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A Decision Tree with Updated Views of Timing of Implant Placement for Single Maxillary Anterior Residual Root

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Abstract

Single residue root in maxillary anterior region is prevalent in dental implant clinic. Decision making on choosing post-core, immediate, early, or late implant for single maxillary anterior residue root is challenging. Although some guidelines have been proposed, the treatment approaches have been updated quickly and a number of evidence based clinical researches have been carried out, changing the views on each decision factor dramatically. It is of great necessity to summarize all the updated views and propose an updated decision tree. This review summarized the updated views on all relevant factors for single maxillary anterior residue root treatment decision-making and updated the decision concept based on the strength of evidences, and finally proposed a clear and feasible decision tree for the clinician's reference.

Keywords: Updated decision tree; Maxillary anterior residual root; Implantation restoration; Esthetics

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Abbreviations

BPs: Bisphosphonates; BRONJ: Bisphosphonate-Related Osteonecrosis of the Jaw; T2DM: Type 2 Diabetes Mellitus; PES: Pink Esthetic Score; FGM: Free Gingival Margin; IDR: Immediate Dentoalveolar Restoration; SST: Socket Shield Technique; CTG: Connective Tissue Graft; CBR: Cortical Bone Reposition

Introduction

Single residual root caused by crown fracture, dental caries, etc. in the maxillary anterior region is prevalent in the dental clinic. Recent published scientific evidence showed post-core crown restoration and resin-bonded fixed dental prostheses present as a truly reliable treatment option with higher success and survival rates in the esthetic anterior zone [1]. For those whose condition is not suitable to receive post-core crown restoration or resin-bonded fixed dental prosthetics, implant therapy could be a choice. However, the timing of implant placement is sophisticated especially in the maxillary anterior region where calls for higher esthetics [2]. Based on the healing process of gingiva and alveolar bone after tooth extraction, the timing of implant placement has been classified into four types [3]. Type 1 placement refers to immediate placement with no healing of bone or soft tissues. Type 2 placements means early placement with healed soft tissues typically within 4 to 8 weeks of tooth extraction. Type 3 placement refers to early placement with significant bone healing, which occurs about 12 to 16 weeks after extraction. Type 4 placement means delayed placement with fully healed tissues after 6 months or more time of the tooth extraction. Timing of implant placement counts a lot in treatment outcomes affecting hard and soft tissue preservation around the residual root. Therefore, a clinically referable standard for dentists is of great significance.

Though there exist several decision guidelines on the timing of implant placement the treatment concept updated quickly accompanied by growing knowledge and a deeper understanding of dental Implantology [4,5]. Platform-switched implants have been developed to compromise the mesiodistal distance restriction [6]; infection of extraction socket was considered to be a contraindication for immediate implantation in the past, while recent studies found that it was no longer a contraindication [6-10]; it was previously proposed that extraction site with intact and >1 mm thickness labial bone wall could receive immediate implant, while socket shield technique was developed to deal with immediate implantation with the insufficient thickness of labial bone wall

Table 1: Specific modified GRADE criteria used to describe the level of evidence [12,13].

Level of evidence	Definition criteria
Level 1	Systematic review with meta-analysis
Level 2	Systematic review without meta-analysis, single multicenter RCT, multiple RCTs
Level 3	Single RCT, RCTs designed for a different reason
Level 4	Case series, CCTs
Level 5	Expert opinion, ideas, editorials
Level 6	Animal research
Level 7	*In vitro* (test tube) research

[11]. Therefore, it is of great necessity to conduct a literature review, update the decision guideline and draw the relatively complete implant decision tree for a single residual root to provide an efficient clinical reference for dental clinicians in the timing of implantation.

In this manuscript, we first summarized relevant decision-making factors according to documented clinical and basic scientific researches. Then literature retrieval on each factor was conducted and summed up with updated views. Based on the strength of the evidence (Table 1) [12,13], we corrected these determinants and proposed an updated decision tree of single maxillary anterior teeth post-extraction. It is our ambition that the summarized treatment decision tree with updated views for single maxillary anterior teeth after extraction will help clinicians to make more accurate treatment decisions which are promising to get the most predictable prognosis based on evidence-based medicine.

For residual root, clinicians need to carefully and thoroughly evaluate implantation timing before tooth extraction and many factors should be taken into consideration to make proper decisions. The main factors can be summarized as restoration factors, systemic factors, primary stability, local infection, and esthetic factors, which are recommended to get a thorough evaluation before decision making. Though there exist several studies aimed at analyzing one or more of these factors [4,14] the relationship between various factors has not been systematically sorted out.

Restoration factors assessment

Restoration factors are a vital part that determines the feasibility of the final restoration design based on the concept of restoration-oriented implantation. The restoration factors of the single anterior implant could mainly be divided into four aspects: Oral condition (oral healthy, local and adjacent teeth condition), restoration space (mesiodistal space and occlusal-gingival space), occlusion relationship (bruxism, guide forward occlusion type, and malocclusion) and the application of temporary restoration, of which the restoration space and bruxism have got some updated views (Table 2).

Bruxism: Is generally considered as a restoration contraindication to implant treatment. A study showed that the implant failure rate of bruxers was 4 to 5 times higher than that of non-bruxers, the probability of ceramic chipping or facture is about 11 times higher [15], and the probability of mechanical complications is also higher. However, some updated views suggest implants can be carried out with positive bruxism intervention. For patients with bruxism, Zhou et al. [16].

Summarized their clinical experience and concluded that the following auxiliary methods can be used.

1) Use of long implants to increase the contact area between the implant and bone tissue and reduce stress.

2) The inclined plane of the prosthesis should not have occlusal contact, and the length of the cantilever and the size of the crown should be reduced.

3) For patients with nocturnal bruxism, a night guard occlusal stabilization appliance can be used, and so on [15]. The occlusal splint has also been used to reduce occlusal burden in patients with molar, but systematic reviews are still void [17]. A randomized controlled study showed a significant reduction in nocturnal bruxism activity in patients with intermittent occlusal splint treatment after 4 weeks [18]. However, long-term clinical studies of these methods are still lacking. In a word, based on the review of available literature, bruxism seems to be a risk factor for mechanical complications rather than biological complications around dental implants. Under positive interventions like optimal occlusal design, occlusal splint, proper maintenance, and medical advice, an implant could be carried out in patients with bruxism [15,19]. However, patients suffered from vertical dimension defect, severe bone defect and temporomandibular disorders caused by bruxism need to be treated with caution [20-22].

