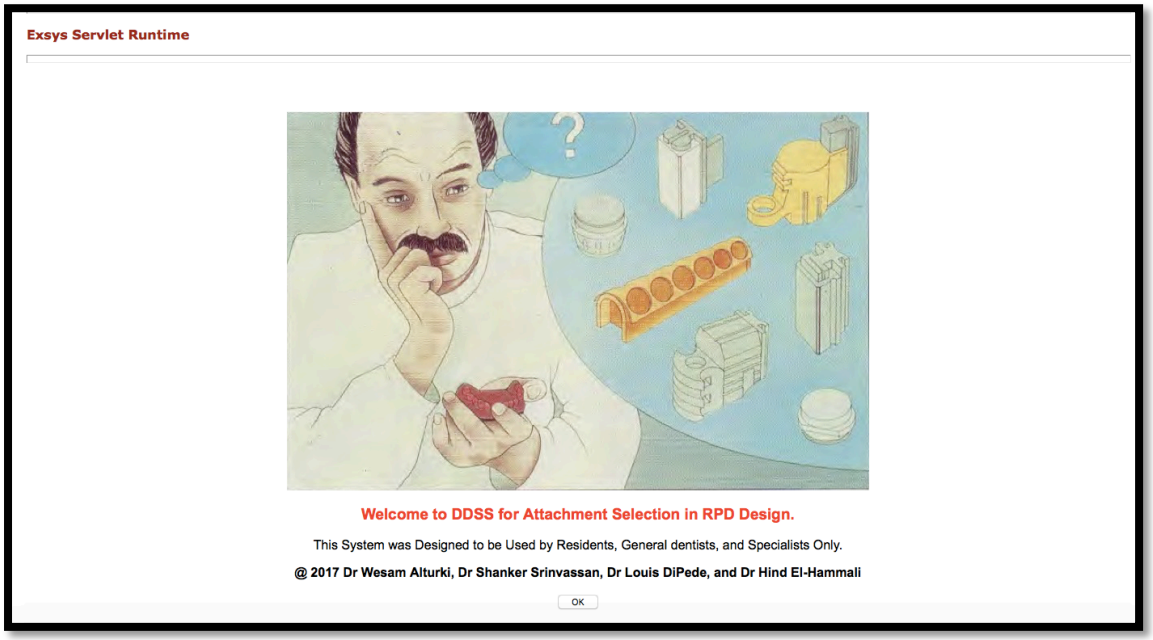


Figure 3-3 Title screen was designed to match our system's objectives and promote critical thinking process upon treatment planning of selection an attachment.

The screen was designed an "OK" button to initiate the system when the user is ready.

3.4.1 Logical system flow:

DDSS aids in building an accurate treatment plan. It can be logically expressed as a system output phase as shown in (Figure 3-4). The front page of the system contains a simple description of general flow chart, to help the user understand how the system works. Any dental professional, either resident, dental student or a licensed dentist could use the system for assistance with treatment planning of selection an appropriate attachment. After a patient is examined the next step in the process in the process is for the provider to collect

patients' dental and medical history. After the system chains through rules in the knowledge base to determine which type of attachment is suitable for specific patients (18 relevant factors for attachment selection) entered by provide. If the basic information is sufficient enough to make a decision (known as the primary evaluation phase) given the presented conditions, the patient becomes ineligible or eligible for a certain attachment. If a patient is medically unstable or they don not have enough intra-occlusion space such as , (intraocclusion space is less than 7 mm in case of Kennedy class I or class II), or abutments that are used for attachments are in poor prognosis, so DDSS jumps to the end of the process flow to recommend if the patient is ineligible for the attachment. However, if the patient is medically stable with enough intra-occlusion space, and their abutment condition is in good prognosis. The system prompts the provider to enter additional relevant information (known as secondary evaluation phase) as it may be based on patient's specific situation and rules in the knowledge base.

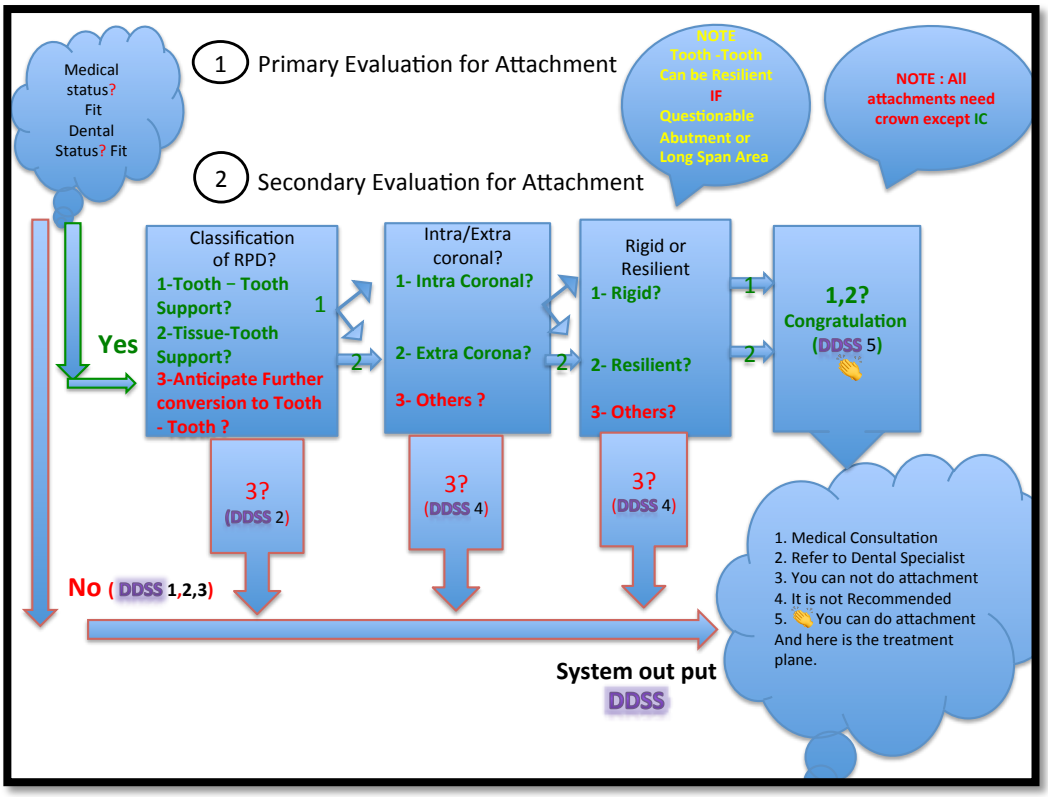


Figure 3-4 The front page of the system's user interface.

3.4.2 Primary Evaluation Phase:

The most important function of the primary evaluation phase is the collection of basic patient data and the comprehensive evaluation of numerous clinical parameters relative to the tooth itself as shown in (Table2-8), and the inter-occlusion space (the existing space between opposing dentition and soft tissue). The sole objective of this phase is to determine if the patient is eligible for attachment or not. The primary evaluation phase in treatment planning is data collection that focuses on the patient's current medical status and dental status as shown in (Figure 3-5).

The rules relative of dental status evaluation included: abutments condition and intra-occlusion space available in patients' oral cavity as shown in (Figure 3-5).

The patient is questioned regarding his/her current medical status in which available answers are either medically fit or not. In the case of the patients' fit, the provider can proceed through the system and go to secondary evaluation. In case a medical condition is reported potential risks or complications are anticipated before, during or after dental treatment visits, DDSS does not proceed to the next (secondary evaluation) phase and instead jumps to the end of the workflow to provide a recommendation. DDSS recommends the clinician to refer the patient to a physician for medical consultation and request for medical clearance, because in this time the patient is ineligible for attachment.

Values for both theses' variables are determined by prompting the user for accurate information. Only after primary evaluation phase is determined dose DDSS proceed to the secondary evaluation phase. Otherwise, it jumps to the end of the process flow to recommend that the patient is not eligible for attachment, since the patient is not medically stable.

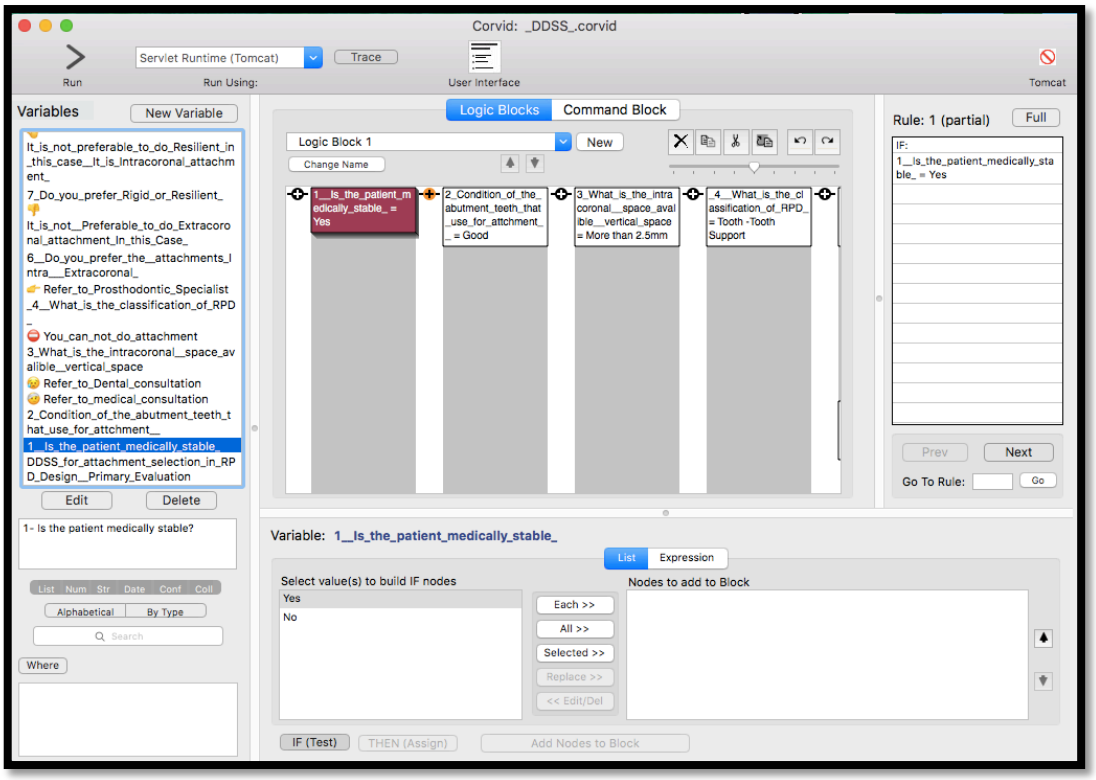


Figure 3-5 Screenshot of logic block containing rules pertaining to primary evaluation phase.

Another important factor of primary evaluation is intra-occlusion space. It is important to carefully measure the intra-occlusion space available in the patients' oral cavity, especially with extra-coronal attachment. Space is important while deciding the attachment to be used. The space available vertically, bucco-lingually and mesio-distally play a critical role in attachment selection. Vertical space refers to the existing space between opposing dentition and soft tissue (Figure 3-6). It is measured from opposing teeth to soft tissue.

Vertical space= 1mm + length of attachment + length of restorative material.

1mm is the existing space between of attachment and soft tissues.

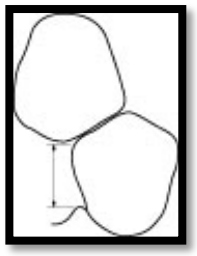


Figure 3-6 Vertical space

In the case that the Intra-occlusion space is more than 8.5 mm, the provider can proceed through the system and go to secondary evaluation, but in case of intra-occlusion space less 6 mm, DDSS does not proceed to the next (secondary evaluation) phase and instead jumps to the end of the workflow to provide a recommendation. The clinical decision is "Patient not eligible for attachment". So, the clinician cannot do the attachment, since there is not enough intra-occlusion space to host the two parts of the attachment (Figure 3-7)

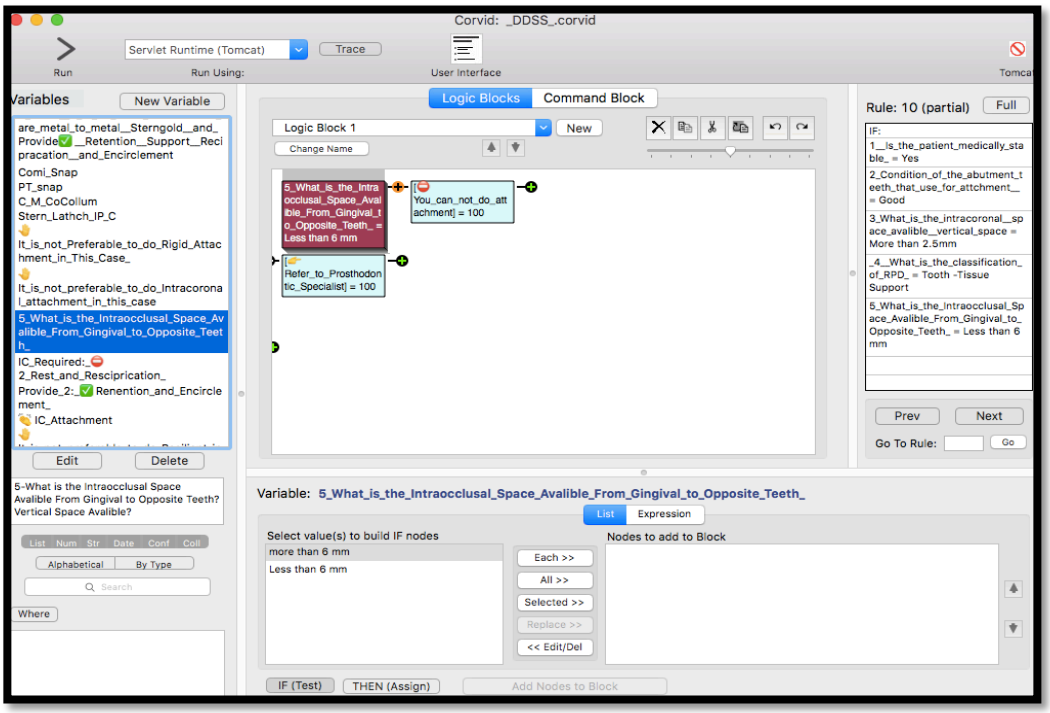


Figure 3-7 Screenshot of logic block representing Intra- occlusion space rule.

3.4.3 Secondary Evaluation Phase:

The most important function of this phase is to determine the specific attachment for the eligible patients by evaluating all relevant factors to determine the most optimal treatment recommendation. It is based on the comprehensive evaluation of numerous clinical parameters. There are some criteria that help the clinician to decide the appropriate attachment based on the individual needs of the case.

1-Type of prosthesis

2- location

3- Function

4-Manufacture

5- Space

6-Sources.

These evaluation processes will result in an accurate treatment recommendation. The rules relative to the type of prosthesis evaluation included type of RPD. According to Kennedy classification (1952), RPD is classified as:

Class I: bilateral edentulous areas located posterior to the remaining natural teeth.

Class II: Unilateral edentulous area located posterior to the remaining natural teeth.

Class III: Unilateral edentulous area with natural teeth both anterior and posterior to it.

Class IV: Single, bilateral edentulous area located anterior to remaining natural teeth.

As shown in the header image in the system Figure (3-8).

Based on the type of prosthesis, RPD is classified in DDSS as:

1- Tooth-Tooth support, which represented class, III or IV.

2- Tissue-Tooth support, which represented class II or I.

3- Anticipate further conversion to tooth –tooth, which express tooth-tooth support today, tissue-tooth support tomorrow.

