Dental Implants in Patients with Ectodermal Dysplasia and Tooth Agenesis: A Critical Review of the Literature

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Purpose: The aims of this article are to critique the available literature on dental implants in patients with ectodermal dysplasia (ED) syndrome and tooth agenesis, review the outcomes of implant therapy in these patients, and provide recommendations on the timing of implant placement for these patients. ***Materials and Methods:*** Searches were performed using Medline, Embase, All EBM Reviews, and Pre-Medline for articles relating to implant patients suffering from ED. Articles unrelated to the topic of dental implants in patients with ED and tooth agenesis, without abstracts, or in languages other than English were excluded. Selected articles were graded according to levels of evidence based upon guidelines set forth by the Agency for Health Care Policy and Research. Articles found to have a level of evidence of IV were excluded from this study. ***Results:*** The literature on dental implants in patients with ED and tooth agenesis was found to be scarce. No randomized controlled or case-controlled studies were found. Only 12 articles were found to satisfy all inclusion criteria. ***Conclusion:*** Implant survival rates vary between 88.5% and 97.6% in patients with ED and between 90% and 100% in patients with tooth agenesis. Implants placed in adolescent ED patients do not have a significant effect on craniofacial growth, while implants placed in ED patients younger than 18 years have a higher risk of failure. *Int J Prosthodont 2009;22:268–276.*

Ectodermal dysplasia (ED) is a group of hereditary disorders involving an absence or deficiency of tissues and structures derived from the embryonic ectoderm.[1] Clinical signs include trichodysplasia (abnormal hair) in 91% of cases, tooth agenesis in 80%, onychondysplasia (abnormal nails) in 75%, and dyshidrosis (abnormal sweat glands) in 42%.[2] ED has been divided into 34 subgroups and over 100 variations have been identified.[3] The birth prevalence of ED has been estimated to be between 1 in 10,000 and 1 in 100,000.[4] Hypohidrotic ED is one of the more common and severe forms of ED. It is X-linked recessive and is associated with heat intolerance, frequent episodes of pyrexia, and tooth agenesis. This is often accompanied by characteristic facial features including a low nasal bridge, small nose with hypoplastic alae nasi, full forehead, prominent supraorbital ridges, prominent lips, and sparse hair.[5] More recently, the gene responsible for hypohidrotic ED was identified.[6]

Tooth agenesis is a common occurrence in patients with ED, and the congenital absence of teeth may result in reduced alveolar bone growth. This has implications in the support for partial or complete removable prostheses, development of lower facial height, and the placement of dental implants. Furthermore, tooth agenesis has been shown to have a significant impact upon the oral health–related quality of life (OHRQoL) of patients aged 11 to 15 years.[7]

Oral rehabilitation of ED patients has historically involved partial or complete removable prostheses supported by tissue or teeth (overdentures). The development and acceptance of screw-type osseointegrated dental implants has provided an additional treatment modality for these patients.

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Table 1 Levels of Evidence for Studies of Therapeutic Effectiveness*

I	Evidence from at least one randomized controlled trial
II	Evidence from at least one controlled study without randomization
III	Evidence from descriptive studies (eg, comparative, correlation, or case studies)
IV	Evidence from expert committee reports or opinions and/or experiences of respected authorities

*Based on AHCPR 1993.

Sufficient data in the literature have allowed for analysis of the survival rates of implants and implant-borne prostheses. The survival of dental implants after 10 years varies between 82% and 94%.[8] Meta-analyses estimate survival rates of 86.7% for implant-borne fixed dental prostheses (FDPs), 77.8% for tooth-implant–borne FDPs, and 89.4% for implant-borne single crowns.[9] There is, however, little data on the effect of treatment with implants on OHRQoL.[10]

The University of Sydney, Westmead Centre for Oral Health accepts the referral of patients requiring complex oral rehabilitation. Patients with ED receive interdisciplinary treatment, often involving implants. Appropriate planning and treatment require evidence on the outcomes of implant therapy and timing for implant placement. Hence, the aims of this review were to *(1)* critique the available literature on dental implants in patients with ED and tooth agenesis, *(2)* review the outcomes of implant therapy in these patients as presented in the literature, and *(3)* provide recommendations on the timing of implant placement for these patients. The questions to be considered were what the outcomes of implants and optimal age for implant therapy were for patients with ED and tooth agenesis.