Restoration space: To deal with insufficient restorative space, slightly occlusal adjustment and orthodontic treatment can be used to enlarge missing tooth space [23]. But it should be adjusted with low intensity and high frequency, and each adjustment should not exceed 1 mm. Some other different methods have been proposed recently to further reduce space limitation. For implant sites with insufficient mesiodistal distance, the platform-switched implants can be applied. A retrospective study showed that the distance between implants and adjacent teeth can be reduced to an average of 0.99 mm using the platform-switched implant, and after the average loading period of 13 months, the vertical and horizontal bone resorption is 0.43 mm and 0.36 mm respectively [24]. A prospective study showed that the average marginal bone level around platform-switched implants decreased 0.23 mm ± 0.38 mm on average during the observation period of 1 to 5 years, suggesting the stable preservation of bone tissue [25]. When vertical space for the prosthesis is insufficient, Joseph et al. [6] suggested that alveolectomy may be appropriate if adequate bone is available for implants in the vertical dimension; otherwise adopted the fixed prosthesis or the implant-level retention of the prosthesis. These approaches can help reduce space restriction, thus expand the implant indication.

Systemic factors assessment

The main systemic risk factors that have been reported include osteoporosis, diabetes, a history of taking bisphosphonates, neurocognitive impairment (depression, Parkinson's disease, etc.), cardiovascular disease, and radiation therapy, and so on [26]. Updated views on these factors have been summarized below (Table 3).

Bisphosphonates intake: High dose of Bisphosphonates (BPs) intake used to be considered as a contraindication, mainly due to the severe complication Bisphosphonate-Related Osteonecrosis of the Jaw (BRONJ) [27]. However, this does not mean that implant surgery cannot be operated on all of these patients. Oral taking of BPs did not affect the success rate of implantation. Javier et al. Meta-analysis including 368 patients receiving BPs with a total of 1,090.

Implants showed that the failure rate of the experimental group was high (risk ratio: 1.43), but there were no statistical differences [28]. There was a study indicating that oral taking of

Table 2: Updated views of restoration factors.

Restoration factor	Previous views	Updated views	Reference	Research conclusion	Type of experiment	Case number	Observation time	Level of evidence
Bruxism	Bruxism is generally considered as a restoration contra indication to implant treatment	The risk of bruxism could be positively intervened and the implant could be carried out.	Yi Z et al. [15]	Several techniques could be used to reduce the risk of bruxism: 1) Long implants; 2) The inclined plane of the prosthesis should not have occlusal contact; 3) Reduce the length of the cantilever and the size of the crown; 4) For nocturnal bruxers, a night guard occlusal stabilization appliance can be used, and so on.	Expert opinion	/	/	5
			Matsumoto H et al. 2015 [18]	Bruxism activity could significant reduce with intermittent occlusal splint treatment.	RCT	20 bruxers	4 weeks	3
Restoration space	Insufficient restorative space could be solved by occlusal adjustment or orthodontic treatment	More methods could be used to deal with the insufficient space: platform switch, implant-level retention, and alveolectomy.	Xavier V et al. [24]	Platform-switched implants could help to reduce the mesiodistal space demand.	Retrospective study	70 platform-switched implants	An average loading period of 13 months	4
			Laura L et al. [25]	Platform-switched implants have a stable preservation effect on bone tissue.	Prospective study	67 implants in the posterior region	1-5 years	4
			Joseph C et al. [81]	Alveolectomy could be applied if adequate bone is available for implants in the verticle dimension; otherwise the fixed prosthesis.	Expert opinion	/	/	5

Table 3: Updated views of systemic factors.

Systemic factor	Previous decision tree	Updated views	Reference	Research conclusion	Type of experiment	Case number	Observation time	Level of evidence
Bisphos phonates (BPs)	A high dose of BPs was thought to be considered as a contraindication due to the BRONJ.	Oral taking BPs have a small effect on the early success rate of implant treatment. While receiving intravenous BPs should still be cautious.	Javier A et al. [28]	Dental implant placement in patients receiving BPs does not reduce the dental implant success rate.	Systematic review and meta-analysis	9 studies	/	1
			Memon S et al. [31]	The use of oral BPs at the time of implant placement and during healing did not affect early implant success rates.	Retrospective study	200 women	5 years	4
			Grant BT et al. [29]	Oral BPs therapy did not appear to significantly affect implant success.	Retrospective study	458 patients (115 of them had taken oral bisphosphonate)	38 months on average	4
			Madrid C et al. [30]	The placement of an implant may be considered a safe procedure in patients taking oral BPs for <5 years.	Systematic review	4 studies (1 prospective and 3 retrospective studies)	/	2
Radiotherapy	Radiotherapy had a high risk to lead to osteoradione crosis of the jaw bone, which was listed as one contraindication	Radiotherapy would not affect the implantation success rate if the aseptic operation of surgery, the interval of radiotherapy, and the radiotherapy dose were satisfactory.	Bruno R et al. [39]	There is no statistical difference in survival when implants were inserted before or after 12 months after radiotherapy.	Meta-analysis	54 studies (10 controlled clinical trials and 44 retrospective studies)	/	1
			M M Curi et al. [38]	The implantation success rate in patients with a low dose of 50-70Gy radiotherapy was satisfactory.	Retrospective study	35 patients (169 dental implants)	7.4 years (range 0.3-14.7 years)	4
Osteopo rosis	Osteoporosis was thought to be relative risk factors for implantation, which reduce the bone-to-implant contact area, decrease bone density and prolong the healing period	Osteoporosis would not affect the implant survival rate if the quality of the jaws was carefully evaluated before implantation.	Tara Aghaloo et al. [27]	Osteoporosis would not decrease the implant survival rate. The implant survival rate of patients with osteoporosis was 98%, which had no statistical difference from that of normal patients.	Systematic review	17 studies	/	2
			F de Medeiros et al. [40]	Compared with normal patients, osteoporosis would not increase the implant failure rate.	Systematic review with meta-analysis	217 osteoporosis patients with a total of 702 implants	/	1

Diabetes	Diabetes was a relative risk factor that would cause bone resorption and wound healing problems around implants.	Patients with moderate controlled T2DM could also get implantation if better oral hygiene and glycemic levels were maintained.	Zeev Ormianer et al. [42]	Patients with moderate controlled type 2 diabetes (T2DM) showed the implant survival rate of 94% and no difference with the control group.	Retrospective Study	169 patients (with 1,112 implants)	8.7 years on average	4
			Caroline C Eskow et al. [43]	The poorly controlled T2DM seems to have a less adverse effect on implant results.	Observational cohort study	23 participants (72 implants)	2 years	4
			Leandro C et al. [44]	The dental implant was practical for patients with moderately controlled diabetes when glycemic levels and oral hygiene are strictly maintained.	Expert Opinion	/	/	5

Table 4: Updated views of primary stability prediction.