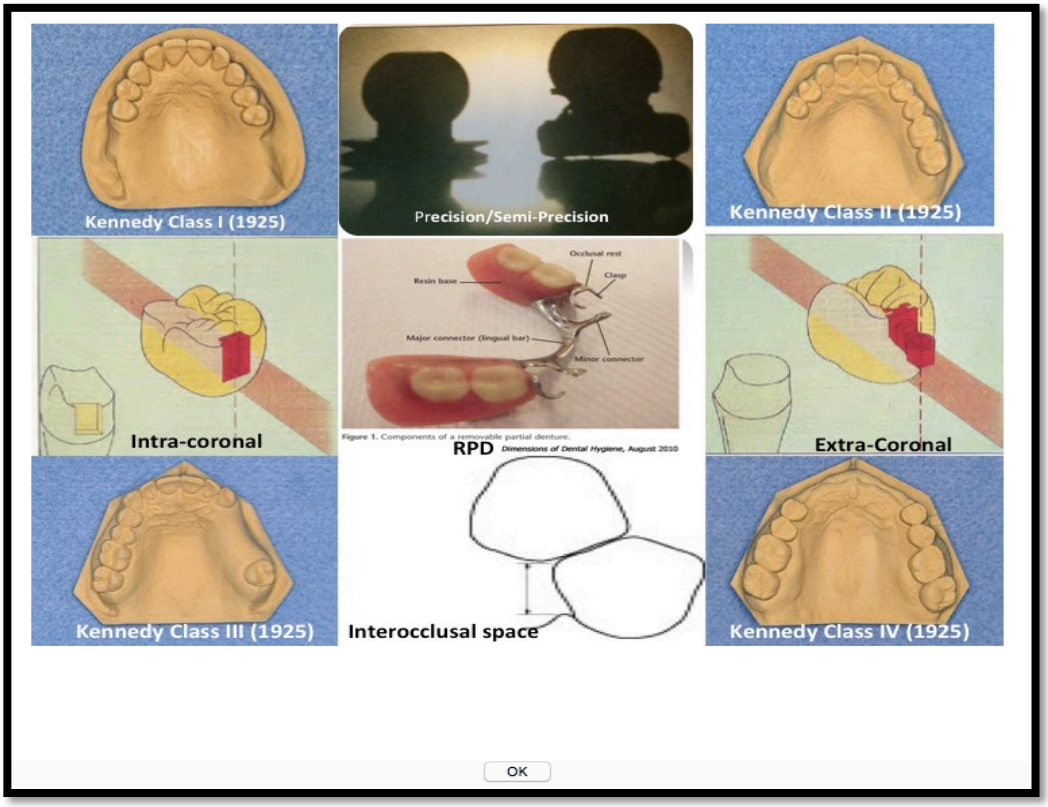


Figure 3-8 . Header image was displayed at top of each screen in DDSS. Header image illustrated all primary and secondary evaluation for selection an appropriate attachment in RPD design in the system.

The sequential order of these factors represents its weight and importance in dental decision making of selecting an appropriate attachment. The provider is required to perform careful clinical examinations to be able to accurately respond to the system's prompts in this step of evaluation. In fact, the majority of dental students, general dentists, and recent specialty graduates are trained adequately to collect information in this regard (Figure 3-9). Inaccurate data collection during this phase may results in misinterpretation and faulty treatment recommendation outcomes

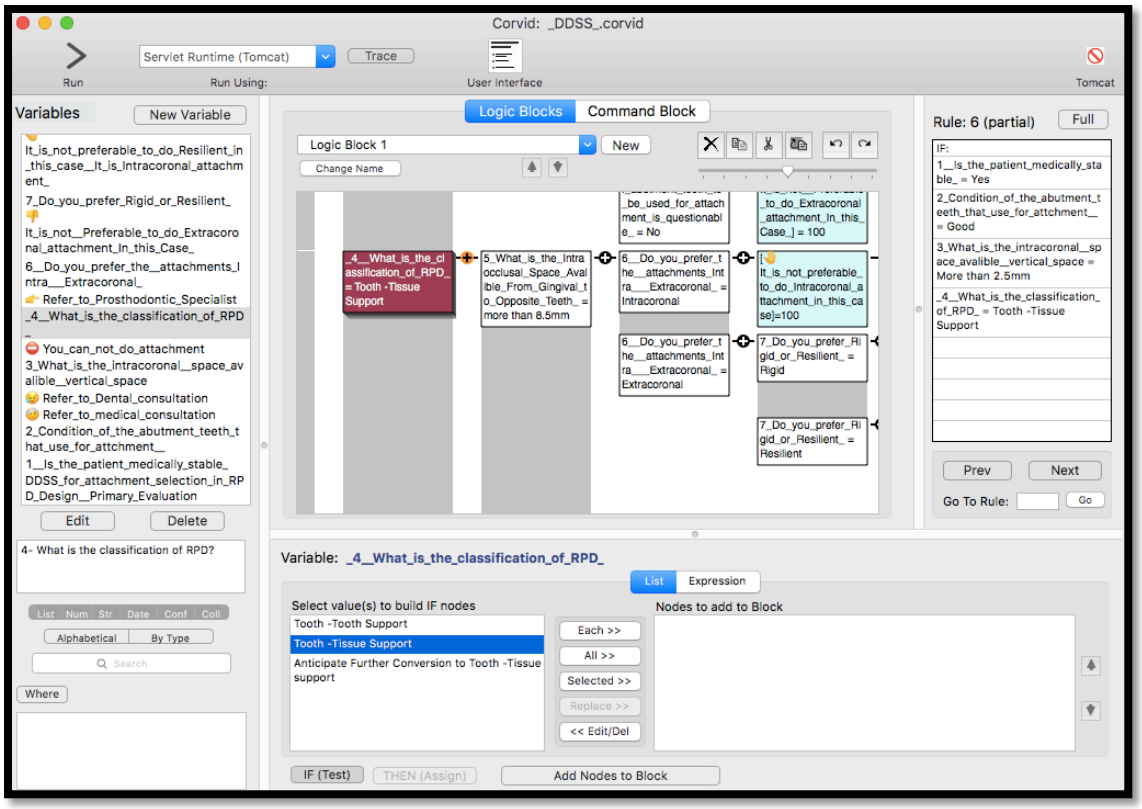


Figure 3-9 screenshot of logical block represented type of RPD in second evaluation phase

Based on the location, attachments are divided into: Intra-coronal or extra-coronal as shown in (Figure 3-10). Extra-coronal refers to any prefabricated attachment (for an RPD) in which the matrix and patrix components are positioned outside the normal contour of the abutment tooth, while Intra-coronal refers to any prefabricated attachment in which the matrix and patrix are positioned within the normal contour of the abutment tooth, it usually requires a box preparation to allow the attachment to fit within the crown contour. Since all intra-coronal attachments are non-resilient, double abutting is recommended.

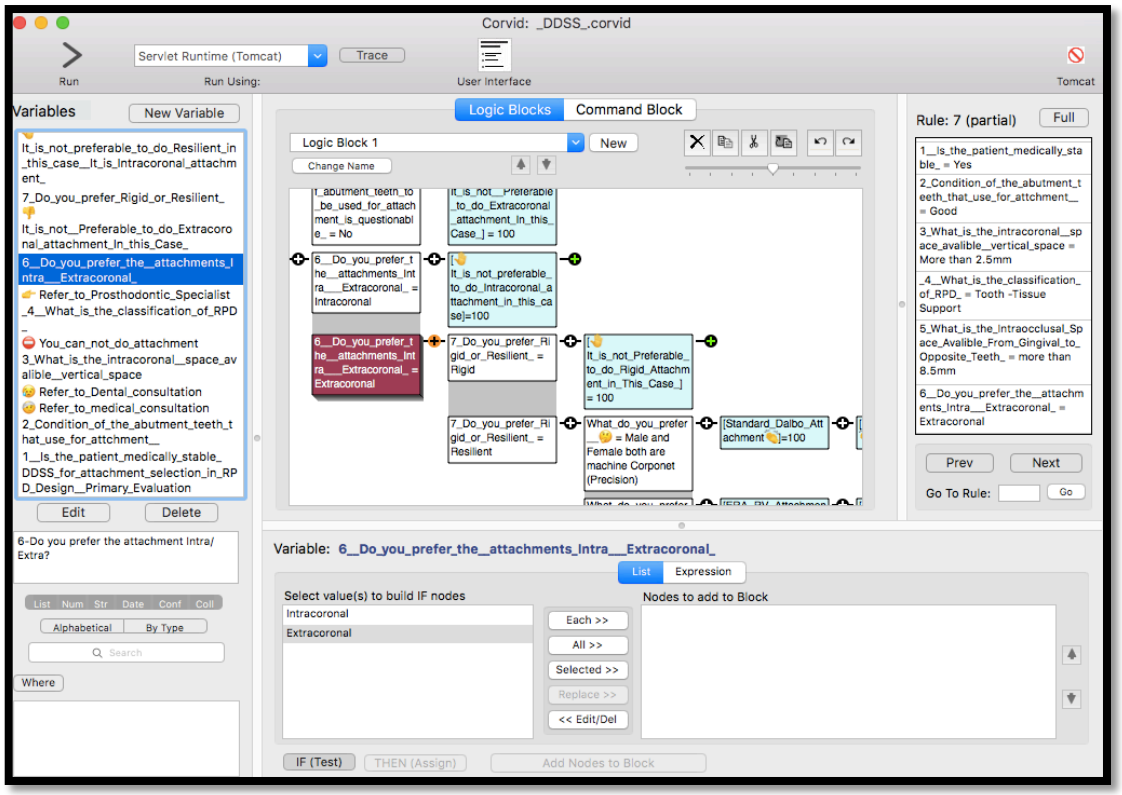


Figure 3-10 screenshot of logical block represented location of attachment in second evaluation phase

In addition, based on the function, attachments are divided into ‘rigid’ or ‘resilient’. Tooth- tissue support attachments are considered resilient. They are categorized into 5 classifications ranging from vertical to universal resiliency. A resilient attachment gives a tooth / soft tissue borne RPD sufficient mechanical flexure to withstand the variations in seating of the prosthesis due to deformations in the mucosa and underlying tissues, without placing excessive stress on the abutment. However, tooth-tooth support restorations are considered rigid. They are classified in to two types, ‘non-locked’ and ‘locked’.

Furthermore, the manufacture attachments are divided to a ‘precision’ or a s’emi-precision’. A precision attachment is fabricated from milled alloys and tolerances are

within. 01mm. They are non-resilient and intra-coronal, while a semi-precision attachment is fabricated by direst casting of wax, plastic, or refractory patterns. It is considered semi-precision because a semi- precision fabrication is subject to inconsistent water/powder ratios; burn out temperatures and other variables. They are less costly, esay to fabricate, extra-coronal and resilient.

Space considerations also are important while deciding the attachment to be used as discussed in section 2.4.5 and Figure 2-38. Bucco-lingually and mesio-distally and vertical space of intra-coronal attachment play a critical role in attachment selection. Buccal-lingual or labila-lingual space is also critical, especially in an intra-coronal attachment. It should be measured in an accurate manner to avoid over contouring the restoration. 1mm should be added to buccal-lingual measurements for the metal precision attachment to allow for the casting alloy[28]. Mesial-Distal measurements are important for intra-coronal attachment, because a box preparation is required. The best way to know how much reduction is necessary is to prepare the study model. It is a good idea for the clinician to have the intra-coronal female part available while preparing the abutment.

The minimum intra-coronal space needs for intra-coronal attachment is not less than 2.5mm (Figure 3-11)

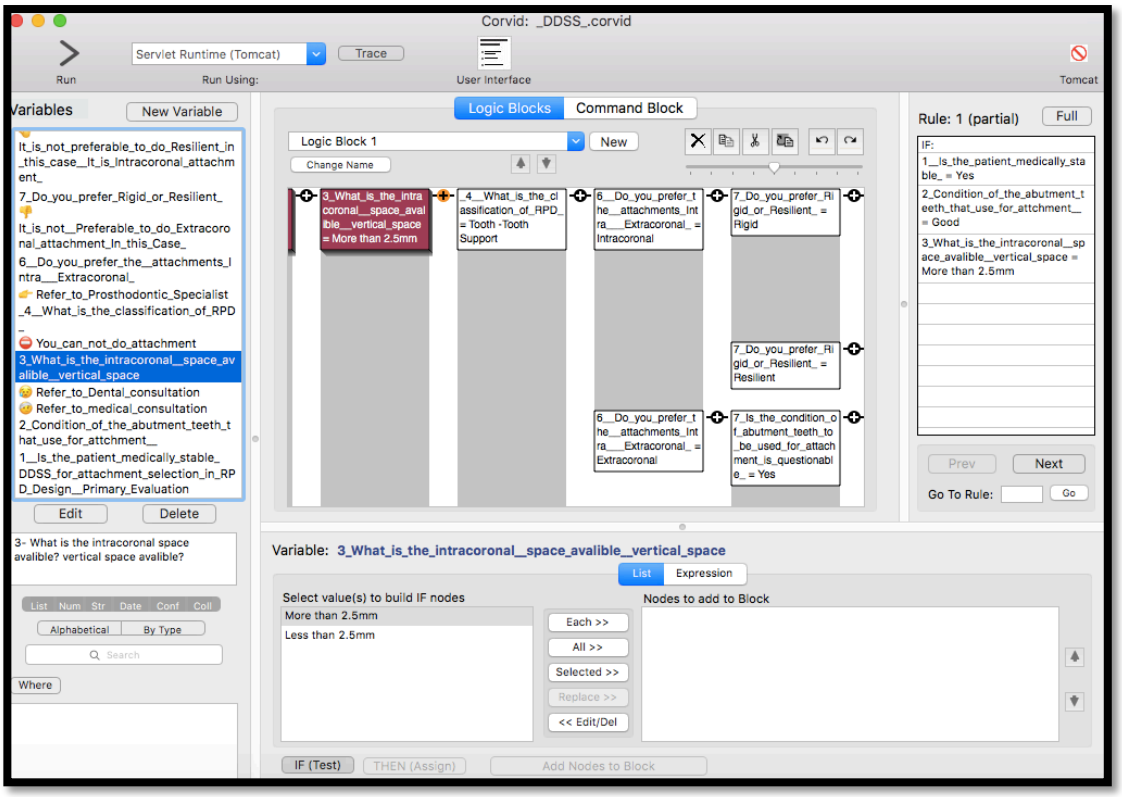


Figure 3-11 screenshot of logical block represented the minimum intracoronal space available to receive an attachment.

Sources of attachments in DSSS were selected from Sterngold, Preat Corporation, Bredent, and Rhein 83.

3.4.4 System output phase (confidence Variable):

This is the final step of the workflow system. It makes the final decision (treatment plan). All relevant factors in the primary evaluation phase are invoked first, followed by the relevant factors in the secondary evaluation phase, and then system will give you treatment plan (known as output phase). However, in some cases, DDSS jumps directly to the end of the process (system output phase). For example: the system recommends, medical consultation since the patient is medically unstable (Figure 3-12). This phase provides the clinician with a treatment plan, recommendations, important notes, and some

additional information that helps user to avoid any possible errors. (Figure 3-13) represents an example of the results screen generated by the expert system at the end of treatment planning session.

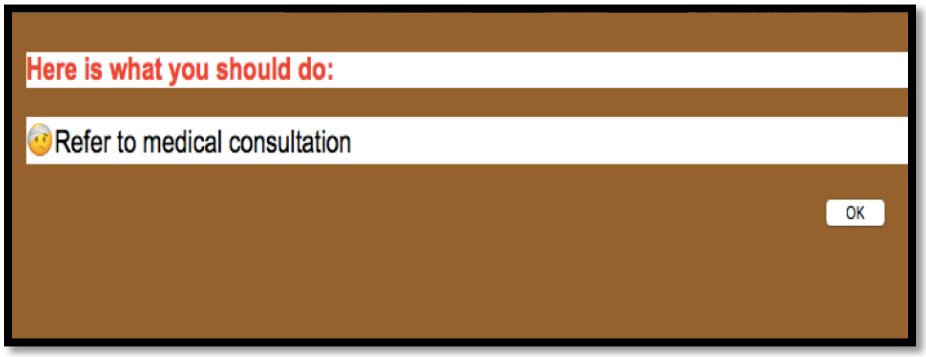


Figure 3-12 Result screen generated by the expert system at the end of treatment planning session. This screen shows system jumps to the end of process flow.