Materials and Methods

Search Strategy

Searches were performed using Medline articles from 1950 to present, Embase articles from 1966 to present, all EBM Reviews (Cochrane Database of Systematic Reviews, ACP Journal Club, Database of Abstracts of Reviews of Effects, Cochrane Central Register of Controlled Trials), and Pre-Medline. Where possible, keywords were based on the Medical Subject Headings of the National Library of Medicine to cover the breadth of this search. Articles without abstracts and in languages other than English were excluded.

Levels of Evidence

The grading of evidence originated from guidelines developed by the Agency for Health Care Policy and Research (AHCPR).[11] The grading system was simplified to four levels that correlate with the current levels of evidence guidelines of the AHCPR (Table 1).

Exclusion and Inclusion Criteria

Articles unrelated to the topic of dental implants in patients with tooth agenesis were excluded. All case reports and articles with the lowest level of evidence (level IV) were also excluded. Because of the scarcity of articles relating to the topic, no further exclusion criteria were used. The reference lists of the included articles were screened for further possible references. The initial screening of abstracts, exclusion of articles, grading of articles, and handsearching of cited references within the included papers was completed by the primary author.

Results

Literature on dental implants in patients with ED was found to be scarce. Table 2 outlines the search strategy. Results of the initial search yielded 151 articles, of which 113 contained abstracts and were written in the English language. Analysis of the abstracts excluded 39 irrelevant articles, leaving 74 articles that were related to the topic of dental implants in patients with tooth agenesis. After exclusion of all case reports, 41 articles remained.

The remaining articles were then graded according to the corresponding level of evidence. Overall, the levels of evidence were found to be weak. No randomized controlled or case-controlled studies were found, reflecting the prevalence of ED and the ethical difficulties in conducting controlled trials on children. Levels of evidence of all selected articles were graded III or IV (Table 3).

Articles with level IV evidence were excluded, leaving only 12 articles. The articles were then divided into their major topics, which are outlined in Table 4. Data were extracted from the articles and summarized in Table 5.

Implants in Patients with ED and Tooth Agenesis

Survival rates of implants ranged from 88.5% to 97.6% in the three studies that only focused on treating patients with ED.[12–14] This was similar to the survival rates of 90% to 100% reported by the five studies in which oligodontia or special needs patients were treated.[17–19,22,23]

Table 2 Synopsis of Search Strategy and Outcome Using Ovid Medline

Search heading	No. of articles	Search heading	No. of articles
Ectodermal dysplasia (MeSH)	2,523	Dental implants (MeSH)	10,034
Anodontia (MeSH)	2,339		
Oligodontia	245		
Hypodontia	643		
Tooth abnormalities (MeSH)	4,319		
Tooth agenesis	107		
Tooth aplasia	8		
Congenitally missing teeth	102		
Total no. of hits using "OR" option	8,355		10,034
No. of articles referencing all of the above terms and dental implants	151		
No. of articles with abstracts and in English	113		

MeSH = Medical Subject Headings from the National Library of Medicine.

Table 3 Level of Evidence of Selected Articles

Level of evidence	No. of articles
I	0
II	0
III	12
IV	29

Table 4 Major Topics of Selected Articles

Major topics	No. of articles
Implants in patients with ED and tooth agenesis	7
Age, growth, and implants	2
Interdisciplinary management	3
Total	12

When failure rates of implants in ED patients were calculated at the subject level, the percentage of subjects with one or more implant failure ranged from 16.7% to 35.7%.[12–14] In oligodontia patients, the subject level failure rate ranged from 4.3% to 38.5%.[17,18,22]

In ED patients, 93% to 100% of implant failures occurred before prosthesis insertion.[12–14] Implant failures were also found to be higher in the maxilla than in the mandible, with percentages ranging from 5% to 29% and 0% to 9%, respectively.[12–14] This was similar to the findings of Finnema et al in which the failure rate of oligodontia patients was 14% in the maxillae and 4% in the mandibles.[17]

Bone augmentation procedures were provided for 50% of ED patients at the time of implant placement.[13] In oligodontia patients, 61.5% to 84.6% received bone augmentation procedures before implant placement.[17,18]

All 109 patients (75 with ED, 34 with oligodontia or special needs) in five studies received implant-borne prostheses despite implant failures.[12–14,17,19]

Three studies reported on prosthetic complications.[14,19,23] Prosthesis success/survival was 94% and retreatment was 6% 1 year after insertion.[12] The most frequent technical complications reported were screw loosening and sore spots, both of which occurred equally during the first year of function.[19] Prosthesis complications were reported to occur in 17.4% of implants up to 11.8 years (mean = 5.0 years) after prosthesis insertion.[23]

One study reported on satisfaction, treatment experience, and mandibular function impairment in oligodontia patients by using a questionnaire.[17] Satisfaction was reported by all patients, confidence improved in 69.2%, and level and quality of functional impairment improved significantly after implant and prosthodontic treatment.