Previous views	Updated views	Reference	Research conclusion	Type of experiment	Case number	Observation time	Level of evidence
No conclusion on the accurate standard of primary stability prediction for different implant timing was provided	It is related to factors, including bone density, insertion depth (>2 mm) and sagittal root position	Kan et al. [82]	The implant should be inserted 4 to 5 mm beyond the root apex.	Expert opinion	/	/	5
		Yan et al. [46]	The implant should be inserted 2 mm beyond the socket bottom.	Systemic review	13 RCTs	/	1
		M. Herekar et al. [47]	High bone density (HU=850~1250) was beneficial to get better primary stability than low bone density HU=350~850 and HU=150~350)	*In vitro* experiment	60 implant sites	/	7
		Kan et al. [48]	Class-I sagittal root position is suitable for immediate implantation; Class II and II relies on contact with extraction socket; Class IV is a contraindication for immediate implantation.	Retrospective study	100 patients	/	4

BPs did not affect the success rate in the early and medium-term of implantation, suggesting implantation therapy can be an option for patients receiving oral BPs medication [29-31]. Patients treated with intravenous bisphosphonates seemed to have a higher chance of developing BRONJ [30,32,33]. A study of 26 BRONJ patients showed that different drugs were inconsistent and it took an average of 16 months from implant implantation to the appearance of BRONJ. A study of 1,330 implants from 528 bisphosphate users revealed a failure rate of 8.5% (control group: 1.6%) and osteonecrosis in 78 patients at 11 years of follow-up [34]. However, BRONJ appears to occur less frequently in patients receiving oral BPs treatment [29,31,35]. Although oral bisphosphonate treatment might also have a lower possibility of BRONJ, it had a small effect on the early success rate of implant treatment, and implant treatment could be considered after sufficient communication with patients, for bisphosphate intravenous chemotherapy for cancer patients need to be careful, while patients using bisphosphonate intravenously should be cautious [28]. Besides, it should be noted that the insertion of dental implants during or after BPs treatment accelerated the development of BRONJ while BRONJ occurred less frequently when the implants had been inserted before BP therapy had been started [36].

Radiotherapy: May lead to osteoradionecrosis of the jaw bone, which was used to be listed as a contraindication for implantation. Studies have shown that the probability of osteoradionecrosis was significantly increased when the radiotherapy dose is >65 Gy [28,37]. A study showed that the implant survival rate of 169 patients who received low-dose radiotherapy for head and neck cancer (50 Gy to 70 Gy) reached 92.9% after an average follow-up of 7.4 years, indicating a good long-term effect. Meanwhile, the 5-year success rate of male patients was higher than that of female (98.9% *vs.* 81.6%), and the difference of radiotherapy methods also affected the success rate: The 5-year success rate of implants in patients receiving intensity-modulated radiation therapy was higher than that of conventional conformal radiotherapy (96.1% *vs.*74.3%) [38]. A recent meta-analysis showed that patients who received radiotherapy had a lower implant survival rate than those in the control group, but there was no effect on the implant survival rate if the implantation was conducted 12 months before or after radiotherapy [39]. The failure of dental implants in irradiated patients was subjected to many other considerations and predictability was dependent upon issues like the chemotherapy, the timing of the implant placement concerning radiation therapy, and so on. For the risk influence of the radiotherapy, Pedro et al. [28] have concluded that implant surgery should be best carried out >21 days before radiotherapy and >9 months after radiotherapy, total radiation dose should be <66 Gy or <50 Gy to reduce osseointegration failure: Avoiding implant site/portals and antimicrobial prophylaxis. These may offer a guideline for clinician encountering this situation. Form above, we could get that for patients receiving radiotherapy for head and neck cancer, the aseptic operation of surgery, the interval of radiotherapy and the radiotherapy dose should be strictly observed.

Osteoporosis was thought to be a relative risk factor for implantation, which reduces the bone-to-implant contact area, decreases bone density, and prolongs the healing period [5]. A recent meta-analysis by Tara et al. showed that the implant survival rate of

Table 5: Updated views of local infection.

Previous view	Updated views	Reference	Research conclusion	Type of experiment	Case number	Observation time	Level of evidence
Implant sites with local infection should wait 4-8 weeks for the infection to subside and thus type II placement will be conducted	Infection of extraction socket is not a contraindication for immediate implantation provided that cautious preliminary debridement was performed	Lee et al. [10]	When there's enough healing time, immediate implant placement in infected sites and non-infected sites achieve the same result.	Animal study	6 Beagle dogs (Second, third and fourth	1 and 3 months	6
		Crespi et al. [32]	The left of granulomatous tissue in infected fresh sockets does not harm implant outcome.	RCT	60 patients (186 sites removed granulomatous tissues, 186 sites didn't)	12, 24, 36-month follow-up	3
		Anitua et al. [50]	The infected fresh socket was not an absolute risk factor for immediate implant survival while soft and hard tissue augmentation was recommended at the same	Cohort study	30 patients (43 implant sites)	6 years (range 1 to 8 years)	4
		Zuffetti et al. [9]	Immediate implant placement into infected sites is safe, providing preliminary debridement.	Retrospective study	369 patients (334 implants in the infected group and 193 in the control group)	More than 50 months	4
		Chen et al. [26]	Infection of extraction socket is not a contraindication for immediate implantation.	Systemic review with meta-analysis	9 clinical studies (NOS score range from 5 to 8)	/	1

Table 6: Updated views of esthetic factors.

Esthetic factor	Updated views	Reference	Research conclusion	Type of experiment	Case number	Observation time	Level of evidence
Labial bone wall thickness	With the practice of autogenous bone chip grafting, absorbable membrane+allograft grafting and socket shield technique, type II socket (the labial bone wall was partially or absent) can receive immediate implant	Robert Noelken et al. [53]	Autogenous bone chip grafting in immediate implantation of type 2 sockets could get a satisfactory outcome.	Case series	16 patients (type 2C sockets)	13 to 36 months	4
		Rosa et al. [55]	Immediate implant with absorbable membrane+allograft grafting of type 2 sockets could get a satisfactory outcome.	Case series	18 patients (12 with type 2C sockets and 6 with type 2B sockets)	58 months	4
		Sarnachiaro et al. [56]	Immediate implant with absorbable membrane+allograft grafting of type 2 sockets could get a satisfactory outcome.	Case series	10 patients (type 2A or 2B sockets)	6 to 9 months	4
		Sun et al. [58]	Immediate implant with socket shield technique could get a satisfactory outcome.	RCT	30 patients	24 months	3
		Bäumer et al. [57]	The socket shield technique offers less invasiveness high esthetic results.	Case series	10 patients	5 years	4
		Mazzotta et al. [59]	With the proper surgical technique, CTG was able to produce an optimal and predictable esthetic outcome.	Review	10 studies (1 RCT, 4 prospective studies, and 5 case reports)	/	2
Gingival biotype	The esthetics risk of thin gingival in immediate implantation could be compensated by the proper Connective Tissue Graft (CTG) technique.	Daniel et al. [60]	CTG was feasible to reduce the esthetic risk of implantation.	Systematic review and meta-analysis	4 studies	/	1
		Robert Noelken et al. [53]	Autogenous bone chip grafting in immediate implantation of type 2 sockets could get a satisfactory outcome.	Case series	16 patients (type 2C sockets)	13 to 36 months	4

patients with osteoporosis was 98% (based on 17 studies), which had no statistical difference from that of normal patients [27]. Another meta-analysis aiming at 217 osteoporosis patients with a total of 702 implants, showed that compared with normal patients, there was no difference in the failure rate of implants at the implant level or the patient level (4.70% *vs.* 3.57%, 5.85% *vs.* 4.89%); the more marginal bone loss was observed in osteoporosis patients (0.18 mm *vs.* 0.05 mm) but within the acceptable range [40]. These studies suggest the feasibility of implant therapy for osteoporosis patients. To guarantee the success rate of implant, experts proposed that for patients with osteoporosis, but patients taking bisphosphonates, the possible adverse conditions should be fully informed [27,28].