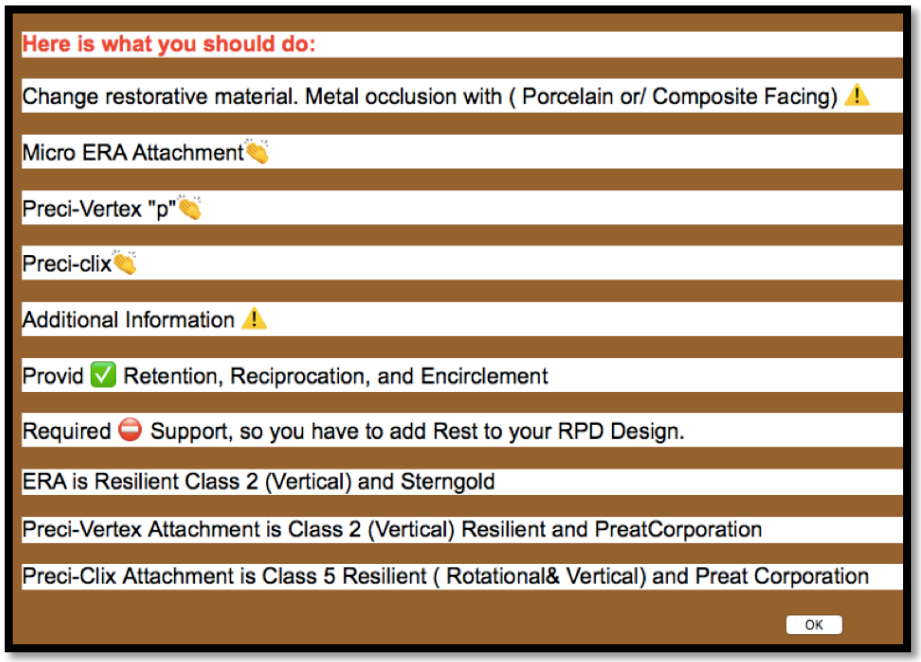


Figure 3-13 : Result screen generated by the expert system shows treatment plan, system recommendation and additional important information

System output phase has 5 main decisions; all these decisions are put into the system under 'Confidence Variables' and given 'confidence values' in the rules. Every decision

relies on a number of relevant factors. These factors are represented by 'if statement' in both primary evaluation and secondly evaluation phase are put into the system. Decision number 5 (which says that the clinician should do the attachment) is subdivision in to 38 types of attachments. You have to take in to consideration many factors in order to decide which one of 38 attachments is suitable for each case or if it is possible to do more than one attachment for the case. For this reason, the various of relevant independent factors in the secondary evaluation phase play an important role to select which attachment is suitable for every specific case.

Although we have adopted a complex and multi-factorial comprehensive evaluation approach, we were able to tabulate the set of rules criteria that must be considered for accurate treatment recommendations in this aspect of decision-making.

The current section will discuss in detail the confidence variables. These variables are usually one of multiple possible options that the system will select from. Confidence variable can be assigned a 'Confidence Value' that determines if they are an appropriate or inappropriate recommendation, based on the end user's input. The numeric value assigned indicates if that choice is 'good' or 'bad' based on the logic of rule and the end user's input. Corvid provides many ways to work with confidence values to select the best recommendation(s) to give. The recommendations from the Corvid system based on literature evidence and clinician's expertise.

For example:

IF……Then X is a good choice

IF……Then X should not be used

IF……Then X is better than Y. (X and Y should be Confidence Variables)

Confidence Variables are generally the best type of variable to use if there are many possible items, and each item is being selected or rejected based on multiple rules and factors. Knowledge and factors that are involved in this aspect of decision- making were taken into considerations. Confidence variables were assigned positive or negative numerical values based on their impact on the treatment outcomes. The scoring system used was highly dependent on the concept of evidence-based dental practice guidelines where clinical expert and literature knowledge were taken into consideration. A specific confidence variable may be assigned multiple values by many rules.

These values are combined from all the rules that fire to determine the overall confidence value for the variable- which determines if the variable is the best recommendation. This system was designed to perform forward chaining only to maintain simplicity of the system and its outcomes. It should be identified that the system starts with a cumulative score (confidence variable) of 100 proceeds. A large positive value implies the appropriate decision, and will assure that a variable is in the recommendation, while a large negative value implies an inappropriate decision and eliminate a variable from the results.

The actual value to assign can be any number; the values should be scaled appropriately relative to each other. If the rule should slightly increase the likelihood of a particular

confidence variable, it can be giving a few points. If it is a more significant factor, it could increase it by many points. If the confident variable is not appropriate should be assigned similar negative values to decrease its likelihood. At the end of a run, the confidence variable(s) with the highest overall score will be displayed in the results as the 'best' based on the input.

In DDSS, the confidence variables are assigned a value in the 'THEN' part. This is indicated by the name of the confidence variable in square brackets, and an '=' followed by the value to be assigned. For example:

IF patient is medically stable: Yes **then** {you can do attachment}=90

IF patient is medically stable: NO **then** {you can do attachment}= -90

IF existing space between opposing dentition and soft tissue is ≤ 6mm **then** {You can do extra-coronal attachment} =-90

IF existing space between opposing dentition and soft tissue is more than 6mm and less than 8.5mm **then** {Change restoration material, this is the only way to do extra-coronal attachment in this case} = 80

IF existing space between opposing dentition and soft tissue ≥8.5mm **then** {You can do extra-coronal attachment} =90

- If the overall value is 90 = It is highly recommended (an appropriate decision). A large positive value will assure that a variable is in the recommendation
- If the overall value is -90 = It is not recommended (not appropriate decision). A large negative value is given to eliminate it of other values it may get from other

rules.

- If overall value is 80 = It is recommended (appropriate decision). In previous example attachment highly recommended if you change restoration material to metal occlusion. This is the only way to do extra-coronal attachment in this case.

The rules assigns a high confidence variable making sure it will have an overall high score. The system now has rules defined in terms of variables, and in a form that will make them easy to add into Corvid. Very large positive values will assure that a variable is in the recommendations, while large negative value will eliminate a variable from the results.[18] (www.exsys.com)

In our system the recommendations are arranged in order. They include the confidence value they received. However, it is not necessary to have every rule assign a value to each confidence variable. Only assign values when there is a logical reason to do so. "confidence" and "probability". According to Exsys Corvid Core Advanced Tutorial 'confidence variable' have many uses and support various ways to combine the values assigned to confidence variables. While true statistical probability formulas are supported, in practice these are not often used because most real world problems do not have the needed underlying statistical data or strictly follow the rules of probability. Unless you are building a system related to dice, card, coin tosses or some problem where there is very good statistical data, you are going to use "confidence" rather than true " probability"". If the confidence value in the system was not wanted, selecting the "Only display Prompt" checkbox when we built the custom screen command to display the confidence variables

could have left it off.

Confidence factors can be used more than true probability in many situations. This is what experts use everyday to say " I think the cause of problem is x . This is not a true probability statement; they are expression their confidence in a particular outcome based on expert experience and knowledge-not mathematical probability". The most common way to use confidence variables is to combine the implication of several mutually independent factors. That is the way it will be used in this system. It is considers as medical status, space available as independent factors that combine to an overall recommendation. In some cases, one or other of these may become the controlling factor and govern the decision-but in most cases they combine to build an overall recommendation.

3.5 System validation:

After system design and development, the system cannot be established online until validation. The system validation assures that the system was developed correctly and included all the factors for attachment selection in RPD Design. All the relative factors and rules for attachment selection are inserted into the system. The system is validated by nine expert prosthodontics. Some prosthodontics are faculty members in the School of Dental Medicine, Rutgers University, Newark, New Jersey, others are from NYU and IOWI University. The prosthodontics reviewed the actual system on the computer and reviewed all the rules of the relevant factors for attachment selection tables. After that, the prosthodontics gave their opinion about the system and the rules that need to be modified, added or removed from the system. Also, the prosthodontics filled a questionnaire about

their impression of the system and their degree of agreement with the system rules (Appendix A), The questionnaire contains ten questions that have a 5-point Likert scale from "strongly disagree" to "strongly agree".

1 Strongly Disagree	2 Disagree	3 Neutral	4 Agree	5 Strongly Agree

The survey questions are: validation items are

1. Do you feel there is a need to develop a system to guide the inexperienced clinician in selecting an appropriate attachment for RPD.

2. The system is practical simple to use

3. The system is a useful tool to assist dentists to select attachment in RPD design

4. The system is a good tool for training dental students

5. The system is a good tool for continuing dental education courses

6. The system contains most of the relevant factors for attachment selection in RPD design.

7. The system provides appropriate recommendation for attachment selection in RPD

8. The system provides insightful information about different types of attachments

9. Would the system be useful in a private practice setting in addition to a school setting?

10. Your overall, do you think this is a valuable system?

The questionnaire items were statistically analyzed using IBM® SPSS Statistics software. Our proposal system assessed the reliability and internal consistency of the questionnaire items using Cronbach's Alpha test.

4 CHAPTER IV RESULTS:

4.1 Clinical scenarios and case studies

The new clinical decision support system was successfully developed using Exsys Corvid Core software. The knowledge is based of the system was developed using dental experts' guidelines and were retrieved from the literature. The software was successfully loaded with 100 rules representing many different clinical scenarios for a variety of attachment types. Based on the information entered by the user, the system arrives at a recommendations and treatment plan.

In this section, we presented three case examples of the system; these examples demonstrate the ability of the DDSS to form a treatment decision based on expert and evidence-based guidelines. These three clinical scenarios demonstrate the process and steps required for providers to complete, upon practical application of the system in common clinical settings.

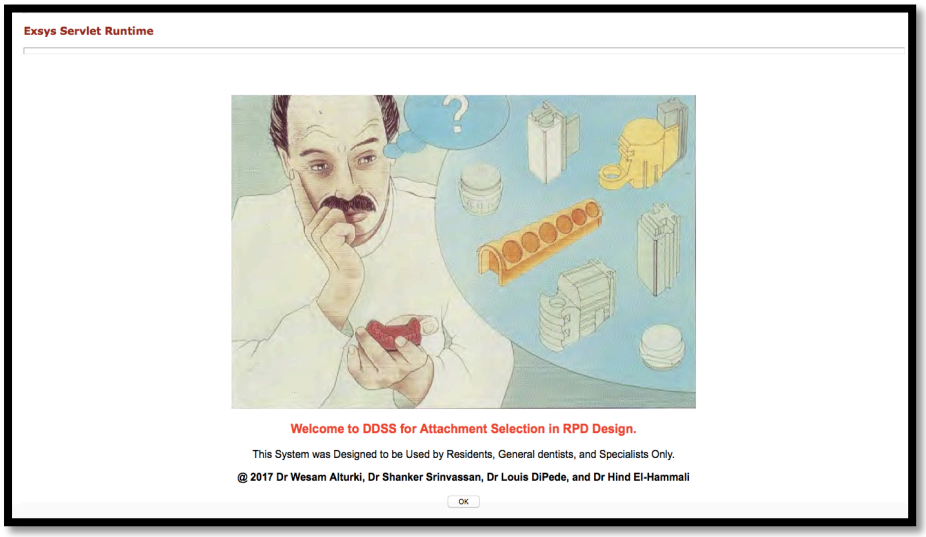
Clinical Scenario#1

Patient complains of bilateral missing teeth in the mandibular arch. A review of the medical status indicates that the patient is medically stable. On clinical evaluation the patient is missing the mandibular left canine, and all mandibular molars and premolars. The remaining mandibular anterior teeth are in good condition and meet the minimum requirements to be used as abutments for removable partial denture (RPD) attachments. The patient has high treatment expectations and esthetic demands. The patient demonstrates good oral hygiene, a high degree of compliance with instructions and more

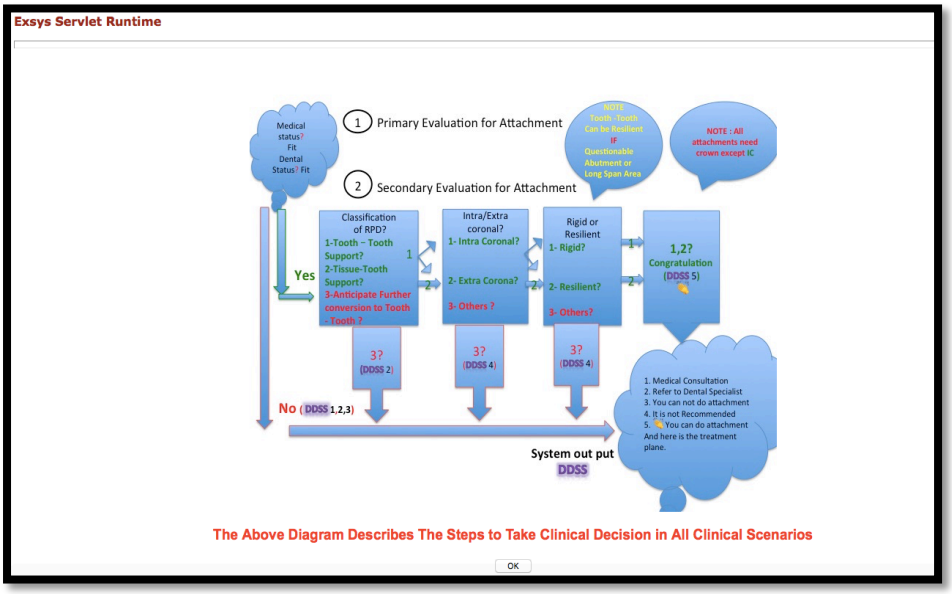
than adequate financial means. The treatment plan consists of replacing the missing mandibular teeth with a RPD and splinted crowns for the remaining anterior teeth. The use of attachment will therefore be considered

DDSS Steps Showing Decision-Making Process and Treatment Plan Recommendation: Firstly, system will display title and front screen then proceed into the system

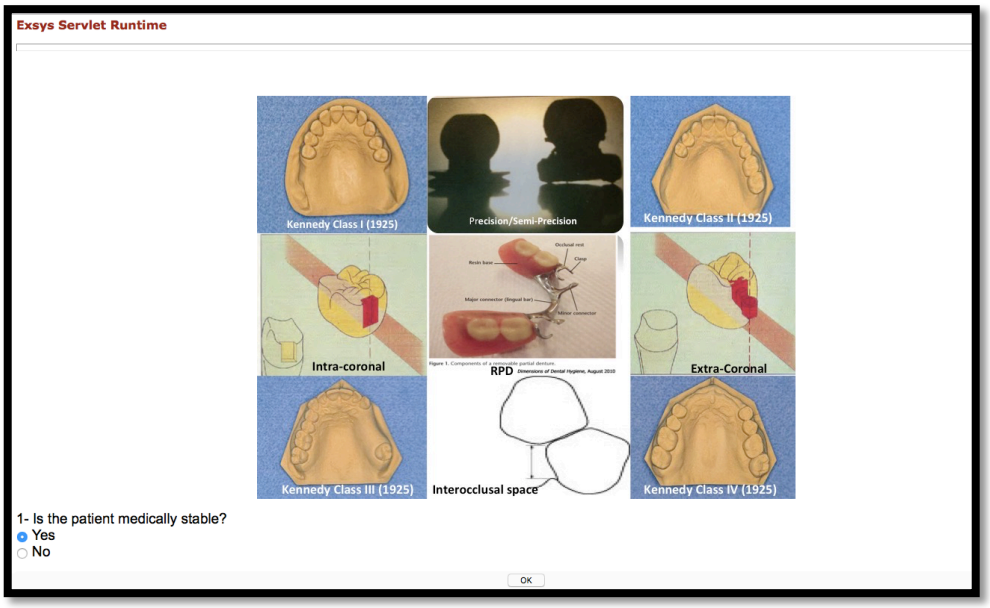
Title screen:



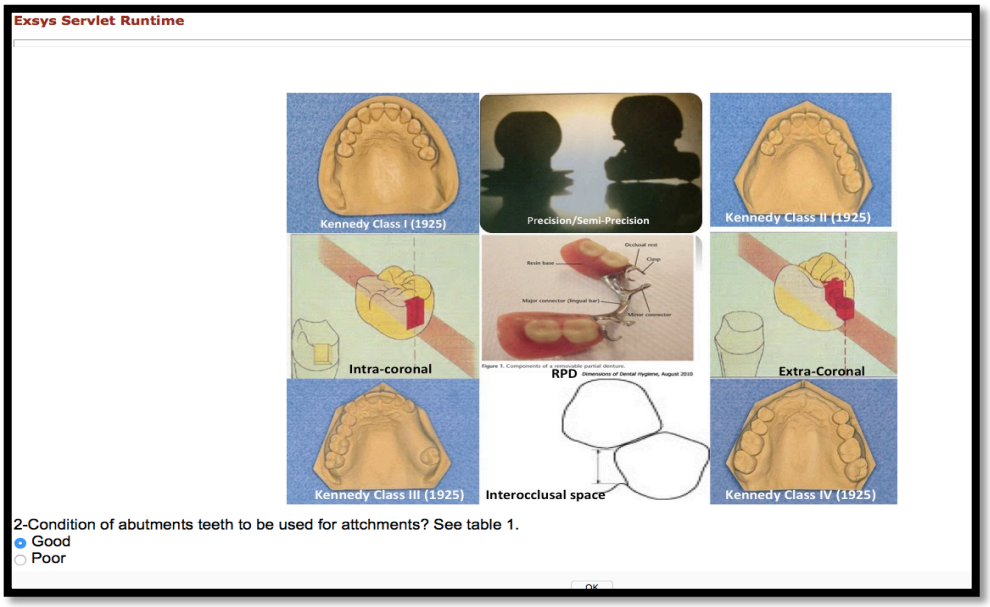
Front-page screen:



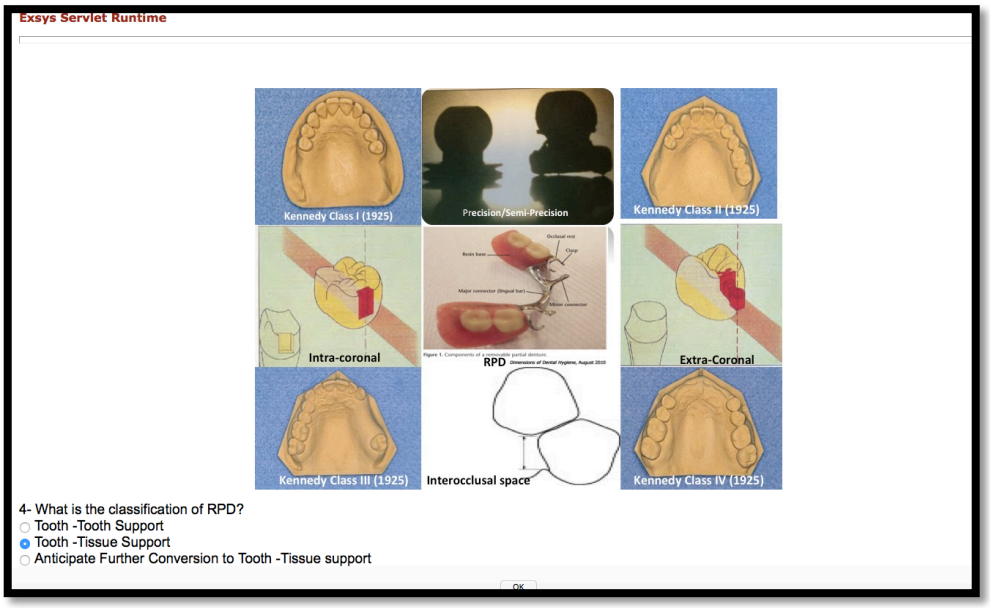
Step 1:


Exsys Servlet Runtime
Kennedy Class I (1925)
Precision/Semi-Precision
Kennedy Class II (1925)
Intra-coronal
RPD
Extra-Coronal
Kennedy Class III (1925)
Interocclusal space
Kennedy Class IV (1925)
1- Is the patient medically stable?
Yes
No
OK

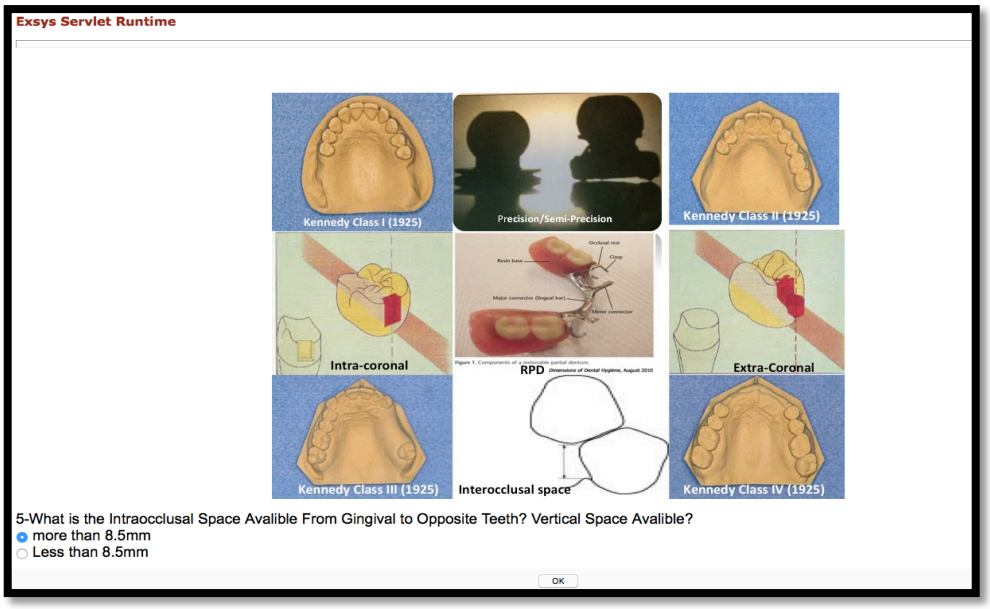
Step 2:


Exsys Servlet Runtime
Kennedy Class I (1925)
Precision/Semi-Precision
Kennedy Class II (1925)
Intra-coronal
RPD
Extra-Coronal
Kennedy Class III (1925)
Interocclusal space
Kennedy Class IV (1925)
2-Condition of abutments teeth to be used for attchments? See table 1.
Good
Poor

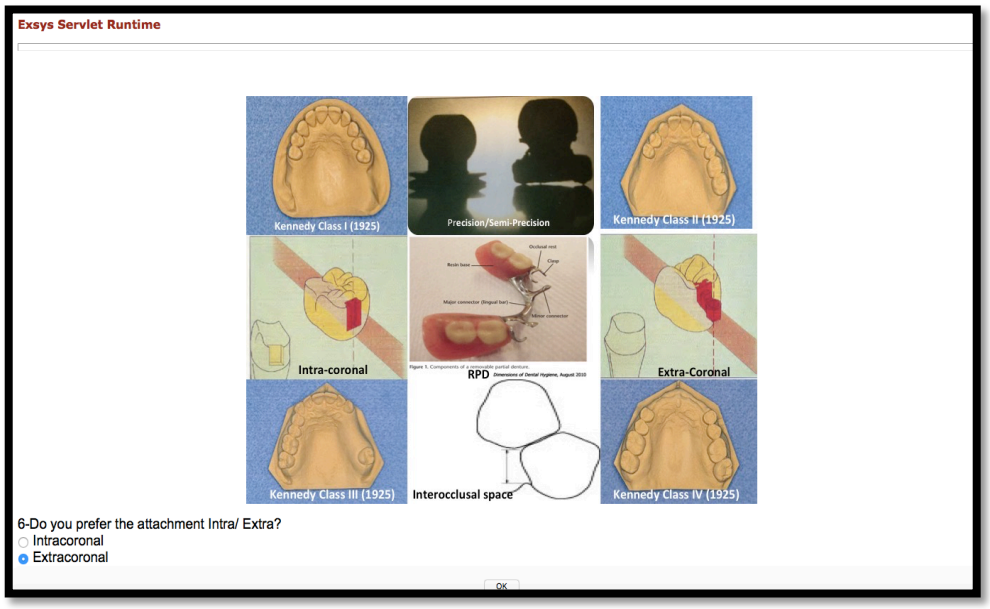
Step 3:


Exsys Servlet Runtime
Kennedy Class I (1925)
Precision/Semi-Precision
Kennedy Class II (1925)
Intra-coronal
RPD
Extra-Coronal
Kennedy Class III (1925)
Interocclusal space
Kennedy Class IV (1925)
4- What is the classification of RPD?
Tooth -Tooth Support
Tooth -Tissue Support
Anticipate Further Conversion to Tooth -Tissue support
OK

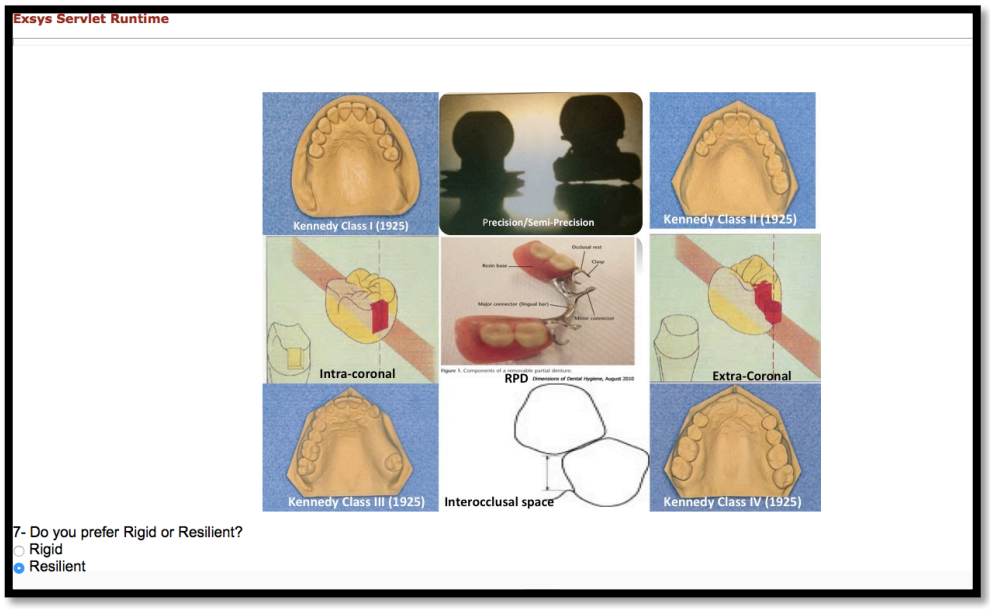
Step 4:


Exsys Servlet Runtime
Kennedy Class I (1925)
Precision/Semi-Precision
Kennedy Class II (1925)
Intra-coronal
RPD
Extra-Coronal
Kennedy Class III (1925)
Interocclusal space
Kennedy Class IV (1925)
5-What is the Intraocclusal Space Avalible From Gingival to Opposite Teeth? Vertical Space Avalible?
more than 8.5mm
Less than 8.5mm
OK

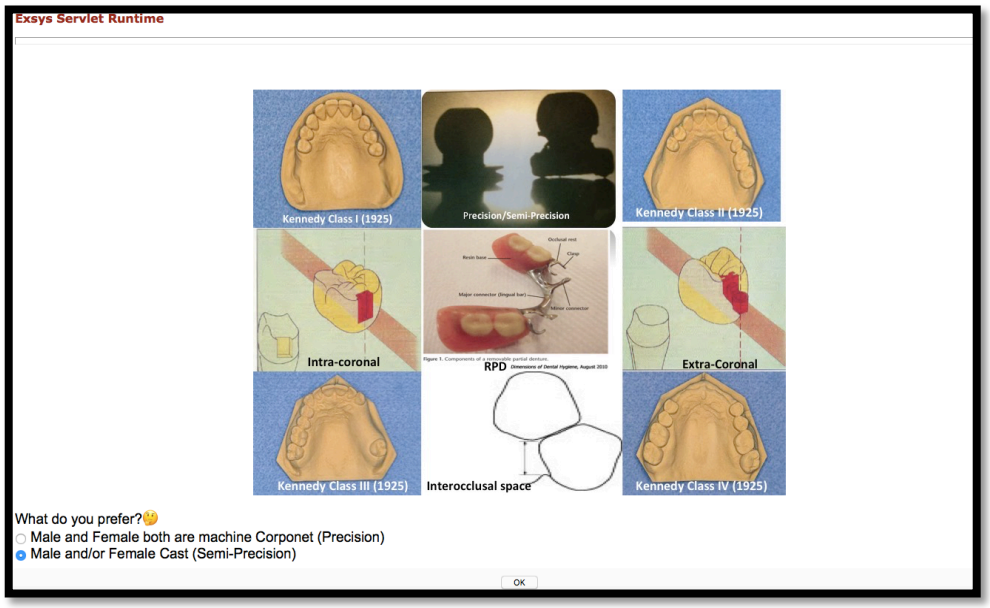
Step 5:


Exsys Servlet Runtime
Kennedy Class I (1925)
Precision/Semi-Precision
Kennedy Class II (1925)
Intra-coronal
RPD
Extra-Coronal
Kennedy Class III (1925)
Interocclusal space
Kennedy Class IV (1925)
6-Do you prefer the attachment Intra/ Extra?
Intracoronal
Extracoronal
OK

Step 6:


Exsys Servlet Runtime
Kennedy Class I (1925)
Precision/Semi-Precision
Kennedy Class II (1925)
Intra-coronal
RPD
Extra-Coronal
Kennedy Class III (1925)
Interocclusal space
Kennedy Class IV (1925)
7- Do you prefer Rigid or Resilient?
Rigid
Resilient

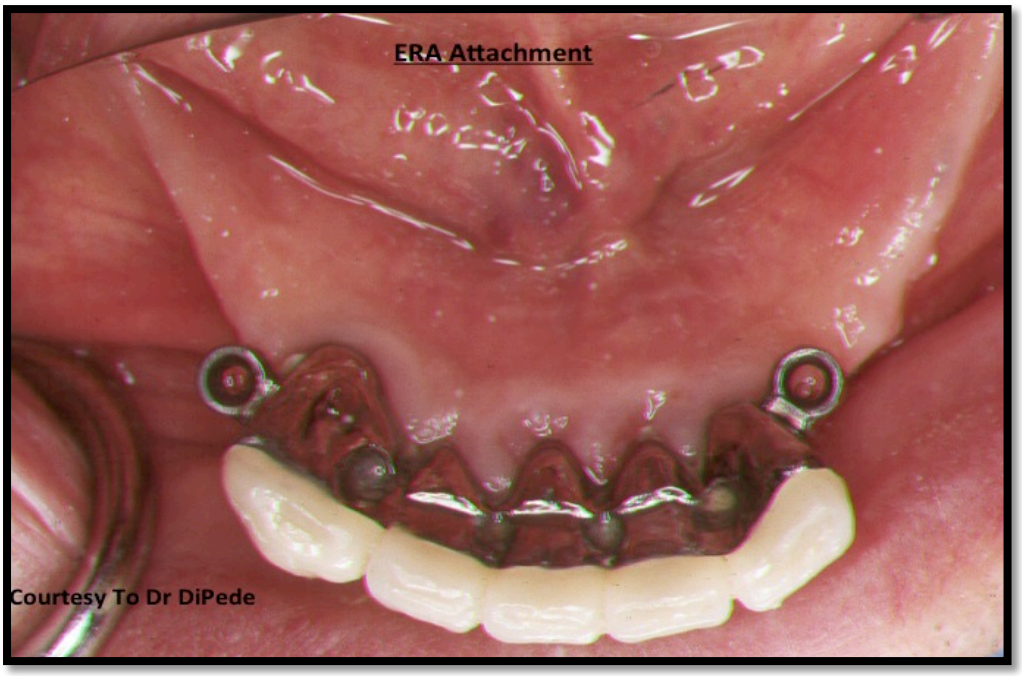
Step 7:



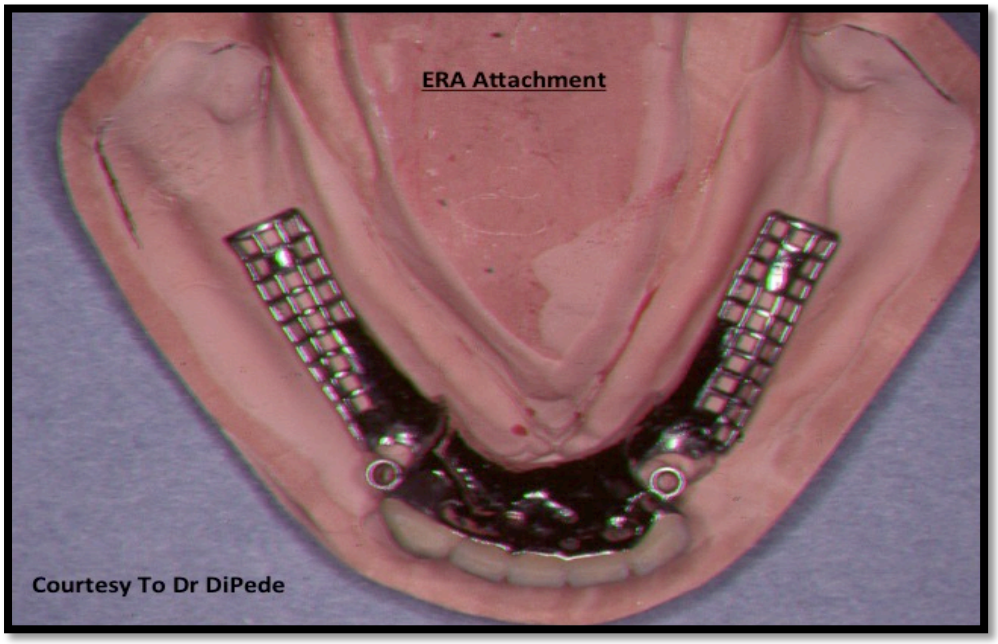
Result Screen 1:

Result Screen 2:

Result Screen 3:

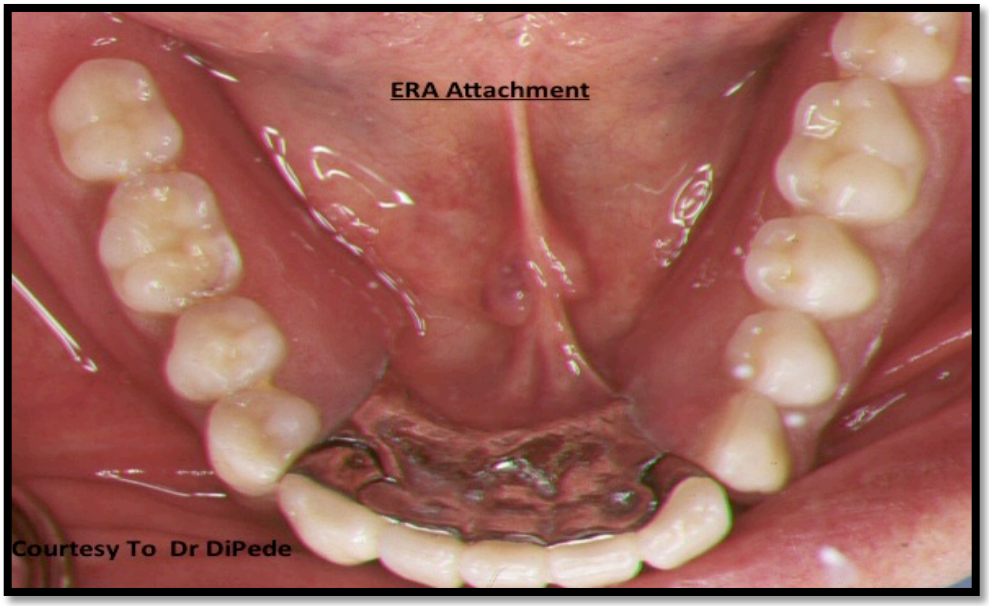


Result Screen 4:

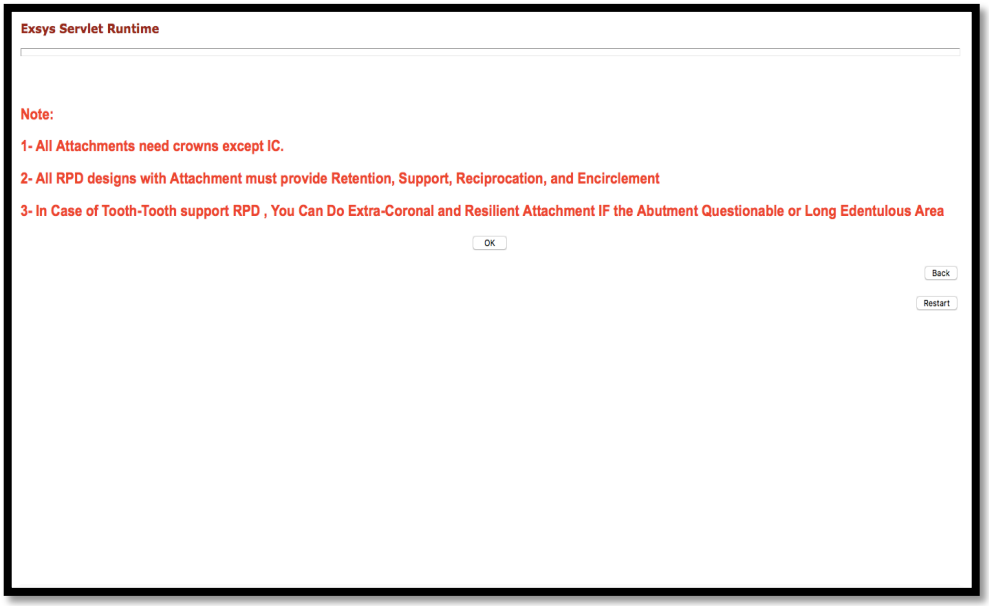


Result Screen 5:

Result Screen 6:



Result Screen 7:

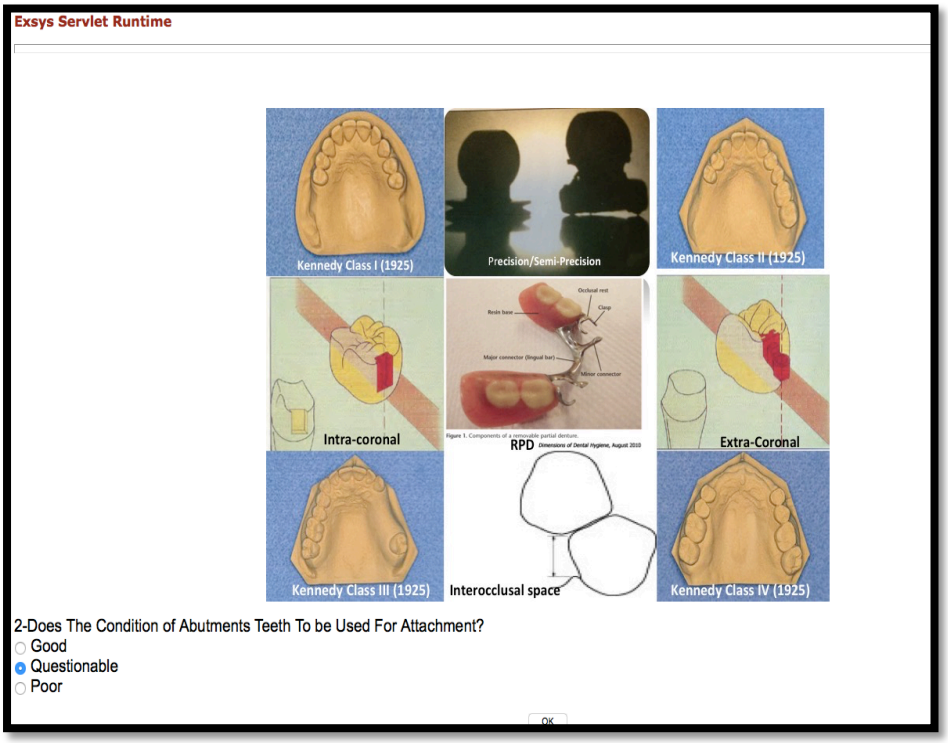


Clinical Scenario# 2

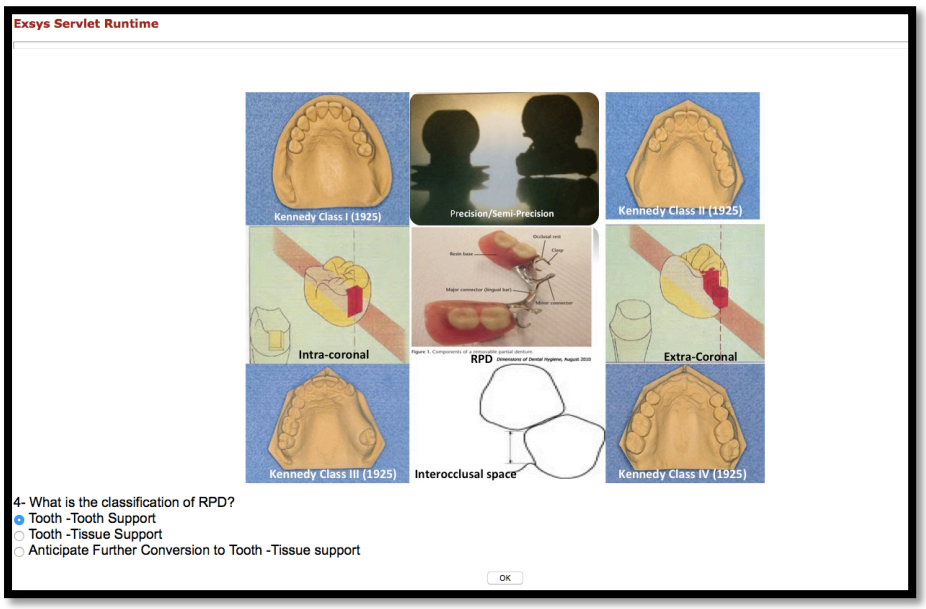
A Patient presented to the dental office with a complaint of: “I have missing teeth and want to replace them”. A review of medical status revealed no significant medical condition. On clinical examination, the patient has missing maxillary right first molar, left second molar and maxillary premolars bilaterally. A non-serviceable fixed partial denture is in place restoring the anterior sextant. The maxillary left canine is heavily restored and has a questionable prognosis. The maxillary right canine exhibits moderate bone loss and is likewise questionable. Other teeth are in good condition. The interocclusal space is less than 8.5mm. The patient demonstrates good oral hygiene and is compliant with instructions. The patient has high treatment expectations and esthetic demands. After a discussion with the patient, the treatment plan will consist of replacing tmissing teeth with a RPD, and a new fixed partial denture for the anterior teeth. The use of attachments will therefore be considered.

DDSS Steps Showing Decision-Making Process and Final Treatment Plan Recommendation: Firstly, the system will display the title and front screen then primary evaluation phase as showed in case 1, after that:

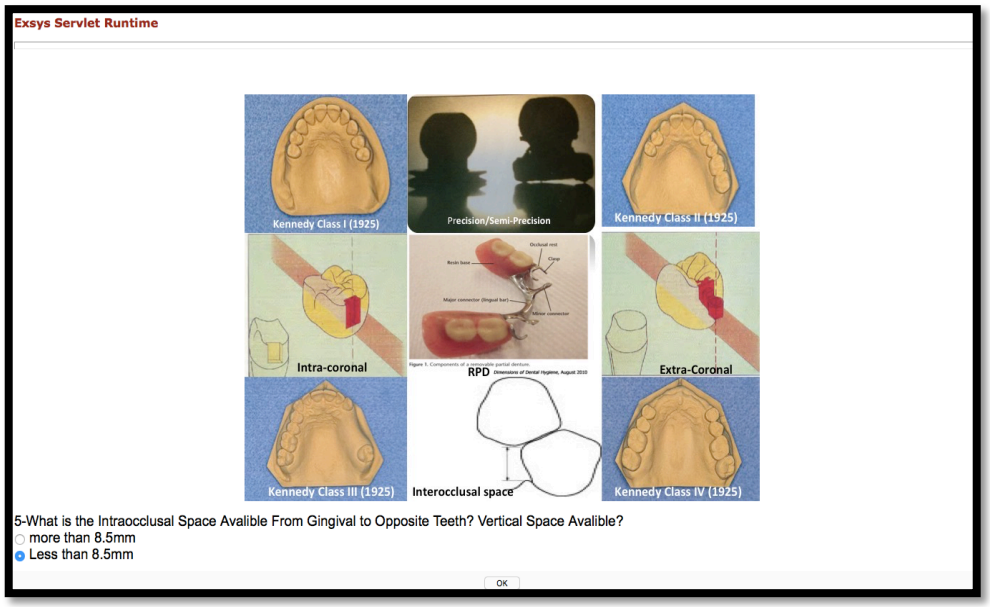
Step 1


Exsys Servlet Runtime
Kennedy Class I (1925)
Precision/Semi-Precision
Kennedy Class II (1925)
Intra-coronal
RPD
Extra-Coronal
Kennedy Class III (1925)
Interocclusal space
Kennedy Class IV (1925)
2-Does The Condition of Abutments Teeth To be Used For Attachment?
Good
Questionable
Poor
OK

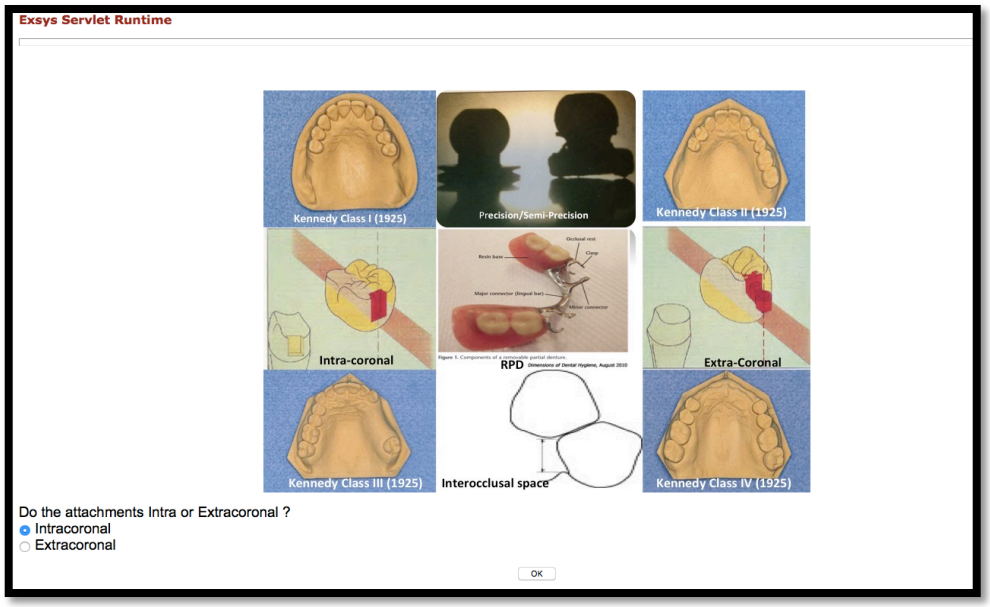
Step 2:


Exsys Servlet Runtime
Kennedy Class I (1925)
Precision/Semi-Precision
Kennedy Class II (1925)
Intra-coronal
RPD
Extra-Coronal
Kennedy Class III (1925)
Interocclusal space
Kennedy Class IV (1925)
4- What is the classification of RPD?
Tooth -Tooth Support
Tooth -Tissue Support
Anticipate Further Conversion to Tooth -Tissue support
OK