Two studies reported on the number and position of teeth present in ED patients.[14,16] Both studies reported that the maxillary teeth most likely to be present were central incisors (42% to 71%), first molars (41% to 54%), and canines (22% to 43%); mandibular teeth most likely to be present were first molars (39% to 40%). However, the presence of mandibular canines and premolars was not similar between the two studies.

Age, Growth, and Implants

Only one study compared implant survival in different age groups of ED patients.[12] When implant survival was compared in ED patients younger than 11, 11 to 18, and older than 18 years, no significant differences were found. However, when patients younger than 18 years were compared to those older than 18, a hazard ratio of 2.5 was found.

Table 5 Synopsis of Included Studies in Order of Topic and Study Design

Author	Study summary	Primary outcome measures	Outcomes	Major weaknesses
Guckes et al[12]	• Level of evidence = III, prospective case series • n = 51 ED patients (8–68 y, mean = 20.5 y) with > 13 missing permanent teeth, 264 implants • Data up to 6.5 y after 2nd stage surgery (median 1.9 y)	• Implant survival • Kaplan-Meier survival rates and Cox regression models to compare 3 age groups (< 11, 11-18, > 18 y)	• Survival rate at implant level = 90% for up to 2 years after 2nd stage surgery • 27% at subject level had failure of ≥ 1 implant • 93% of implant failures occurred at or before 2nd stage surgery • Implant failure in the anterior maxilla = 14%–29%; anterior mandible = 8%–9% • Implants in the anterior maxilla had a hazard ratio of 2.8 compared to the anterior mandible (interpret with caution because of the small sample size) • No significant differences in survival in the 3 age groups • Subjects younger than 18 y had a hazard ratio of 2.5 compared to subjects older than 18 y • Implant-supported prostheses were provided for all subjects (maxillary prostheses = complete removable with bar-clip attachments, mandibular prostheses = fixed or removable with bar-clip attachments)	• Short-term data • Basic implant survival criteria (implant survival = nonmobile and supporting a prosthesis) • No information on loss to follow-up
Kearns et al[13]	• Level of evidence = III, prospective and retrospective case series • n = 6 patients with ED (4 prospective, 2 retrospective) (5–17 y, mean = 11.2 y), 41 implants • Data up to 10 y (mean = 6 y) after prosthesis insertion	• Implant survival • Growth assessment using cephalometric radiographs	• Survival rate at implant level = 97.6% up to 10 y after prosthesis insertion • 16.7% at subject level had failure of ≥ 1 implant • Implant failure occurred at 2nd stage surgery • Implant failure in the maxilla = 5.3%; mandible = 0% • 50% of subjects received bone augmentation at the time of implant placement. • 75% of subjects receiving maxillary implants received bone augmentation at the time of implant placement • Implant-supported prostheses were provided for all subjects (9 removable, 1 fixed prosthesis) • Mandibular and maxillary sagittal or transverse growth did not adversely affect implant position • Mandibular and maxillary vertical growth adversely affected implant position in 2 subjects (33%). Submergence of implants required longer abutments and prosthesis revisions	• Relatively small sample size • Basic implant success criteria (implant success = asymptomatic and supporting a prosthesis) • No information on loss to follow-up
Sweeney et al[14]	• Level of evidence = III, retrospective case series • n = 14 ED patients (12.2–21.9 y, mean maxilla = 17.4 y, mean mandible =18.5 y), 61 implants • Data up to 5.1 y after prosthesis insertion (mean = 2.4 y)	• Implant success • Prosthodontic success[15] • Number and position of missing and present permanent teeth	• Survival rate at implant level = 88.5% 1 y after prosthesis insertion • 35.7% at subject level had failure of ≥ 1 implant • All implant failures occurred at or before abutment connection • Implant failure in the anterior maxilla = 20%; anterior mandible = 8.7% • Implant-supported prostheses were provided for all subjects (14 fixed, 3 removable) • Prosthesis success/survival = 94% 1 y after prosthesis insertion • Prosthesis retreatment (repair) = 6% 1 y after prosthesis insertion • Average number of missing permanent teeth = 22.5 • Maxillary teeth most likely to be present were central incisors (71%), first molars (54%), and canines (43%)	• Relatively small sample size • Short-term data • No information on prosthesis design
Guckes et al[16]	• Level of evidence = III, cross-sectional study • n = 52 ED patients (5.9–60.9 y, mean = 18.7 y)	• Position of missing and present teeth • Wilcoxon signed-rank test to compare quadrants	• Mandibular teeth most likely to be present were canines (40%), first premolars (40%), and first molars (40%) • Maxillary teeth most likely to be present were central incisors (42%), first molars (41%), canines (22%), and second premolars (15%) • Mandibular teeth most likely to be present were first molars (39%), second molars (17%), and premolars (12%) • Mandibular anterior teeth were least likely to be present	• Selection bias (study population was respondents to a call for trial subjects involving dental implants)
Finnema et al[17]	• Level of evidence = III, retrospective case series • n = 13 oligodontia patients (17–30 y, mean = 20 ± 3 y), 87 implants • Data up to 8 y after prosthesis insertion (mean = 3 ± 2 y)	• Implant survival • Patient satisfaction, treatment experience, and mandibular function impairment by questionnaire • Radiographic periimplant bone level • Soft tissue indices • *t* tests for paired data; Pearson correlation tests for unpaired data	• Survival rate at implant level = 90% 8 y after prosthesis insertion • 38.5% at subject level had failure of ≥ 1 implant • Implant failure in the maxilla = 14%; mandible = 4% • 84.6% of subjects received bone augmentation before implant placement • No difference in failure rates between bone-graft augmented sites and ungrafted sites • Satisfaction reported by all patients • Confidence improved in 69.2% of patients • Level and quality of functional impairment improved significantly • Persisting complaints occurred in 18.2% of patients who received bone augmentation • Bone loss (mean = 1.6 ± 0.9 mm) occurred around single-tooth restorations during the mean functional period of 3 y • Positive correlation between Bleeding Index, Plaque Index, and Probing Depth • The average number of missing permanent teeth = 12 ± 4 (range: 6–18)	• Relatively small sample size • Short-term data • Recall bias (retrospective analysis with the questionnaire)