Diabetes: Most studies believe that diabetes would cause bone resorption and wound healing problems around implants [41]. Tara et al. [27] meta-analysis of 2,248 implants in diabetic patients showed that the short-term implant survival rate reached 98%, with no statistical difference from the control group. A retrospective study on 1,112 implants of patients with moderate controlled Type 2 Diabetes (T2DM), an average follow-up time of 8.7 years, showed the implant survival rate of 94% and no difference with the control group; the average bone loss of 1.98 ± 1.81 mm. It also indicated that less bone loss around implants of delay insertion than that of early insertion, and less in the anterior region than in the posterior region [42]. It is notable that even for patients with poorly controlled T2DM, the results of an observational cohort study showed an implant survival

rate of 96.6% after 2 years of implantation, and only 29% of subjects developed peri-implant mucositis [43]. These all suggest that diabetes is a relative risk factor rather than a contraindication for implantation. Although many studies have revealed that diabetes was not a cause of bone resorption and wound healing problems around implants, the severity of clinical outcomes around implants may be related to HbA1c levels. Poorly controlled type 2 diabetes (HbA1c >8.0%) may lead to poorer implant outcomes. However, implant therapy may be an option for diabetic individuals with controlled blood glucose levels and oral hygiene. A clinical trial 2 enrolled 90 subjects, divided into three groups of the same sample size (30 individuals each group): Healthy patients (HbA1c 4.0% to 5.0%), pre-diabetes patients (HbA1c 5.7% to 6.4%) and T2DM patients (HbA1c>6.4%). The implant surgery was performed in each group. The results showed that the mean marginal bone resorption around the implant was significantly higher in patients with pre-diabetes and diabetes than in healthy patients, with an average of 2.1 mm, 2.5 mm and 0.7 mm, respectively. There was still inadequate robust researches evaluating bone loss around implants of patients with diabetes, and that implant therapy may be the option for patients with poorly controlled T2DM if better oral hygiene and glycemic levels were maintained [44].

Primary stability prediction

Placing an implant in the tooth extraction socket at a proper three-dimensional position with good initial stability is a prerequisite for implantation, especially for type I and type II implant placement, which has more difficult to achieve sufficient primary stability in the remaining bone due to the unhealed socket [13]. However, no conclusion on the accurate standard of primary stability prediction for different implant timing was provided.

In recent years, several works of the literature revealed that primary stability prediction should consider several factors, such as insertion depth of implant beyond root apex, root position and angulation, bone architecture (bone density, bone formation, etc.), implant design, and surgical procedure [18,45]. It is believed that to obtain sufficient primary stability, an implant should be inserted into the socket 4 mm to 5 mm beyond the root apex [43]. While Yan et al. recommended that more than 2 mm of the distance between the implant and the bottom of the socket could achieve satisfying primary stability [46]. Also, bone density affects the insertion depth. A novel formula predicting the relationship between bone quality, torque value, and ISQ has been invented by Herekar et al. [47], which revealed that the group with higher bone density (HU=850~1250) has higher primary and secondary stability than the group with lower bone density (HU=350~850 and HU=150~350). This suggests that implant in lower bone density may need deeper implantation to get enough stability.

Moreover, the three-dimensional implant position is closely related to the root position and the sagittal angle between the root axis and alveolar bone long axis. Kan JY has the sagittal root position into four types: as for Class I sagittal root position (the root is against the labial cortical plate), the alveolar bone is adequate for immediate implantation and restoration to achieve satisfying primary stability; Class II (the root is located medially of the socket without engaging either the labial or the palatal cortical plates at the apical third of the root) depends on the amount of bone apical to root apex; Class III (the root is positioned against the palatal cortical plate) requires enough labial bone volume; Class IV (at least two-thirds of the root is engaging both the labial and palatal cortical plates) is not recommended to perform immediate implant placement [48].

To put it in a nutshell, indicators like the distance from implant tip to the bottom of root apex, sagittal root direction, and bone density can be applied to predict primary stability and to guide the implant procedure (Table 4). More clinical studies focused on these novel indicators are still in demand.

Local infection assessment

Infection at the recipient site has been a matter of concern in conjunction with implant placement in the extraction alveolus and is considered a contraindication. It is previously considered that implant sites with local infection should wait 4 to 8 weeks for the infection to subside and thus type II placement will be conducted [9]. It has been well substantiated that infection could decrease the implant success rate [49], suggesting that inflammation may not be a reasonable implant condition. Thus, a thorough check on the complained teeth and extraction socket to estimate local infection is a vital step in determining the implant timing.

However, recent studies hold the belief that immediate implant placement in the infected site is a feasible procedure after performing preliminary site debridement. Several animal experiments have offered evidence of the statement. Lee et al. used three different implants to perform immediate implantation in non-infected and chronic infected sites of Beagle dogs, and no statistical significance differences of marginal bone change and implant success rate were observed in clinical outcome parameters between infected and non-infected sites [10]. Clinical research also comes out with similar results. A retrospective cohort study carried by studying 30 long-term cases of immediate implantation with immediate loading in infected sites and concluded that the infected fresh socket was not an absolute risk factor for immediate implant survival while soft and hard tissue augmentation was also recommended at the same time to avoid excessive mucosa recession and bone resorption [50]. A multicenter retrospective clinical study of 527 implants (334 in non-infected sites and 193 in infected sites) and discovers that no significant difference in implant survival between the two groups based on preliminary debridement being well performed [25]. A systemic review with a meta-analysis of 9 clinical pieces of research from 2009 to 2017 has been done by Chen et al. and revealed that there was no statistically significant difference between infected and non-infected sites in implant survival rate, bone and soft tissue change [7].

All of these seem to demonstrate that infection may not be a definite contraindication for immediate implantation, provided that cautious preliminary debridement was performed and adequate soft and hard tissue could be achieved to avoid related complications (Table 5). It must be noted that though there was some evidence for the safety of put an implant into the infected socket, it is still a controversial issue, and clinicians are still suggested to make a more cautious decision on this.

Esthetic factors assessment

It is well documented that the esthetic prognosis of type I placement with insufficient soft tissue is more unpredictable than other types of placement [51]. After several weeks of soft tissue healing, type II implantation could provide more keratinized mucosa for wound healing and bone regeneration. Therefore, for better long-term esthetic stability, esthetic factors should be carefully assessed before type I implantation, and patients with high esthetic risk are not recommended for type I implantation [13]. Many factors can affect

Table 7: Updated views in a re-evaluation of the esthetic condition and bone volume.