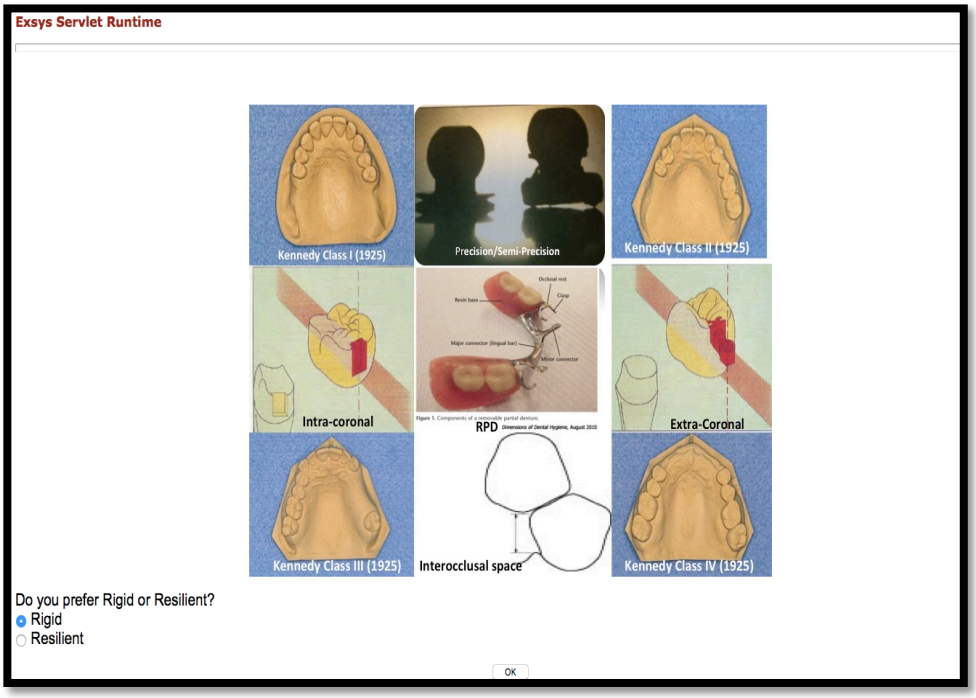
Step 3:


Exsys Servlet Runtime
Kennedy Class I (1925)
Precision/Semi-Precision
Kennedy Class II (1925)
Intra-coronal
RPD
Extra-Coronal
Kennedy Class III (1925)
Interocclusal space
Kennedy Class IV (1925)
5-What is the Intraocclusal Space Avalible From Gingival to Opposite Teeth? Vertical Space Avalible?
more than 8.5mm
Less than 8.5mm
OK

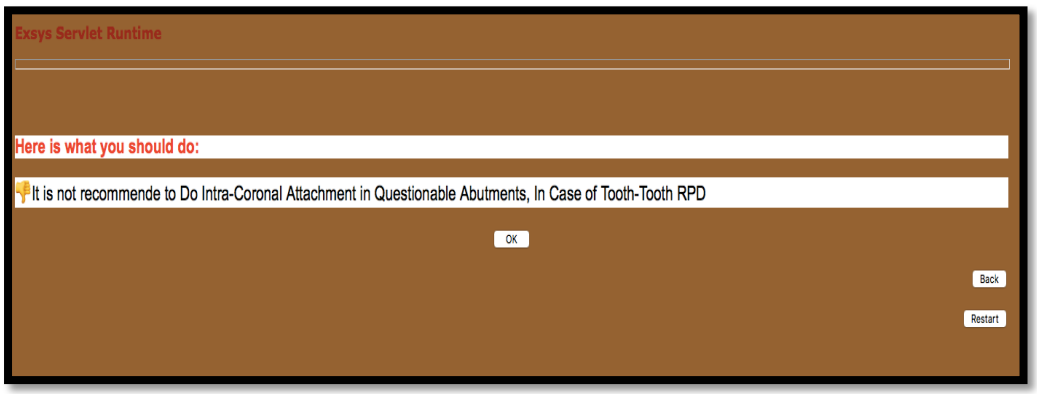
Step 4:


Exsys Servlet Runtime
Kennedy Class I (1925)
Precision/Semi-Precision
Kennedy Class II (1925)
Intra-coronal
RPD
Extra-Coronal
Kennedy Class III (1925)
Interocclusal space
Kennedy Class IV (1925)
Do the attachments Intra or Extracoronal ?
Intracoronal
Extracoronal
OK

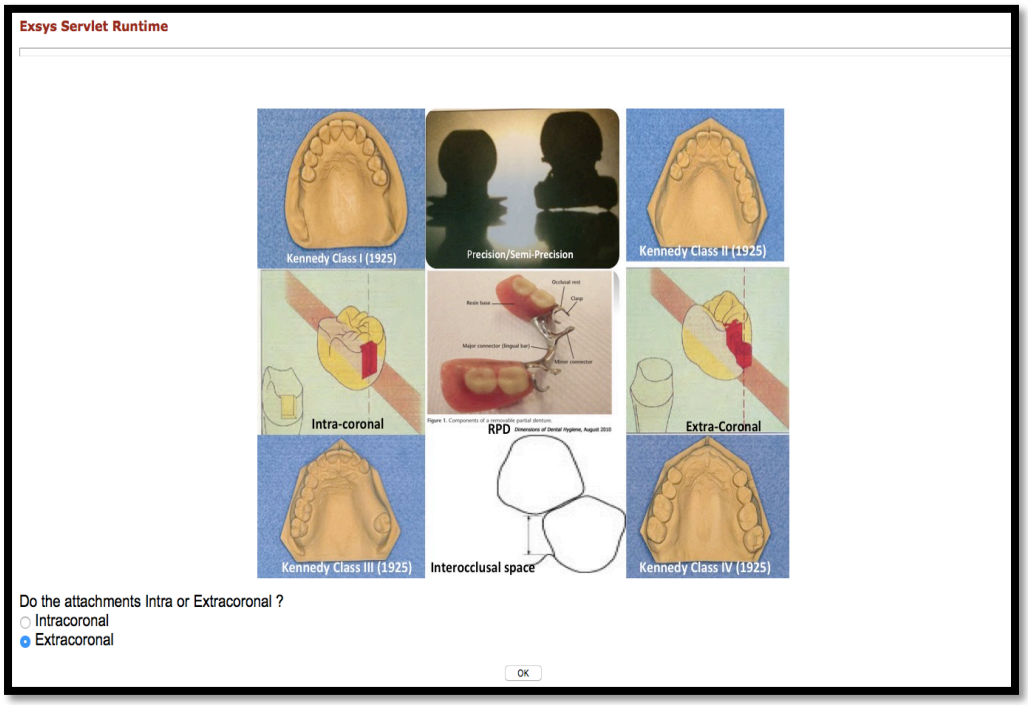
Step 5:



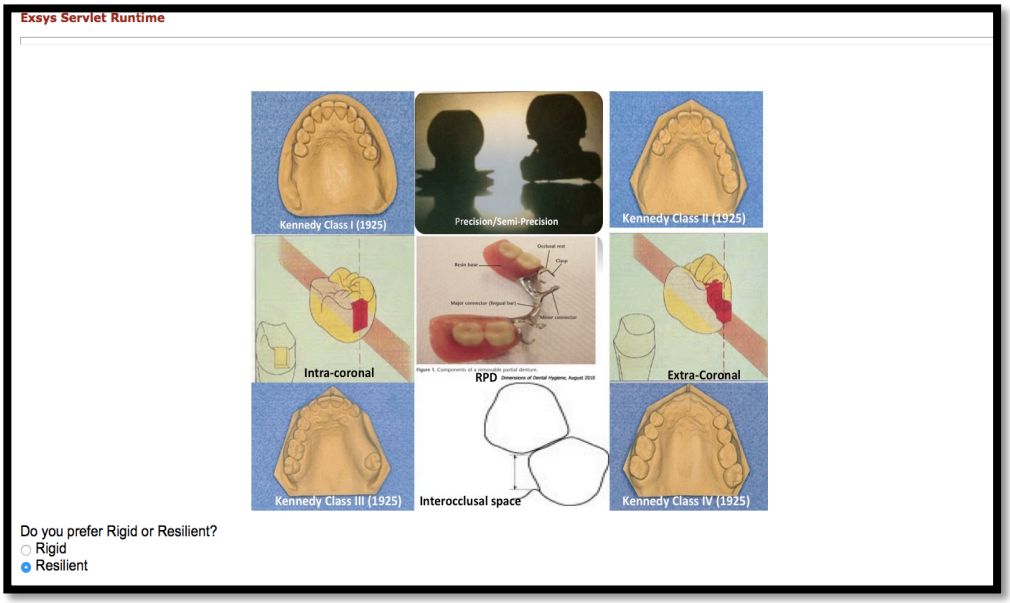
Result screen 1:



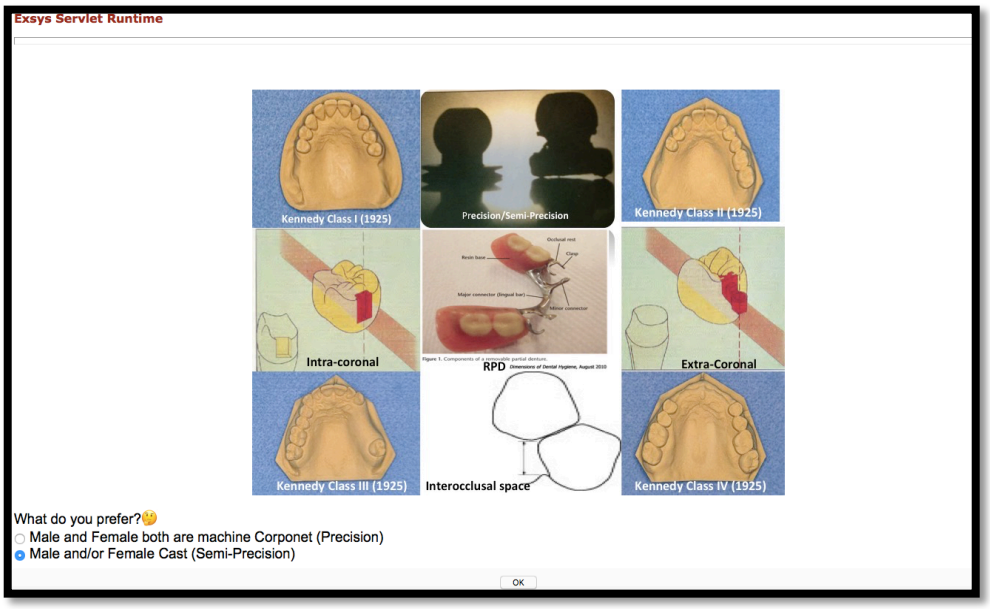
Step 6:


Exsys Servlet Runtime
Kennedy Class I (1925)
Precision/Semi-Precision
Kennedy Class II (1925)
Intra-coronal
RPD
Extra-Coronal
Kennedy Class III (1925)
Interocclusal space
Kennedy Class IV (1925)
Do the attachments Intra or Extracoronal ?
Intracoronal
Extracoronal
OK

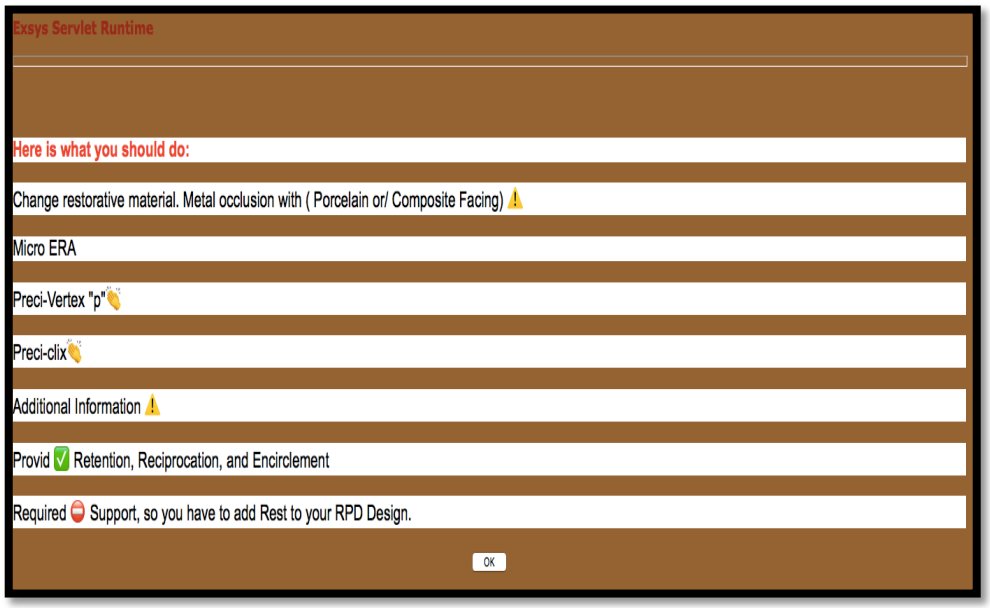
Step 7:


Exsys Servlet Runtime
Kennedy Class I (1925)
Precision/Semi-Precision
Kennedy Class II (1925)
Intra-coronal
RPD
Extra-Coronal
Kennedy Class III (1925)
Interocclusal space
Kennedy Class IV (1925)
Do you prefer Rigid or Resilient?
Rigid
Resilient

Step 8:



Result Screen 2:



Result screen 3:

Result screen 4:

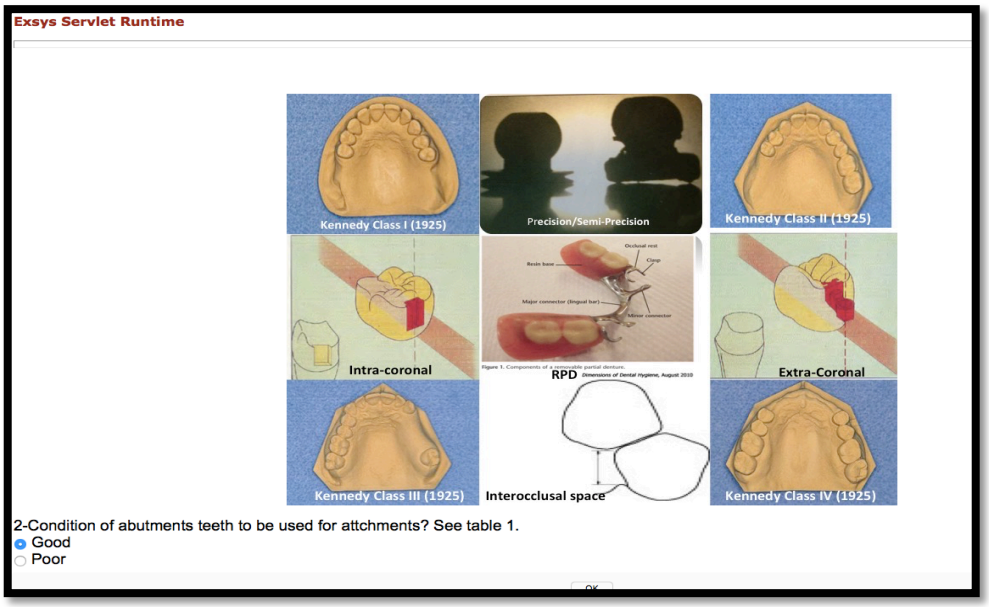
Result screen 5:

Clinical Scenario# 3

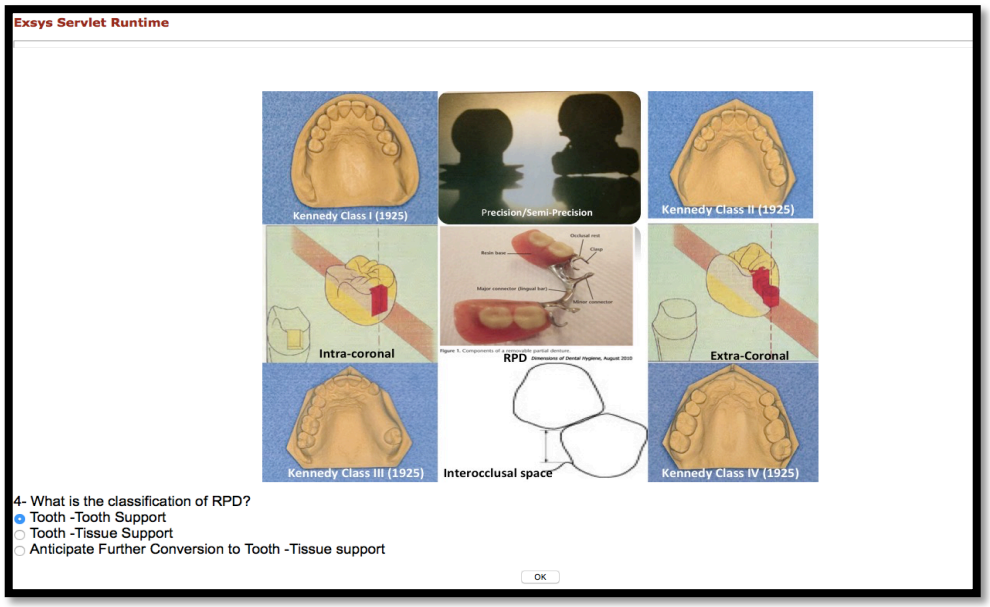
Patient presented with a chief complaint of: “I want to replace my missing front teeth” A review of medical history was unremarkable with no contraindication to dental treatment. On clinical evaluation, the patient has missing maxillary lateral and central incisor teeth, as well as missing maxillary left first molar tooth. All remaining maxillary teeth have a good prognosis and meet the minimum requirements to be used as abutments for RPD with attachments. The patient has high treatment expectations and esthetic demands. The patient demonstrates good oral hygiene, compliance to instructions and financial ability. After a discussion with the patient, the treatment plan will consist of replacing the missing maxillary teeth with a RPD. Therefore, attachments will be considered

DDSS Steps Showing Decision-Making Process and Final Treatment Plan Recommendation: Firstly, system will display title and front screen then primary evaluation phase as showed in case 1, after that:

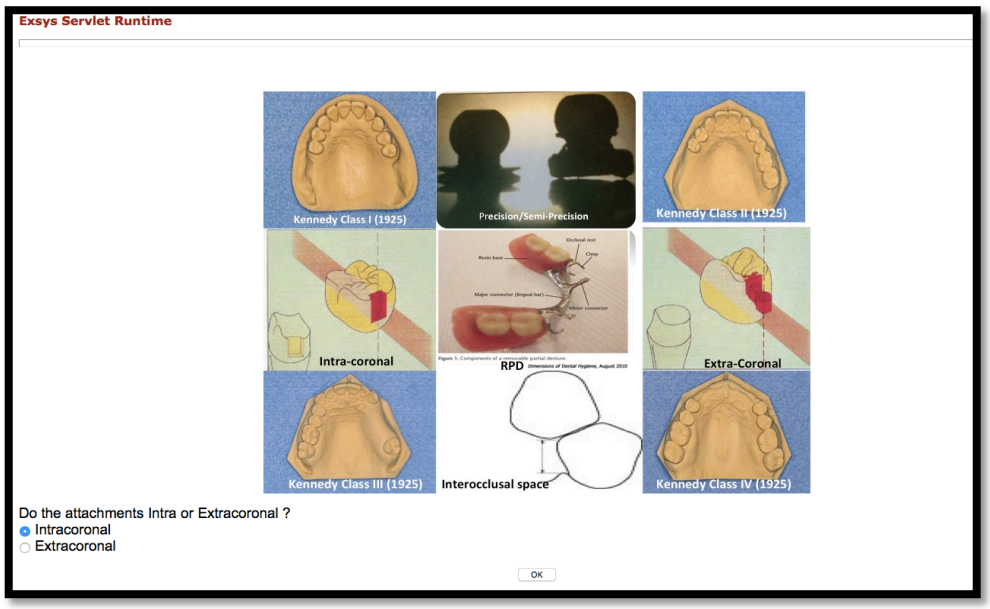
Step1:



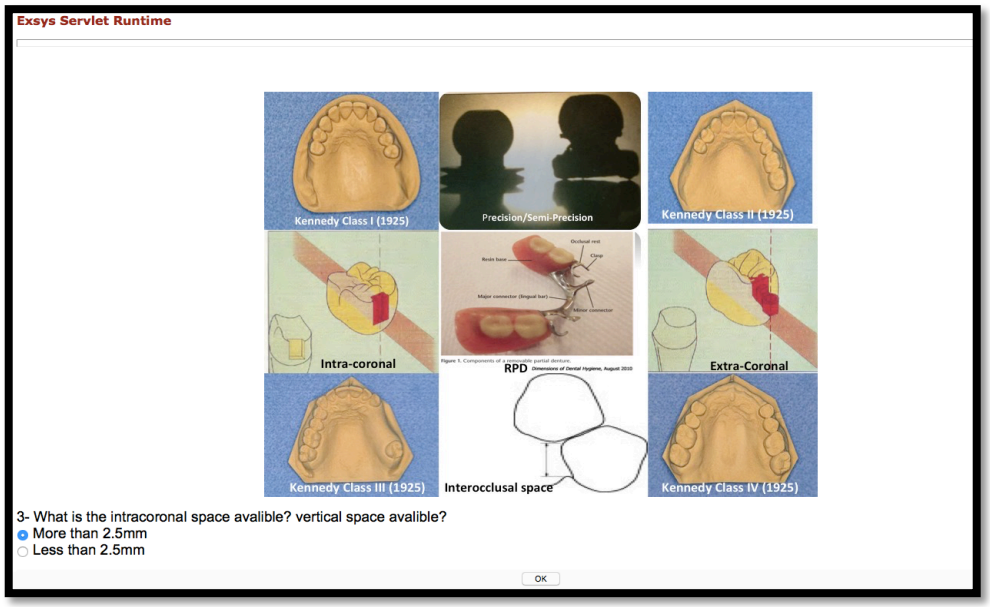
Step 2:


Exsys Servlet Runtime
Kennedy Class I (1925)
Precision/Semi-Precision
Kennedy Class II (1925)
Intra-coronal
RPD
Extra-Coronal
Kennedy Class III (1925)
Interocclusal space
Kennedy Class IV (1925)
4- What is the classification of RPD?
Tooth -Tooth Support
Tooth -Tissue Support
Anticipate Further Conversion to Tooth -Tissue support
OK

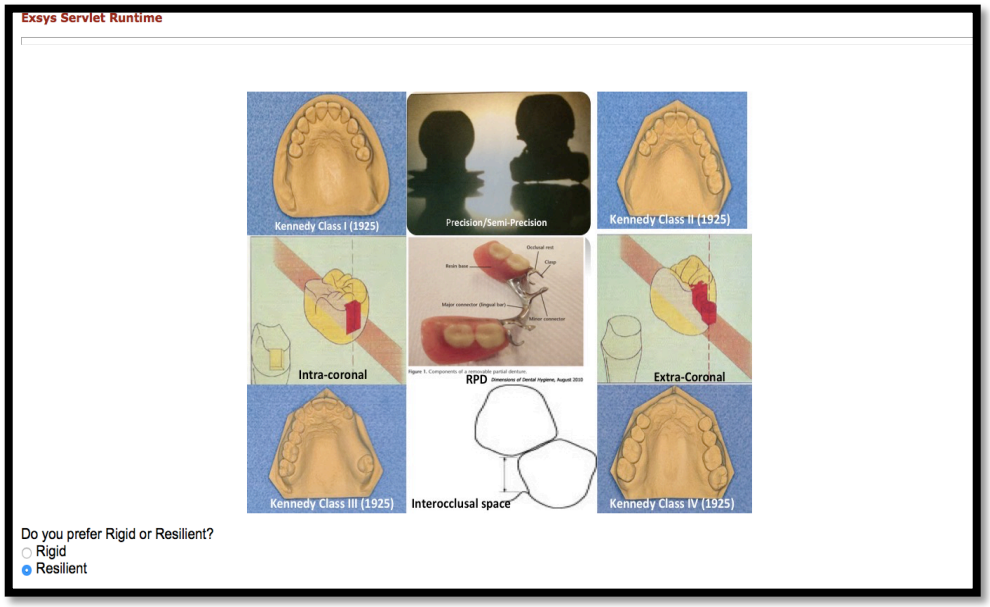
Step 3:


Exsys Servlet Runtime
Kennedy Class I (1925)
Precision/Semi-Precision
Kennedy Class II (1925)
Intra-coronal
RPD
Extra-Coronal
Kennedy Class III (1925)
Interocclusal space
Kennedy Class IV (1925)
Do the attachments Intra or Extracoronal ?
Intracoronal
Extracoronal
OK

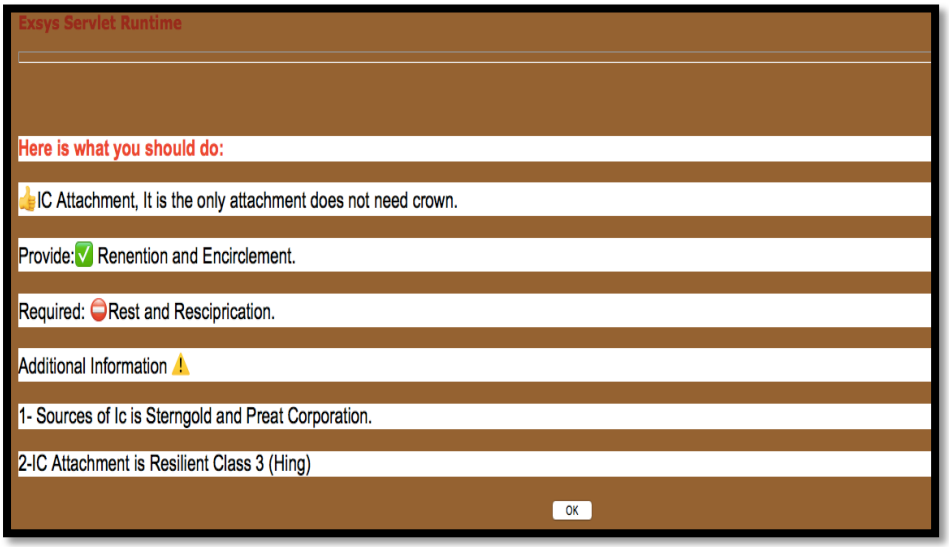
Step 4:


Exsys Servlet Runtime
Kennedy Class I (1925)
Precision/Semi-Precision
Kennedy Class II (1925)
Intra-coronal
RPD
Extra-Coronal
Kennedy Class III (1925)
Interocclusal space
Kennedy Class IV (1925)
3- What is the intracoronal space avalible? vertical space avalible?
More than 2.5mm
Less than 2.5mm
OK

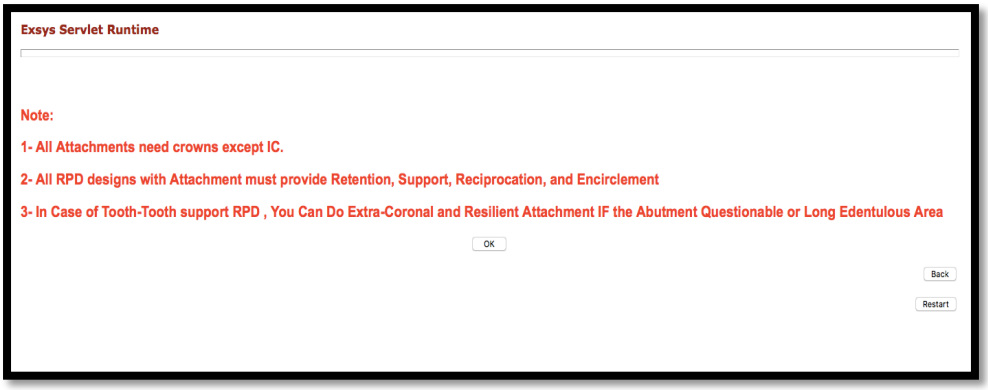
Step 5:


Exsys Servlet Runtime
Kennedy Class I (1925)
Precision/Semi-Precision
Kennedy Class II (1925)
Intra-coronal
RPD
Extra-Coronal
Kennedy Class III (1925)
Interocclusal space
Kennedy Class IV (1925)
Do you prefer Rigid or Resilient?
Rigid
Resilient

Result Screen 1:



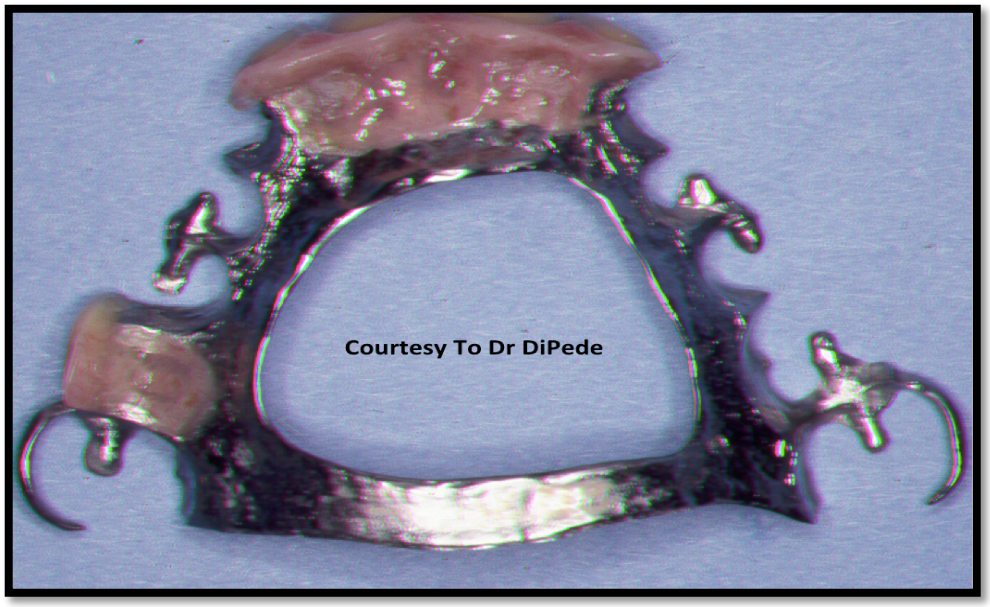
Result Screen 2:



Result Screen 3:

Result Screen 4:

Result Screen 5:



Result Screen 6:

4.2 Post-programming validation and statistical analysis:

The validation questionnaire was distributed to ten expert prosthodontics. Nine of them have responded to the questions relative to the rules and clinical scenarios of varying complexity (Table 4-1). The prosthodontics that responded to questions filled out the questionnaire about their degree of agreement with the system's rules and gave valuable opinion to improve the system. The distribution and percentages of the expert prosthodontics response according to the Likert scale are shown in tables (4-2 to 4-11). The questionnaire items were statistically analyzed using IBM® SPSS Statistics software.

```
FREQUENCIES VARIABLES=q1 q2 q3 q4 q5 q6 q7 q8 q9 q10
 /ORDER=ANALYSIS.
```

Frequencies

Statistics

		q1	q2	q3	q4	q5	q6	q7
N	Valid	9	9	9	9	9	9	9
	Missing	0	0	0	0	0	0	0

		q8	q9	q10
N	Valid	9	9	9
	Missing	0	0	0

Table 4-1 Frequency statistics tables show the distribution and percentages of the evaluators

Q1

Question 1: Do you feel there is a need to develop such a system to guide an inexperienced clinician in selecting an appropriate attachment for RPD?

1 Strongly Disagree	2 Disagree	3 Neutral	4 Agree	5 Strongly Agree

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	4	1	11.1	11.1	11.1
	5	8	88.9	88.9	100.0
	Total	9	100.0	100.0	

Table 4-2 Shows statistics analysis of q1

Distribution and percentage of the prosthodontics to q1 (Table 4-2): 88.9% of evaluators strongly agreed, and 11.1 % agreed that we need DDSS to guide inexperienced clinicians in selecting an attachment. All of the prosthodontics agreed to develop the system. However, 0% disagreed about q1

Q2

Question 2: The system is practical simple to use

1 Strongly Disagree	2 Disagree	3 Neutral	4 Agree	5 Strongly Agree

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	2	1	11.1	11.1	11.1
	3	2	22.2	22.2	33.3
	4	1	11.1	11.1	44.4
	5	5	55.6	55.6	100.0
	Total	9	100.0	100.0	

Table 4-3 Shows statistics analysis of q2

Distribution and percentage of the prosthodontics to q2 (Table 4-3): 55.6% of evaluators strongly agreed, and 11.1 % agreed that system is practical and simple to use. Overall about 66.7% said that the system is simple to use, while 11.1% of them disagreed. 22.2% of prosthodontics' opinion is neutral with this statement.