Table 5 continued Synopsis of Included Studies in Order of Topic and Study Design

Author	Study summary	Primary outcome measures	Outcomes	Major weaknesses
Durstberger et al[18]	• Level of evidence = III, retrospective case series • n = 13 oligodontia patients (9–33 y, mean = 18.9 y), 72 implants • Data assumed to be up to 5 y (mean unknown)	• Implant survival • Augmentation procedure received • Orthodontic treatment received	• Survival rate at implant level = 95.8% at 5 y • 7.7% at subject level had failure of ≥ 1 implant • All implant failures occurred before prosthesis insertion • Implant failure was higher in the maxilla than the mandible (insufficient data to calculate percentages) • 61.5% of subjects received bone augmentation before implant placement • 76.9% of subjects received orthodontic treatment before implant placement	• Relatively small sample size • Vague survival data • No information on loss to follow-up • Unknown criteria for implant survival • Unknown starting point for measurement of survival period • No information on prosthodontic outcomes

Oczakir et al[19]	• Level of evidence = III, retrospective case series
	• n = 25 special needs patients (19–89 y, mean = 55.6 y), 105 implants including 17 implants in 4 ED patients
	• Data 2–12 y (mean = 5.8 y)
		• Implant survival
		• Life table analysis for cumulative survival rates of implants
		• Prosthodontic survival
		• Biologic complications
		• Technical complications
			• Cumulative survival rate at implant level = 93.4% after 5 y
			• Prosthodontic survival = 100%
			• 23 removable and 11 fixed implant-borne prostheses
			• Most frequent biologic complication was peri-implant mucositis
			• Most frequent technical complications were screw loosening and sore spots, both of which occurred equally during the first year
			• In the 4 patients with ED:
			  • Mean age at time of treatment = 31.5 y (range: 23–37 y)
			  • Cumulative survival rate of implants = 100% up to 12 y (range: 3–12 y, mean = 9.5 y)
			  • 2 removable and 3 fixed implant-borne prostheses
			  • Biologic complications: peri-implant mucositis in 1 patient and peri-implant bone loss in 2 patients
			  • Technical complications: porcelain crack in 1 patient requiring replacement after 2 y of function
				• Relatively small sample size
				• Unknown criteria for implant survival
				• Unknown starting point for measurement of survival period (implant placement or prosthesis insertion)
				• Unknown criteria for prosthodontic survival
				• Insufficient data to calculate failure of implants at subject level