Previous decision tree	Updated views	Reference	Research conclusion	Type of experiment	Case number	Observation time	Level of evidence
Implant placement with simultaneous GBR for type 1/4 bone defect	Implant placement without GBR in sites with buccal bone dehiscence (≤ 5mm) is available	Waller et al. [64]	Implant placement in sites with buccal bone dehiscence (≤ 5mm) without GBR also can achieve a satisfactory outcome.	RCT	22 patients (28 posterior implants)	7.5 years on average (at least 6.8 years)	3
Staged GBR with absorbable membranes or space-maintaining devices for type 2/4 bone defect	New technology: cortical bone reposition technology for type 2/4 bone defect	Martinez-de la Cruz G et al. [65]	Cortical bone reposition technology could get satisfactory bone augmentation (from 3.28 mm to 6.46 mm in width) and Implant Stability Quotient (ISQ was 68 at placement and 72 at the second operation for changing abutment).	Case series	7 patients (16 implants)	4 months	4
Staged autogenous bone block grafting for type 3/4 and 4/4 bone defect	New technology: seed technology and inlay bone graft with simultaneous can be used for implant placement with type 3/4 and 4/4 bone defect	Kutlu et al. [67]	Seed technology for the vertical bone defect can achieve a satisfactory outcome.	Case report	1 patient	12 months	4
		El Zahwy M et al. [68]	Inlay bone graft with simultaneous implant placement or vertical bone defect can achieve a satisfactory outcome.	RCT	16 patients, 40 implants	6 months	3

the final esthetic outcome, previous decision tree mainly focused on the thickness and integrity of the labial bone wall and gingival biotype (Table 6).

The labial bone wall: It was recommended that 1mm thick intact labial bone wall was needed for immediate implant placement [4], clinicians were recommended to choose to perform socket preservation when dealing with sockets with the labial bone defect. However, there are some new opinions on whether immediate implant could be achieved in labial bone defect sockets. Elian et al. provided a simple but practical extraction socket classification: Type 1- the labial bone wall and soft tissue were completely intact; type 2- the soft tissue was present while the labia bone wall was partially or absent; type 3- both the labial bone wall and soft tissue were reduced after the tooth extraction [52]. Several reports have revealed that type 2 sockets could operate immediate implant placement with simultaneous bone defect reconstruction. Robert Noelken et al. [53] carried out immediate implant placement and provisional's in 18 socket sites with labial bone plate lost due to long-axis root fracture, using autogenous bone chips harvested from mandibular ramus to reconstruct the labial bone plate without using membranes. After 13 to 36 months of follow-up, the implant success rate reached 94%, the mean interproximally marginal bone levels stabilized at 1.0 mm to 1.3 mm above the first thread and the mean postoperative Pink Esthetic Score (PES) was 12.5 with overall PES remain unchanged before and after implant. These suggest that immediate implantation in labial bone defect sockets as type 2 sockets could be achieved with simultaneous bone augmentation with a satisfactory esthetic outcome.

To better understand the soft tissue esthetic outcome of immediate implantation of type 2 socket, the type 2 socket was further divided into three sub-classification: Type 2A-the coronal one-third of the labial bone plate of the socket is absent with the labial bone crest 5 mm to 6 mm apical to the Free Gingival Margin (FGM); type 2B-the middle to coronal two-thirds of the labial bone plate of the socket is absent with the labial bone crest approximately 7 mm to 9 mm apical to the FGM; type 2C-the labial bone plate is absent with the labial bone crest bone 10 mm or more apical to the FGM [54]. Rosa et al. published the esthetic outcomes of the compromised sockets (12 type 2C; 6 type 2B) restored with Immediate Dentoalveolar Restoration (IDR), which includes immediate implantation, bone augmentation using cortico-cancellous bone graft harvested from maxillary tuberosity to restore the bone defect and provisional full crown at 58 months follow-up. The implant success and prosthesis survival rates are both 100%, with no significant 0.06 mm gingival recession on the facial aspect [55]. Sarnachiaro et al. [56] made immediate implant placement into 10 type 2 sockets (type 2A or type 2B) using an absorbable membrane with allograft to reconstruct the bone defect at implantation which was similar to “ice cream cone” technology. After 6 to 9 months of follow-up, the implant success rates are 100% and the minimal amount of labial bone plate thickness of 2.0 mm was achieved in all treated sites, maintaining the gingival architecture and satisfactory esthetics.

Socket Shield Technique (SST) is also a feasible alternative for immediate implant placement. A retrospective case series of 10 patients conducted by Bäumer et al. [57] showed that SST offers less invasiveness during surgery and high esthetic results with effective preservation of tissue contours. An RCT compared the esthetic and clinical outcomes of conventional flap-Less and SST in immediate implantation and showed that SST obtained satisfying functional and esthetic outcomes [58]. This research all suggests us the socket with labia bone wall partially or even totally absent has not been a contraindication for immediate implant placement with simultaneous bone defect reconstruction and the success rate and esthetic outcome are satisfactory.

Gingival biotype: Is also important to esthetic outcomes. It was well recommended that thin gingival biotype has higher esthetic risk such as gingival recession and mental exposure of abutment. Buser et al. [4] have suggested that intact facial bone wall with thick wall phenotype (>1 mm) and thick soft tissue biotype as selection criteria of immediate implant placement. However, it seems that some treatments have been proposed to compensate for the lack of gingival thickness. When it comes to cases of a thin gingival biotype with or without slightly bone dehisces, immediate implant placement accompanied with Connective Tissue Graft (CTG) is believed to obtain the optimal esthetic result by resisting mucosal recession as well as enhancing wound closure procedure.

Mazzotti et al. [59] published a review about soft-tissue dehiscence coverage and recommended that the most evidence-based surgical technique for soft-tissue augmentation was the coronally advanced

flap with connective graft. The impact of this technique on mucosa dehiscence coverage has studied by one RCT, four prospective studies and five case reports in this review and all exhibited less marginal mucosa recession and almost completely soft tissue dehiscence coverage, which indicated that with proper surgical technique CTG, was able to produce an optimal and predictable esthetic outcome. Another systemic review with meta-analysis believes that the CTG contributes to fewer marginal bone resorption compared with non-grafted sites. In this meta-analysis, two out of four included studies report marginal bone level changes, which is more evident in the control group (without CTG) than in the test group (CTG treated) [60]. These researches remind us that the esthetics risk of thin gingiva in immediate implantation could be compensated by the proper CTG technique. However, this technique also has some disadvantages, such as violation of greater palatine artery from donor site caused by incautious surgery, postoperative bone exposure, pain, and so on [61]. Therefore, clinicians must make a more careful decision for patients with thin gingiva.

Bone volume assessment

Implant placement simulation offers the references to assess the bone volume of the extraction site, by which classify the probable bone defects into five types: Type 0, type 1/4, type 2/4, type 3/4, type 4/4. Type 0 refers to that there is an adequate bone for implant placement in a correct 3D position. As for the other four bone defect types, implant placement with simultaneous GBR was recommended for type 1/4, staged GBR with absorbable membranes or space-maintaining devices for type 2/4 and type 3/4 respectively, and staged autogenous bone block grafting for type 4/4 [62]. In terms of implant timing, only the type 1/4 bone defects can have type 3 implant placements, while the other bone defects are passively group to type 4 implant placements due to the waiting time for bone healing after staged augmentation procedures [63].