Q3

Question 3: The system is useful tool to assist the dentists to do attachment selection in RPD design

1 Strongly Disagree	2 Disagree	3 Neutral	4 Agree	5 Strongly Agree

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	2	1	11.1	11.1	11.1
	3	1	11.1	11.1	22.2
	4	4	44.4	44.4	66.7
	5	3	33.3	33.3	100.0
	Total	9	100.0	100.0	

Table 4-4 . Shows statistics analysis of q3

Distribution and percentage of the prosthodontics to q3 (Table 4-4): 3 of evaluators strongly agreed and 4 agreed with this statement, this is about 77.7%, while 11.1% of them disagreed and the same percentage were neutral.

Q4

Question 4: The system is a good tool for training dental students.

1 Strongly Disagree	2 Disagree	3 Neutral	4 Agree	5 Strongly Agree

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	4	3	33.3	33.3	33.3
	5	6	66.7	66.7	100.0
	Total	9	100.0	100.0	

Table 4-5 Shows statistics analysis of q4

Distribution and percentage of the prosthodontics to q4 (Table 4-5): 6 evaluators strongly agreed and 3 agreed that system is a good training tools for dental students and inexperienced dentists, over all they are about 100% in agreement, while 0 % disagreed.

Q5

Question 5: The system is a good tool for continuing dental education courses.

1 Strongly Disagree	2 Disagree	3 Neutral	4 Agree	5 Strongly Agree

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	3	1	11.1	11.1	11.1
	4	3	33.3	33.3	44.4
	5	5	55.6	55.6	100.0
	Total	9	100.0	100.0	

Table 4-6 Shows statistics analysis of q5

Distribution and percentage of the prosthodontics to q5 (Table 4-6): 5 evaluators strongly agreed and 3 agreed regarded to this statement. This is about 88.9 % agreed with the system, while 0% disagreed.

Q6

Question 6: The system contains most of the relevant factors for attachment selection in RPD design.

1 Strongly Disagree	2 Disagree	3 Neutral	4 Agree	5 Strongly Agree

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	2	1	11.1	11.1	11.1
	4	5	55.6	55.6	66.7
	5	3	33.3	33.3	100.0
	Total	9	100.0	100.0	

Table 4-7 Shows statistics analysis of q6

Distribution and percentage of the prosthodontics to q6 (Table 4-7): 3 evaluators strongly agreed and 5 agreed regarded to this statement, this makes up 88.9%. However, very few of the prosthodontics was neutral with this statement about 11.1% and none of them disagreed.

Q7

Question 7: The system provides appropriate recommendation for attachment selection in RPD.

1 Strongly Disagree	2 Disagree	3 Neutral	4 Agree	5 Strongly Agree

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	3	1	11.1	11.1	11.1
	4	4	44.4	44.4	55.6
	5	4	44.4	44.4	100.0
	Total	9	100.0	100.0	

Table 4-8 Shows statistics analysis of q7

Distribution and percentage of the prosthodontics to q7 (Table 4-8): 4 evaluators strongly agreed and 4 agreed, over all they are about 88.8 %. However, none of the prosthodontics were disagreed. 11.1% of them were neutral.

Q8

Question 8: The system provides insightful information about different types of attachments

1 Strongly Disagree	2 Disagree	3 Neutral	4 Agree	5 Strongly Agree

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	3	2	22.2	22.2	22.2
	4	4	44.4	44.4	66.7
	5	3	33.3	33.3	100.0
	Total	9	100.0	100.0	

Table 4-9 Shows statistics analysis of q8

Distribution and percentage of the prosthodontics to q8 (Table 4-9): 33.3% of evaluators strongly agreed and 44.4% agreed, (over all about 77.7 %), while 22.2 % were neutral and none of them disagreed.

Q9

Question 9: Would the system be useful in a private practice setting in additional to a school setting?

1 Strongly Disagree	2 Disagree	3 Neutral	4 Agree	5 Strongly Agree

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	2	1	11.1	11.1	11.1
	3	3	33.3	33.3	44.4
	4	2	22.2	22.2	66.7
	5	3	33.3	33.3	100.0
	Total	9	100.0	100.0	

Table 4-10 Shows statistics analysis of q9

Distribution and percentage of the prosthodontics to q9 (Table 4-10): 3 evaluators strongly agreed and 2 agreed , over all they were about 55.5%. While only one of evaluators disagreed, who represented about 11.1% of the total.

Q10

Question 10: Your overall agreement, do you think this is a valuable system?

1 Strongly Disagree	2 Disagree	3 Neutral	4 Agree	5 Strongly Agree

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	2	1	11.1	11.1	11.1
	4	2	22.2	22.2	33.3
	5	6	66.7	66.7	100.0
	Total	9	100.0	100.0	

Table 4-11 Shows statistics analysis of q10

Distribution and percentage of the prosthodontics to q10 (Table 4-11): Only one evaluator disagreed that it is not a valuable system. The majority of other evaluators agreed that the system is valuable, almost 90%.

The questionnaire results were statistically analyzed using Cronbach's Alpha test. This test is used to measure the reliability and internal consistency of the questionnaire items. The coefficient of Cronbach's Alpha ranges between 0 and 1 and it is calculated using the specific equation.

A higher the alpha coefficient means that the questionnaire items have good internal consistency. The rule of thumb in interpreting the Cronbach's alpha coefficient is[175]:

- Excellent when alpha is equal to or more than 0.9
- Good when alpha is equal to or more than 0.8
- Acceptable when alpha is equal to or more than 0.7
- Questionable when alpha is equal to or more than 0.6
- Poor when alpha is equal to or more than 0.5
- Unacceptable when alpha is less than 0.5

Cronbach's Alpha Coefficient

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.893	.889	10

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
q1	38.00	36.500	.310	.	.899
q2	38.78	28.694	.624	.	.886
q3	38.89	27.111	.936	.	.858
q4	38.22	35.694	.321	.	.898
q5	38.44	34.778	.298	.	.901
q6	38.78	28.444	.864	.	.865
q7	38.56	31.278	.769	.	.875
q8	38.78	30.944	.725	.	.877
q9	39.11	27.611	.788	.	.870
q10	38.44	29.278	.689	.	.878

Table 4-12 The results of Cronbach's Alpha test for the questionnaire items

In this study, the Cronbach's alpha coefficient for the validation questionnaire was 0.893, which represents good internal consistency of the questionnaire items as suggested by Gliem and Gliem. The results of the validation questionnaire showed that all prosthodontics agreed with the need to develop such a system for selecting an appropriate attachment for RPD. Additionally, all of the prosthodontics was agreed that the system is good tool for training dental students. About 89% of prosthodontics was agreed that the system contains most of the relevant factors for attachment selection in RPD design.

5 CHAPTER V DISCUSSION:

Attachment selection in removable partial dentures (RPD) design is considered one of the most challenging treatment decisions in dentistry. Errors in selection an appropriate attachment are common due to the overwhelming number of choices, various levels of practitioner knowledge, experience or training, and the complex interplay between masticatory forces, dental prostheses, and their supporting structures. Such errors may lead to significant problems for both the dentist and patient. These may include: unintentional injury to the patient, multiple post-delivery complications, additional treatment with their associated risks and costs, premature failure of the prosthesis and associated teeth, unnecessary adjustments and repairs, lost patient time from work, loss of revenue to the practitioner, compromised doctor patient relationship, premature loss of teeth and more.

The complexity of this topic makes it ripe for a clinical decision-making system that will remove much of the subjective and differing viewpoints in treatment planning attachments for a RPD. Such planning involves interdependent and multi-factorial considerations that require an excellent understanding of principles from endodontic, periodontic, orthodontic, and the prosthodontic disciplines of dentistry. It is therefore extremely challenging for dental practitioners to readily recall the extensive list of factors that determine an appropriate attachment for a RPD.

Although, clinical experts in the area of attachment RPD design may be able to assist with knowledge and years of experience they may not always be readily available or accessible. Chang et al ,2012 pointed out that there is faculty shortages in prosthodontics

and clearly that there are immense demands for the faculty in all aspects of dental education in the USA. The 2008 American Dental Associations (ADA) survey shows a significant increase tin he size of the applicant pool in prosthodontics.[170] As a result dental students often suffer in term of faculty-to-student ration, and students exposure to specialty education.

There is a shared concern in dental schools with regard to the difficulty of dental students new dental graduates in mastering the attachments RPD. Despite limited dental school curriculum time pertaining to prosthodontics and faculty shortages, it appears as taught dental students are still exposed to complex prosthodontics cases with high frequency[171]. Deans of US dental schools suggested that low exposure of the students to the skills of prosthodontics should be examined more extensively in the future, because this issue can have a significant negative effect on the dental students and dental education in the USA[171].

This clinical decision support system will help dental students and dentists alike to learn from and think like experts in treatment planning the appropriate choice of RPD attachment, without necessarily having all of the relevant facts and rules in the process committed to memory. Such system teaches the user how to think about the problem holistically rather than focusing on individual procedures, which in turn, leads to improved treatment outcomes.

The limitations of the current scientific foundation and the potential resistance of practitioners to integrate the new system into their usual workflow, may delay a more widespread establishment of the system.[162]In addition, Goh, 2016, concluded that there are some common barriers facing dentists in adopting a decision system within their workflow. These barriers in Table 5-1, included lack of perceived usefulness, complicated social and economic factors, and the difficulty for users to interpret the advice given by the system. Besides, most systems only support a particular kind of treatment, such as treatment planning for dental caries (Park et al., 2010; Mago et al., 2012) or the selection of implant abutments (Lee et al., 2012).

Barriers	Remarks
Perceived usefulness	Limited functions
Sociocultural and economic factors	Resistance towards technology Social and corporate influences
User interface and standards	Lack of standards for datasets Difficult to interpret results

Table 5-1 Barriers to Adopting Decision Support System[178]

Furthermore, (Adams et al, 2010) mentioned that Information system in dental clinics were usually “designed primarily to facilitate administrative functions" centered on billing or at most, automating functions such as appointment alerts and reminders.

Scheleyer et al, 2011a, pointed out that using CDSS for diagnosis or treatment plan is a new treatment modality. This explains the increase in the international research interest for the efficient design, and adoption of the CDSS in typical dental practice.

Our proposed DDSS for attachment selection in RPD is not intended to replace the dentist's judgment and responsibility for decision-making, but to provide assistance in treatment planning. Our system is aimed to expand the clinicians' professional expertise. According to (Demner-Fushman et al., 2009). Table 5-2 presents some system capabilities with examples. The output can be delivered to the user either before, during, or after the clinical decision is made.

Clinical DSS Capabilities	Examples
Preventive care	Screening, immunisation and disease management suggestions
Diagnosis	Lists of ranked differential diagnoses
Treatment plans	Treatment guidelines and drug dosage recommendations

Table 5-2 Major Functionalities of Clinical Decision Support Systems adapted from Dhiman et al 2015

In order to make the CDSS effectively employed for use in actual practice, the function of CDSS should follow "five rights concepts" as discussed in section 2-6 and should has features that attempt to minimize the barriers to the dentist's adaptation of the system. Our proposed system (Exsys corvid system) has positive features that overcomes barriers such as good performance, ease of programing and reasonable cost (Salim el al, 2002).

In addition, our proposed system has an efficient information of knowledge base. The knowledge base of the system was obtained from dental experts, updated evidence from the scientific literature and established practice guidelines. In addition, our system is

designed to enable the user to make effective and efficient treatment plans without having to depend on their personal experience.

We expect that a DDSS will not only be efficient enough to be routinely helpful to dental students and dentists but will also to fit the clinical workflow at point-of-care. Although our proposed system helps students and dentists arrive at an appropriate selection of appropriate attachments, the system does not teach the clinical steps to execute the case. This may be one of One of the potential limitations of the system. Prasad et al 2016, concluded that the use of attachment required appropriate training and experience, technical skills and clinical ability. Inexperienced dentists who may be lacking in this regard, would need more time to master the clinical and laboratory procedures required to use whichever attachment our system suggests.

However, our system can offer an educational platform to teach dentists and dental students to think like experts. Such system teaches them to evaluate and judge challenging clinical scenarios in a holistic and comprehensive approach rather than concentrating on technical details, which in turn enhances treatment outcomes, patient's satisfaction, and overall dental care. One of the goals is for system to serve as a training tool for dental students. The validation questionnaire response of our proposed system showed that 100% of the evaluators strongly agree that the system is a good tool for training dental students. The availability of the system online allows the students to access it anywhere and at any time.

Although many CDSSs have been developed in the field of dentistry, there is still an outstanding need for clinical decision system that can efficiently assist dentists in choosing an appropriate attachment in RPD.

Since the main aim of the study is using CDSS as a teaching aid for students, the future direction of this study should focus on efforts that must be made by dental education institutions to reassess curriculum and make arrangements to incorporate the system as a supplement to traditional classroom teaching. Additionally, we expect that a DDSS is not only efficient enough to appear helpful to dental students and dentists but would also fit the clinical workflow at point-of-care. The system may be useful in a private practice setting in additional to a school setting. A long-term study can be undertaken to evaluate the feedback of the dental professionals after using the system and compare it when they make treatment plan before using the system.

6 CHAPTER VI: SUMMARY AND CONCLUSION:

The Dental Decision Support System (DDSS) for attachment selection in removable partial denture design was successfully developed using Exsys Corvid Core software. Our system is web-based and can be launched at the operatory and can be easily integrated into providers' workflow. The system can efficiently evaluate several considerations that are needed to make the right decision. It can help dentists make correct and timely decisions about patient dental care with reduce errors, reduce costs, and ultimately improve the quality of health care.

In a classroom scenario, DDSS can be incorporated as part of class curriculum to supplement traditional teaching methods. Expert prosthodontics concurred that the system can be effectively employed by training dental students, dentists and residents to select an appropriate attachment. Through this system, knowledge of an attachment RPD can be delivered to the students as well as less experienced clinicians at the point-of-care to minimize decision-making errors and improve treatment outcomes. Clinical decision support system can be used for training students even in the absence of patients, as part of the dental students' electronic curriculum. Since the knowledge base of our system is developed using expert guidelines that are known to be effective, we expect to see improvements in the outcome of treatment with attachment selection in removable partial dentures.

Appendix A: The Distributed Validation Questionnaire

Dear Doctor,

I am inviting you to take part in evaluation of my PhD degree project entitled "Dental Decision Support and training System for attachment selection in RPD design". I am working on my project under the supervision of Dr Shankar Srinivasan , Dr Louis DiPede and Dr Hind Elhammali.

The goal of the project is to develop a computer software that will be available online to help inexperienced clinicians and dental students to select attachment. We have developed a clinical support and training system based on expert knowledge and evidence-based guidelines.

Please review the systems knowledge base rules. I appreciate any suggestion and recommendation to add, remove or modifying any of primary evaluation or secondary evaluation criteria for attachment selection in order to improve the system. After reviewing the rules, please fill out the included questionnaire about your degree of agreement with the system's rules, as your valuable opinion is important to me.

If you have any question regarding the system, please contact me on my e-mail waa33@shp.rutgers.edu. Or Phone number 316-518-5424.

Sincerely

Wesam Alturki
PhD student in Biomedical informatics department
School of Health Professions, Rutgers University

Question 1: Do you feel there is a need to develop such system to guide the inexperienced clinician in selected an appropriate attachment for RPD

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

Question 2: The system is practical simple to use

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

Question 3: The system is useful tool to assist the dentists to do attachment selection in RPD design

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

Question 4: The system is a good tool for training dental students.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

Question 5: The system is a good tool for continuing dental education courses.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

Question 6: The system contains most of the relevant factors for attachment selection in RPD design.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

Question 7: The system provides appropriate recommendation for attachment selection in RPD.

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

Question 8: The system provides insightful information about different types of attachments

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

Question 9: Would the system be useful in a private practice setting in additional to a school setting?

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

Question 10: Your overall agreement, do you think this is a valuable system?

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

Please provide any suggestions or recommendation in order to improves the system:

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