Johnson et al[20]	• Level of evidence = III, prospective case series
	• n = 128 non-ED controls + 50 untreated ED patients + 45 ED patients treated with implants (mean ages unknown)
		• Growth assessment using cephalometric radiographs
		• Comparison between non-ED, untreated ED, and treated ED subjects
		• Comparison between 4 age groups (≤ 5, 5–12, 13–17, > 17 y)
		• Statistical Analysis System and Generalized Estimated Equation analysis
			• In ED patients:
			  • Craniofacial measures did not differ between X-linked ED and autosomal hypohidrotic ED patients
			  • Deviation of craniofacial measures increased with age
			  • Number of missing maxillary permanent teeth was associated with midface hypoplasia in 13–17 and > 17-year-olds (decreased sella to nasion to A point, sella to anterior nasal spine, and anterior nasal spine to nasion to sella)
			  • Flattened profile (decreased anterior nasal spine to nasion to sella and decreased Frankfurt horizontal to sella to menton
			  • Mandibular prognathism or Class III tendency increased (increased pogonion to nasion to sella and sella to pogonion) despite decreased mandibular length
			  • Total facial height, lower anterior, and upper anterior facial heights were within normal limits
			• Treated ED patients did not have a statistically significant change in craniofacial growth compared to untreated ED patients. Only length of the maxilla approached significance.
				• Exclusion of females in comparisons because of genetic variability and small female numbers
				• Follow-up period unknown

Thilander et al[21]	• Level of evidence = III, prospective case series
	• n = 18 adolescents with missing teeth due to tooth agenesis or trauma (13.2–17.2 y, mean = 15.2 y), 47 implants
	• Data up to 10 y after prosthesis insertion
		• Longitudinal changes in infraocclusion
		• Marginal bone loss
			• All implants survived
			• Single tooth implants in the maxillary incisor region:
			  • 13 lateral incisors and 4 central incisors restored in 10 patients
			  • Infraocclusion ranged from 0.1–2.2 mm (mean = 0.98 ± 0.62 mm) 10 y after crown placement
			  • Mean marginal bone loss around implants restoring lateral incisors = 0.75 mm (SD: 0.44), 4.3 mm (SD: 2.7) around adjacent central incisor tooth, and 2.2 mm (SD: 1.7) around adjacent canine tooth
			• Single tooth implants in the canine region:
			  • 2 maxillary canines and 1 mandibular canine restored in 2 patients
			  • Infraocclusion was minimal and not measurable after 10 y
			  • Mean marginal bone loss around implants = 0.6 mm
			  • Mean marginal bone loss around adjacent teeth = 0.8 mm
			• Single tooth implants in the premolar region:
			  • 9 premolars in 3 patients restored
			  • Infraocclusion was minor (0.1–0.6 mm) at the 3-y review
			  • Infraocclusion was minimal after 10 y with all crowns in occlusion
			• Implants restored with fixed prostheses:
			  • Mean marginal bone loss around implants = 0.6 mm 1 y after prosthesis insertion. No measurable marginal bone loss occurred after 1 y
				• Relatively small sample size
				• Did not differentiate between tooth agenesis and trauma cases
				• Did not account for tooth wear when measuring infraocclusion
				• No statistical analyses

Table 5 continued Synopsis of Included Studies in Order of Topic and Study Design