Some updated views need to be noticed (Table 7). For type 1/4 bone defect, Waller et al. reported that placement in sites with buccal bone dehiscence (≤ 5 mm) without GBR also can achieve complete 100% survival rates and stable and healthy peri-implant tissue after a long term follow-up of 7.5 years [64]. For horizontal bone deficiency, a new treatment method called Cortical Bone Reposition (CBR) technology has been proposed, which has been proved by preclinical experiments and clinical cases to accomplish horizontal bone augmentation with satisfying outcomes [65,66]. In CBR, the cortical bone block is cut from the bone defect area and free from the bony surface. Then, the bone block is replaced (horizontally) laterally, fixed by titanium screws, thus creating a secure space for bone regeneration. After healing, implantation could be achieved. It avoids additional surgery and donor site morbidities and needs minimal biomaterials compared with autogenous bone grafting or GBR.

For vertical bone deficiency (type 3/4 and type 4/4 bone defects) in the maxillary anterior region, Kutlu HB et al. [67] reported a new, two-staged method to accomplish implantation, called "seed technology". The implant is first inserted into the maxillary tuber and waits 2 months for osseointegration, and then the osseointegrated implant with surrounding bone was transplanted into the maxillary lateral incisor area and fixed with a mini plate to the adjacent native bone. After 12 months of follow-up, the complete fusion between transplanted bone block and adjacent bone was discovered and the patient was fully satisfied with the function and esthetics of restoration.

Besides, El Zahwy et al. [68] carried out a randomized clinical trial and found that inlay autogenous bone grafting with simultaneous implantation can successfully address the vertical ridge bone augmentation in the esthetic area, showing much more vertical bone formation and less bone resorption than that of only autogenous bone grafting plus simultaneous implantation. This technology dramatically reduced the treatment time and patients suffering from two surgeries, compared to the staged bone autogenous bone block grafting plan.

Decision tree for implant timing and updated views

To achieve the ultimate goal of restoring the lost teeth, the restoration factors should be evaluated first to eliminate risk factors affecting the final crown function (Step 1). While bruxism used to be a relatively high-risk factor of implant, recent studies showed a positive outcome for bruxism patients after a positive intervention such as occlusal splint treatment, using long implants, and reducing occlusal contact area, et al. Insufficient restoration space are relatively common and can be solved by conventional ways like occlusal adjustment and orthodontic treatment, besides, platform switch of implant, and alveolectomy also act as an alternative option.

Secondly, systemic factors should be thoroughly evaluated to guarantee the patients' tolerance to invasive surgery (Step 2). Oral taking BPs was convinced with little effect on the early success rate of implant treatment while more attention should be paid to patients receiving intravenous BPs. It's certified that radiotherapy would not affect the implantation success rate if the aseptic operation of implanting surgery, the interval of radiotherapy, and the radiotherapy dose were ensured. For patients with osteoporosis careful evaluation of jaw bone density could avoid the risk affecting implant and function. Patients with moderate controlled T2DM could also get implantation if better oral hygiene and glycemic levels were maintained.

Placing an implant in a tooth extraction socket with proper three-dimensional position and good initial stability is a prerequisite for immediate implantation; otherwise, a prolonged bone healing period will be recommended (Step 3). Insufficient primary stability is likely to increase the failure rate of implants [69]. It is related to factors including bone density, insertion depth (>2 mm), and sagittal root position compared with type 3/4 placement, type 1/2 placement may not be able to achieve sufficient primary stability limited by the remaining bone around. Therefore, the third step is to access the three-dimensional position of the implant to determine whether sufficient primary initial stability could be reached.

There are still other factors that influence the choice of type 1 and 2 placement. Local infection is another factor that affects the effectiveness of the implants and usually heals within 4 to 8 weeks (Step 4). In this case, type 2 implant placements may be a preferred choice [13,70,71]. Its worth to be noted that, in recent years, some researchers have reported that infection of extraction sockets is not a contraindication for immediate implantation after cautious preliminary debridement.

Besides, to reduce the failure rate and complication rate, extra consideration about the long-term esthetic stability is essential (Step 5). Due to insufficient soft tissue, the esthetic prognosis of type 1 placement is more difficult to predict [52]. Therefore, for better long-term esthetic stability, esthetic factors should be carefully assessed before type 1 implantation, which was set as the fifth step. On the other hand, for cases excluded in the third step, type 1/2 placement

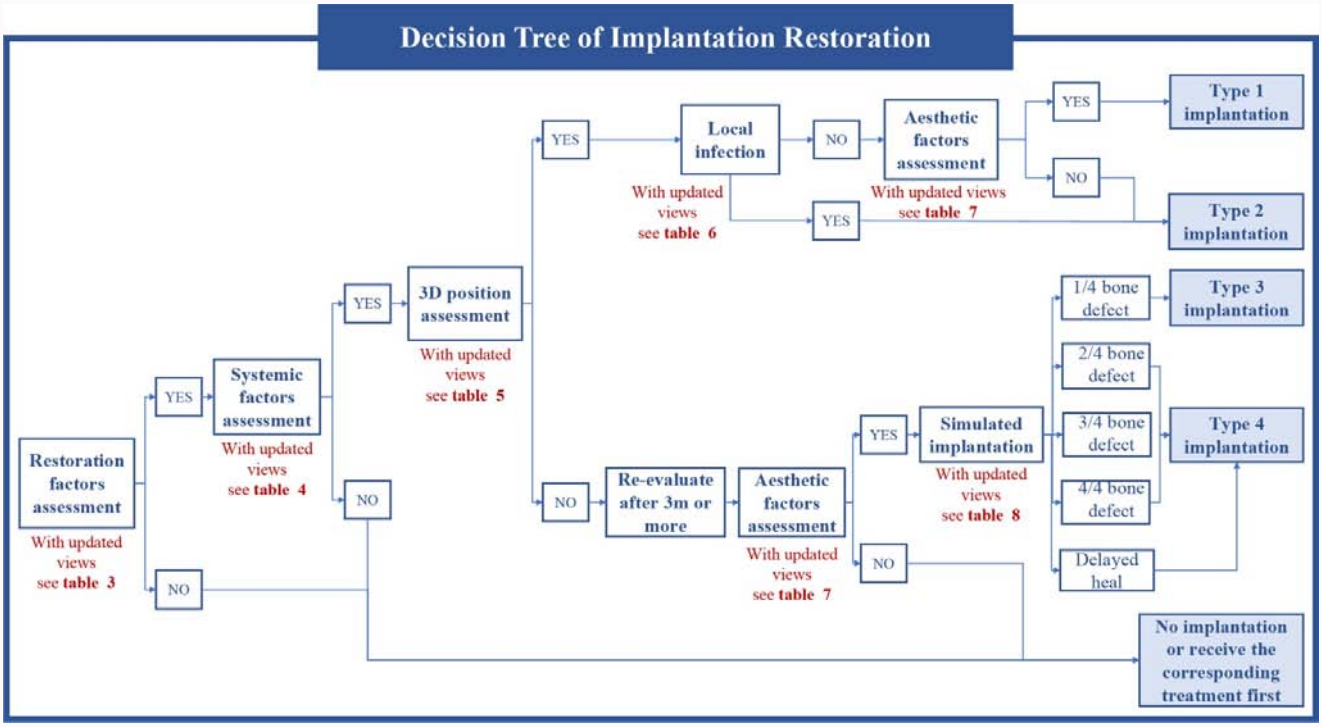

Figure 1: Decision tree for choosing implant restoration timing at the single residual root. Once the residual root was identified for extraction, there would be a five-step process: Restoration factors consideration, systemic factors evaluation, three-dimensional position assessment, local infection evaluation, and aesthetic factor consideration before making a more accurate implantation treatment decision. The updated views of related assessment factors can be found in Table 3-7.

is not allowed. Patients are recommended to return to the clinic for another evaluation 3 or 4 months after tooth extraction [64,72]. Since the anterior zone is essential for appearance, esthetic factors should be taken into account.

Finally, most cases were accompanied by severe bone defects, coupled with continued alveolar bone resorption after tooth extraction [71-73]. Thus it is necessary to conduct a simulated implantation assessment to determine available bone volume. Implant placement could be carried out only in the sites with the bone defect of type 1/4, which are grouped to type 3 implant placements [64]. Others will receive a staged bone augmentation and at least an additional 6 more months to wait before implant placement. In terms of implant timing after tooth extraction, they belong to type 4 implant placement [64], while the bone condition is different from that true type 4 implant placements due to the bone augmentation procedures.

Therefore, the selection of various implanting timing needs to be careful and thorough, among which, the selection of type 4 placement needs to consider some other factors. It happens sometimes that patients come with a not fully healed socket, showing either low density or a hole not filled with new bone in CBCT images, which may be attribute to diabetes [74,75], osteoporotic [76], smoking [77], or taking corticosteroids [78]. These patients are usually advised to wait another one or two months before considering implant restoration until the socket is completely healed, which makes them be passively grouped to type 4 implant placement as well concerning implant timing [64]. Besides, there are other specific reasons making patients get type 4 implant placements, including young age, pregnancy, work-related reasons, and large apical bone lesions such as radicular cysts or ankylosed tooth, all of which can pass the esthetic condition step are passively grouped to type 4 implantation [64].

Taking together we put forward a five-step implant therapy decision tree: restoration factors consideration, systemic factors evaluation, three-dimensional position assessment, local infection evaluation, and esthetic factor consideration [79-82]. For cases that were eliminated in the three-dimensional position assessment, additional reevaluation after 3 or 4 months for esthetic factors and the bone condition is required (Figure 1).

A case analysis based on the proposed decision tree for a single maxillary anterior residual root

To better understand the proposed decision tree and guide clinical decision-making more practically, we apply it to a clinical case. The initial clinical situation of left central incisor in the maxilla with 2 weeks after the trauma (Figure 2). Most dental crowns were deficient, and the residual palatal root existed below the palatal gingival margin nearly 1 mm to 2 mm. The gingival color, texture, and morphology were normal with no swelling and atrophy (Figure 2a, 2b).

The labial gingiva thickness measured by probing (Figure 2c) and was more than 1 mm which implied a thickness gingiva biotype to a certain extent. The patient had a median smile line (Figure 2d). The periapical radiograph showed no obvious crack lines or low-density images of the root apex (Figure 2e). These collectively indicate that the root condition meets the requirement to get perfect RCT. The sagittal CBCT showed the crown fracture in the palatal side which extends obliquely to the alveolar crest, which cannot the requirement of dentin ferrule (Figure 2f). Crown lengthening or orthodontic traction was required if a post-and-core crown was intended. The existing root length was 11.6 mm (Figure 2g) and the length after orthodontic traction would only be 10.1 mm (to get dentin ferrule with the height of 1.5 mm at least), while the crown length of homonym tooth right central incisor was 11.6 mm (Figure 2h) causing the crown-root ratio

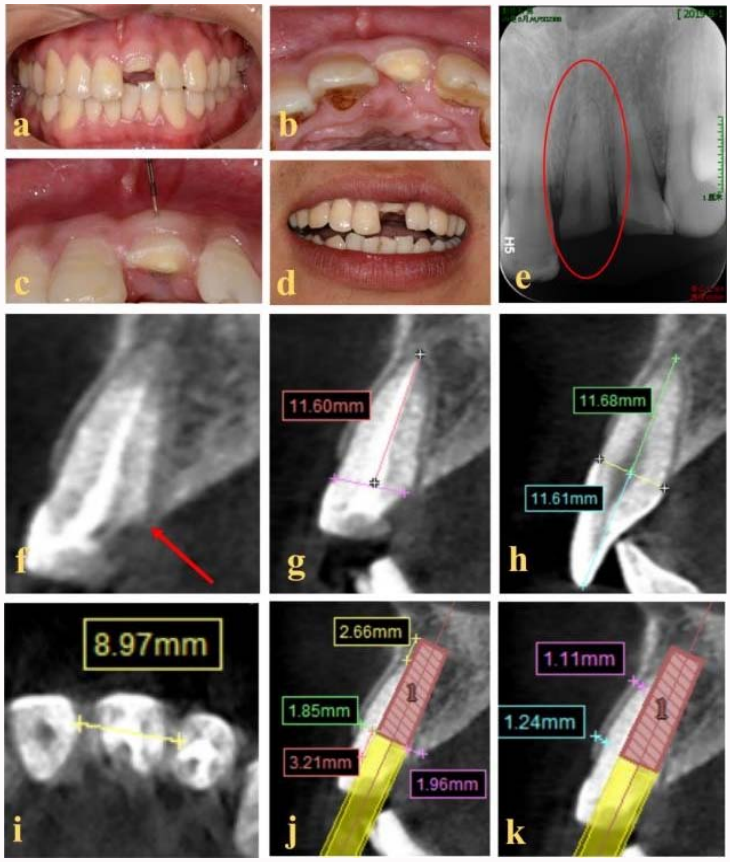

Figure 2: The clinical photograph and image data of one general case. Intra-oral photograph of basic initial clinical situation of the left central incisor (a, b), measurement of the labial gingiva thickness (c), the extra-oral photograph of the smile line, and periapical radiograph (e). The sagittal plane of CBCT image (f) of the complained teeth. Measurement of the root length of complained teeth (g) and the crown length of homonym tooth right central incisor (h). The mesial-distal distance at the alveolar crest level (i). The sagittal plane of implant simulation on CBCT with implant 4.1 mm in diameter and 12 mm in length (j). The labial bone thickness of the left central incisor root (k).

>1:1 (11.6:10.1) after orthodontic traction. Therefore, the complicated root was proposed to be extracted and proceed to implantation restoration clinical pathways (Figure 3a).