Author	Study summary	Primary outcome measures	Outcomes	Major weaknesses

Worsaae et al[22]	• Level of evidence = III, prospective and retrospective case series
	• n = 112 oligodontia patients including 10 with ED (20 prospective, 92 retrospective), (8–48 y, mean = 20.5 y), 283 implants
	• Data up to 5.7 y (mean = 2.3 y)
		• No. and type of orthodontic treatment
		• No. and type of surgical treatment
		• No. and type of prosthetic treatment
			• Survival rate at implant level = 97.9%; follow-up for implants was unknown
			• 4.3% at subject level had failure of ≥ 1 implant
			• All implant failures occurred before abutment connection
			• Implant failure was higher in the maxilla than the mandible (insufficient data to calculate percentages)
			• Mean number of missing teeth per patient = 10 (range: 6–25)
			• Mean number of missing teeth in the 10 ED patients =15
			• Teeth most commonly missing were second premolars (33%), maxillary first premolars, maxillary lateral incisors, mandibular first premolars, mandibular central incisors, and maxillary canines
			• 45.5% of patients completed treatment by the end of the follow-up of 0.1–5.7 y (mean = 2.3 y)
			• Orthodontic treatments:
			  • 96.7% of the 82.1% of patients who had finished treatment or were in active treatment at the beginning of the study received orthodontic treatment
			  • 62% received conventional orthodontics and 34.8% received orthognathic surgery
			• Surgical treatments:
			  • All patients who completed treatment received ≥ 1 surgical procedure including orthognathic surgery (27.5%), inferior alveolar nerve transposition (17.6%), sinus lift (43.1%), bone grafting (72.5%), implant placement (90.2%), or other surgical procedures (19.6% alveolar osseodistraction, vestibular plasty, genioplasty, or nasal lift)
			  • Complications most frequent after orthognathic surgery (42%) and inferior alveolar nerve transposition (29%)
			• Prosthodontic treatments:
			  • Fixed implant-borne prostheses used in 90% of completed cases
			  • Fixed tooth-borne prostheses used in 4% of completed cases
			  • Removable dental prostheses used in 6% of completed cases
				• Short follow-up
				• Follow-up for implants unknown
				• Selection bias (study population was patients referred to Department of Oral Maxillofacial Surgery)

Poggio et al[23]	• Level of evidence = III, retrospective case series • n = 15 patients with tooth agenesis (range unknown, mean = 22.5 y), 24 single-tooth implants • Data up to 11.8 y after prosthesis insertion (mean = 5.0 y)	• Implant survival • Duration of dental treatment • Prosthetic complications	• All implants survived up to 11.8 y (mean = 5.0 y) after prosthesis insertion • Mean duration from diagnosis of tooth agenesis to insertion of definitive prostheses was 6.4 y (range: 1.8–9.0) • 17.4% of implants experienced prosthetic complications • 18.2% of anterior implants demonstrated infraocclusion • No signs of infraocclusion occurred in posterior segments	• Relatively small sample size • Selection bias (study population was orthodontic patients) • No detail on prosthetic complications

Murdock et al[24]	• Level of evidence = III, retrospective case series
	• n = 24 ED patients (4.9–31.1 y, mean unknown) with severe tooth agenesis
	• Data period unknown
		• Treatment modalities
		• Estimated treatment costs
			• Average number of teeth present = 9.1 ± 6.9
			• 84% received prosthodontic treatment
			• Average number of prosthodontic visits = 11 ± 12.9
			• 37% received orthodontic treatment
			• 19% received implant surgery and the average number of implants received = 3.5 ± 4.5 in these patients
			• Dental costs varied widely:
			  • $2,038–$3,298 in patients who received prosthodontic treatment only
			  • $12,632–$41,146 in patients who received prosthodontic, orthodontic, and implant treatment
			  • $2,496 ± $345 of expenses during primary dentition phase
			  • $8,573 ± $1,156 of expenses during mixed dentition phase
			  • $27,894 ± $3,791 of expenses during permanent dentition phase owing to surgery, implants, and additional prosthodontic care
			  • Severity of tooth agenesis and orthodontic and implant treatment were significantly related to increased costs
				• Relatively small sample size
				• No information on follow-up
				• Relied primarily on level IV evidence to formulate treatment models and cost estimates
				• Does not detail treatment model for replication

Four studies reported on the effect of growth on implant position.[13,14,21,23] The first study reported that sagittal and transverse growth of the maxilla and mandible did not affect implant position in patients with ED.[13] However, vertical growth of the maxilla and mandible did affect two of six ED patients. One ED patient received a mandibular implant at the age of 5 years; the other received four maxillary implants at the age of 7. Both ED patients required placement of longer abutments and prostheses revisions.

The second study reported significant infraocclusion of single tooth implants in the maxillary incisor region ranging from 0.1 to 2.2 mm (mean = 0.98) 10 years after crown placement in patients with missing teeth due to agenesis or trauma.[21] Marginal bone loss was also reported. The greatest marginal bone loss of 4.3 mm (SD: 2.7) occurred at maxillary central incisors adjacent to implants replacing maxillary lateral incisors. Also, marginal bone loss at the adjacent tooth was found to increase with decreasing implant-to-tooth distance.

The third study[23] reported infraocclusion in 18.2% of anterior implants in patients with tooth agenesis, while the fourth study[14] reported that no implants demonstrated infraocclusion.

A landmark study by Johnson et al[20] assessed the effects of increased masticatory function (with the use of implant-borne prostheses) on craniofacial growth in patients with ED. The number of missing maxillary permanent teeth was associated with midface hypoplasia in patients 13 years of age or older. This suggests that craniofacial morphology is adversely affected by the lack of function caused by severe tooth agenesis. However, treated ED patients did not have a statistically significant change in craniofacial growth compared to untreated ED patients; only the difference in length of the maxilla approached significance.

Interdisciplinary Management

Three studies presented data on the interdisciplinary management of patients with tooth agenesis.[22–24] The first study assessed the treatment provided by the disciplines of orthodontics, oral maxillofacial surgery, and prosthodontics.[22] Orthodontic treatment was received by 96.7% of completed or active patients; 100% of completed cases received surgical and prosthodontic treatment.

The second study reported on implant survival, prosthetic complications, and treatment duration in a population of orthodontic patients with tooth agenesis receiving single tooth implants.[23] All implants survived for up to 11.8 years after prosthesis insertion and 17.4% of implants had prosthetic complications. The mean duration from diagnosis of tooth agenesis to insertion of the definitive prosthesis was 6.4 years (range: 1.8 to 9.0 years).

The third study reported on the economic impact of dental treatment on patients and families with ED and severe tooth agenesis.[24] In contrast to the previous two studies, which both had strong selection biases, 37% received orthodontic treatment, 19% received implant surgery, and 84% received prosthodontic treatment. Treatment costs increased with the severity of tooth agenesis and the need for orthodontic or implant treatment. Costs were estimated to vary widely, averaging $27,894 ± $3,791 for ED patients in their permanent dentition phase.

Discussion

Implants in Patients with ED and Tooth Agenesis

Survival rates of implants in ED patients were generally high and similar to survival rates in patients with tooth agenesis. However, the majority of studies reporting this data suffered from small sample sizes or short follow-up. These survival rates cannot be extrapolated to the long term.

A generally high percentage of ED patients experienced one or more implant failures. This finding could be related to the fact that ED presents with greater tooth agenesis and that several of the studies primarily reported on patients with oligodontia (more than five missing permanent teeth) and anodontia (missing all permanent teeth). Hence, at the subject level, ED patients were likely to receive more implants than the general population.

Despite the relatively high failure rate of implants in ED patients at the subject level, all ED patients eventually received implant-borne prostheses. Thus, ED is not a contraindication to the placement of implants.

There was agreement between the three studies on ED patients that implant failure was higher in the maxilla than the mandible.[12–14] Implant failure was postulated to be caused not by ED per se, but rather to be associated with deficiencies in bone volume at the implant site and sites with previous surgery (eg, removal of impacted canines, maxillary osteotomy, iliac crest grafted sites, and immediate implant placement).[12,14]

Only one study discussed the rationale behind the choice of prosthesis design in ED patients. In that study, bar-retained implant-borne prostheses were recommended for patients with incomplete growth to reduce the cost of prostheses remakes.[12] Another study concluded that prosthetic bars in the maxilla should be divided at the midline to avoid interference with transverse growth.[13] But the evidence in that study did not support the conclusion, which was based largely upon one reference.

Prosthesis complications were reported to be significant in three studies,[14,19,23] but only one study detailed the type of complication at specific time points over the 10-year follow-up.[19] This study, however, was conducted in a small population of special needs patients, not necessarily suffering from tooth agenesis. A comparison of the disease entities/conditions was not possible and the results cannot be generally applied to patients with ED and tooth agenesis.

Quality of life was shown to improve in oligodontia patients receiving implant and prosthodontic treatment.[17] However, it should be noted that this study was likely to have suffered recall bias since the questionnaire assessed changes retrospectively and thus relied on patients' memory recall.

Age, Growth, and Implants

There is some evidence supporting the claim that implants placed in ED patients younger than 18 years have a higher risk of failure.[12] There have also been reports of submergence of implants placed in two young ED patients (ages 5 and 7 years) who later required placement of longer abutments and prosthesis revisions to accommodate the change in implant positions due to growth.[13] The three studies that reported on infraocclusion made no group comparisons, so no conclusions could be drawn on the relationship between timing of implant placement and extent of infraocclusion.[14,21,23] One study reported that no implants demonstrated infraocclusion.[14] However, in that study no implants were placed adjacent to teeth in growing arches and the follow-up period was short (mean = 2.4 years).