For the implantation restoration decision tree, the first step was to evaluate the restoration risk factors. The occlusal space: the mesiodistal distance at the alveolar crest level was 8.97 mm (Figure 2i) and occlusal-gingival distance both were normal and occlusal dysfunction such as bruxism was not found. Thus the restoration situation was suitable for implantation restoration treatment. The second step was to evaluate systemic risk factors. Through inquiring about the patient's previous medical history, it was known that there was no allergic and bisphosphonates injection history and no systemic disease, so the whole physical condition of the patient could tolerate the implantation surgery. For the third step to evaluate the primary stability of the implant, implant simulation was carried out by using implant software SIMPLANT Mater 17.07 (Materialise Dental, Belgium) with regular type implant 4.1 mm in diameter and 12 mm in length (Figure 2j). It was worth mention that the root was class I sagittal position (the root is against the labial cortical plate), signifying the alveolar bone was adequate for immediate implantation and restoration to achieve satisfying primary stability and ideal sagittal root position could be achieved. As can be seen from the sagittal CBCT image practically, the cervical implant was located 3 mm to4 mm below the boundary of the adjacent enamel-cementum. Enough insertion depth 2.66 mm (>2 mm), the labial jumping gap was 1.85 mm (<2 mm) providing sufficient retention. Thus type 1 and 2 implant placements were both feasible treatment options. No local infection was observed at the implant site. Esthetic factors can then be evaluated for further selection. Clinically, the patient presented medium scalloped gingiva and thick biotype and had a median smile line. The thickness of the labial bone wall was intact and with thickness >1 mm (Figure 2k). Besides, the patient was a healthy and co-operative non-smoker with moderate esthetic expectation. All the above clinical status indicated low esthetic risks, which was more likely to get a satisfactory esthetic outcome.

All in all, through the evaluation of reparation factors, it is concluded that no significant restoration factors affecting final crown functioning. Systemic factors evaluation shows that the patient's systemic conditions are appropriate to receive the implant surgery. Implant position evaluation shows that the bone tissue was sufficient to maintain the implant in the designed position. No local infection was observed at the implant site. The evaluation of esthetic factors indicates that there are few undesirable esthetic factors at this site. In conclusion, the left central incisor in the case preceded to immediate implant clinical pathways (Figure 3b).

Summaries

Patients come with complaints of the residual root in the maxillary anterior region is commonly seen in dental implant clinics. Many complicated factors need to be taken into consideration to

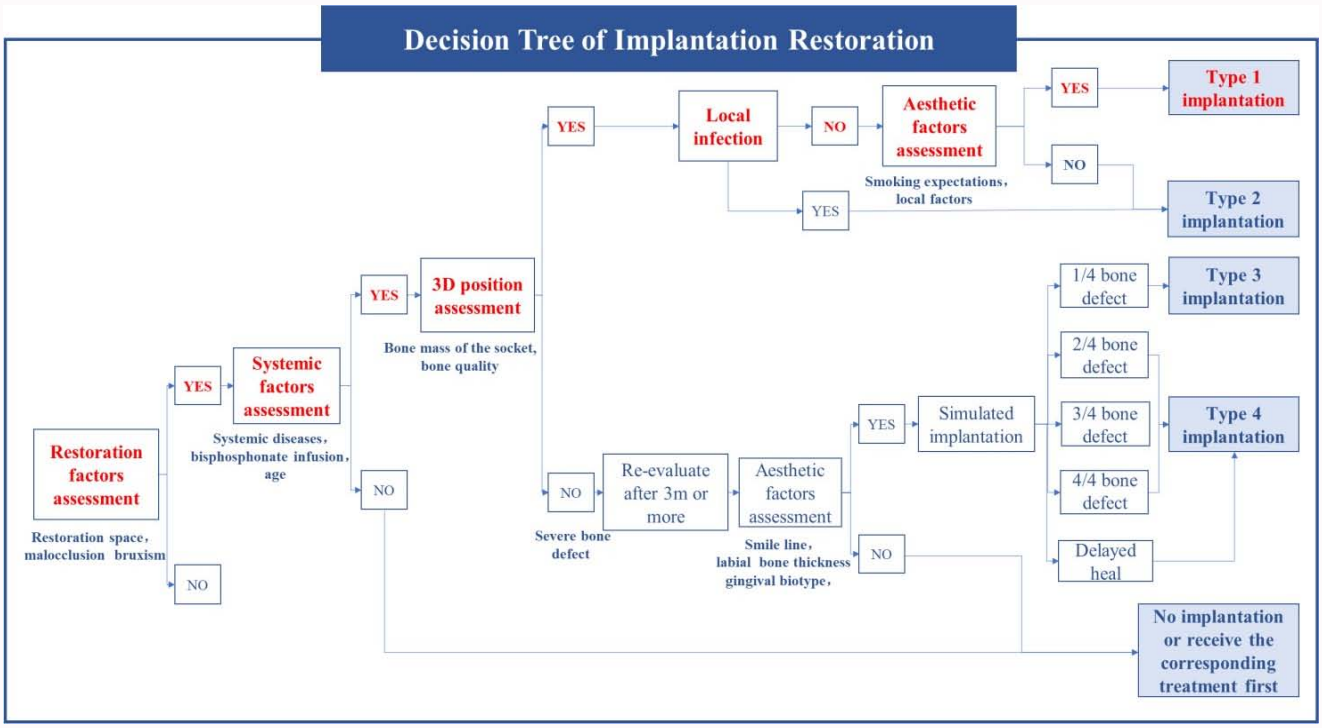

Figure 3: The clinical restoration pathway of the mentioned case (red font). The implantation pathway of the left central incisor: After evaluation of the five-step process of restoration factors consideration, systemic factors evaluation, three-dimensional position assessment, local infection evaluation, and aesthetic factor consideration, type 1 implantation was recommended for this case.

choose a post-core, immediate implant, early implant, or late implant treatment plan. While many efforts have been put into reaching an accurate decision tree on this matter and achieved some success, the views have been changing till now. Therefore, we summed up the latest research updates to make a more reasonable treatment decision-making approach. According to documented clinical and basic scientific researches, we first summarized relevant decision-making factors. Literature retrieval on each factor was conducted and summed up in tables with updated views. Based on the strength of the evidence we corrected these determinants and proposed an updated decision tree of the single maxillary anterior residual root. It is our ambition that the summarized treatment decision tree with updated views for single maxillary anterior residual root will help clinicians to make more accurate treatment decisions which are promising to get the most predictable prognosis based on evidence-based medicine.

We summarize all the updated views on choosing immediate, early, or late implant for a single maxillary anterior residual root based on the strength of evidence. We propose a clear and feasible decision tree of implant timing for the single maxillary anterior residual root based on the summarized updated views which provides a reference for clinicians to make proper treatment decisions.

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All authors contributed to and approved the final manuscript. Mengru, Haiwen, and Xiaoshuang led the conceptualization, analysis, and writing of the manuscript of decision tree of implant timing. Baoxin, Zhuohong, Peisheng collated and provided the clinical case. Baoxin and Zetao contributed to the updated views and all authors revised the final draft of the manuscript.

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