A positive relationship between the number of missing permanent maxillary teeth and craniofacial dysmorphology was demonstrated in ED patients older than 13 years.[20] The authors provided three possible explanations for this correlation: *(1)* severity of maxillary tooth agenesis and craniofacial features are both directly related to the expression of ED genes; *(2)* growth is driven or partially controlled by the epithelium, so failure or lack of development of ectodermal tissues results in lack of stimulation of mesenchymal tissues in order for them to develop to their normal size; *(3)* jaw function influences craniofacial development and hence, decreased function leads to craniofacial dysmorphology.

However, treatment with implants did not produce a significant normalization of growth. The authors recognized that craniofacial growth is largely completed by late adolescence and that the lack of effect on the study population could be explained by the placement of implants in late adolescence in the majority of cases, when inadequate time remained for normalization. The authors concluded that early dental evaluations of ED patients revealing severe tooth agenesis may be predictive of midface hypoplasia. Therefore, a child with ED and severe tooth agenesis may be an appropriate candidate for growth modification.

Interdisciplinary Management

The three studies[22–24] that presented data on the interdisciplinary management of patients with ED and tooth agenesis served to highlight its importance. Although a strong selection bias was present in two of the studies,[22,23] the vast majority of patients required treatment from the disciplines of orthodontics, oral maxillofacial surgery, and prosthodontics. Treatment periods were protracted, which further reinforced the importance of interdisciplinary management.[23]

Treatment costs for ED patients receiving dental implants varied widely.[24] The authors acknowledged that there was an underestimation of true costs, since the cost model excluded any costs associated with work time lost by parents or patients as a result of treatment. Costs were estimated from the perspective of the health care system and the study was performed at a single center, so cost estimates were regional. Furthermore, the study did not calculate maintenance costs. Nevertheless, the financial expense was estimated to be high and positively correlated with the severity of tooth agenesis and the need for orthodontic or implant treatment.

This review contained a potential bias due to the exclusion of non-English studies. The studies included in this review were of a low level of evidence and high heterogeneity. Furthermore, in three studies it was not possible to differentiate the implant survival rates of patients with ED, tooth agenesis, or special needs.[19,21,22] Despite these shortcomings, valuable information regarding dental implants in patients with ED and tooth agenesis was reported. The best evidence currently available suggests that implant survival rates are similar between patients with ED and patients with tooth agenesis, ranging between 88.5% and 100%. Implants placed in adolescent ED patients do not have a significant effect on craniofacial growth, and implants placed in ED patients younger than 18 years have a higher risk of failure.

Oral rehabilitation for patients with ED and tooth agenesis is important from a functional, esthetic, and psychologic standpoint. The principal aims are to restore missing teeth and bone, establish normal vertical dimension, and provide support for facial soft tissues. Management should adopt an interdisciplinary, centralized approach involving pediatric dentists, orthodontists, maxillofacial surgeons, and prosthodontists.

The decision to commence implant therapy early in a child's life is a complex one. The treatment guidelines of the National Foundation for Ectodermal Dysplasias state that implants are only recommended for the anterior portion of the mandible in children older than school age (7 years or older).[25] The financial and biologic cost of early treatment requires careful consideration. The disadvantage of changing abutment configurations and replacement of prostheses should be weighed against the psychologic benefits of the patient receiving more stable prostheses.

If implant-borne prostheses were shown to have significant positive effects on craniofacial growth, social development, self-image, and food choice, their use in the anterior mandible may be recommended for younger patients.

Recently, a study achieved normalization of permanent teeth in dogs with ED by administration of the protein Fc:EDA1.[26] Moreover, treatment restored normal lacrimation, resistance to eye and airway infections, and improved sweating ability. Perhaps one day a cure will be found for the debilitating condition of ED. Until such a time, there will be a need for well-designed, prospective, long-term controlled studies evaluating OHRQoL and implant and prosthodontic outcomes in younger patients with ED and tooth agenesis to elicit the benefits of early treatment. A central register is required to report on outcomes to make information more available and expand knowledge.

Conclusions

Within the limitations of this review, the following conclusions may be drawn. Implant survival rates of patients with ED and tooth agenesis range between 88.5% and 100%. Implants placed in adolescent ED patients do not have a significant effect on craniofacial growth. Implants placed in ED patients younger than 18 years have a higher risk of failure.

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